Scientific Research Publishing

Food and Nutrition Sciences, 2021, 12, 1232-1242
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

Effect of Dehulling and Hydrothermal Treatment on the Amino Acid Content of Soriz (*Sorghum oryzoidum*)

Rodica Siminiuc*, Lidia Coșciug

Department of Food and Nutrition, Faculty of Food Science, Technical University of Moldova, Chisinau, Republic of Moldova
Email: *rodica.siminiuc@adm.utm.md, lidia.cosciug@toap.utm.md

How to cite this paper: Siminiuc, R. and Coșciug, L. (2021) Effect of Dehulling and Hydrothermal Treatment on the Amino Acid Content of Soriz (*Sorghum oryzoidum*). *Food and Nutrition Sciences*, **12**, 1232-1242.
https://doi.org/10.4236/fns.2021.1212090

Received: November 12, 2021
Accepted: December 19, 2021
Published: December 22, 2021

Abstract

Cereals are the basic element in ensuring the food security of the population through the significant intake of carbohydrates, proteins, dietary fiber, vitamins and minerals. The processing of cereals leads to changes in their nutritional quality, which could lead to both reduced nutrients and anti-nutrients. Gluten-free cereal varieties attract attention as raw materials to improve the nutritional quality of food and to diversify the product range. Sorghum (*Sorghum oryzoidum*) is a hybrid of sorghum, obtained at the Institute for Scientific Research for Corn and Sorghum in the Republic of Moldova, by crossing Sudan grass (*S. sudanense*) and bicolor sorghum (*S. bicolor*). The research aimed to determine the impact of dehulling and hydrothermal treatment on the amino acid content of soriz. The obtained results reported that the dehulling and hydrothermal treatment led to the uneven modification of the amino acid content in the investigated samples. As a result of dehulling, the total amount of essential amino acids decreased by 19.8% compared to the native grain. Boiling whole grains without prior hydration led to 34% loss of essential amino acids compared to native grains, and pre-hydration of the grains and subsequent boiling reduced essential amino acid losses by 8% compared to cooked grains without hydration. Boiling grains with pre-hydration had a positive effect on the chemical index of lysine, methionine and cysteine, leucine and tryptophan. However, the nutritional quality of sorghum grain proteins and derivatives obtained, evaluated according to the chemical index, is low. The results obtained reported that dehulling and hydrothermal treatment unevenly altered the amino acid content, and the method of boiling grains with pre-hydration had a positive effect on the CSI of lysine, methionine and cysteine, leucine and tryptophan.

Keywords

Soriz, Dehulling, Hydrothermal Treatment, Amino Acids,

Chemical Score Index

1. Introduction

Cereals, more than any other type of crop, are grown in large quantities worldwide, due to its economic importance and energy intake. Scientific studies suggest that eating whole grains can protect against diabetes, obesity, constipation, cardiovascular disease and other lifestyle disorders [1]. It is the basic element in ensuring the food security of the population through the significant intake of carbohydrates, proteins, dietary fiber, vitamins, minerals and phytochemicals [1] [2] [3] [4]. Cereal proteins make up about 10% of the dry weight of cereals and are essential components in food systems, and their exploration, as an economical and sustainable source for a healthy diet, is current [5] [6]. It is generally characterized by a low content of essential amino acids, in particular lysine, threonine and tryptophan [7] [8] [9] [10]. The processing of cereals leads to changes in their nutritional quality, which could reduce both nutrients and anti-nutrients. At the same time, processing treatments can lead to improved sensory characteristics, digestibility or nutrient availability [4] [11] [12].

Knowing the nutritional value and changes that occur as a result of technological and culinary treatments can help establish policies on assessing nutritional status, formulating therapeutic diets, and investigating the relationship between diet, health, and disease [1]. Gluten-free cereal varieties attract attention as raw materials to improve the nutritional quality of food and to diversify the range of gluten-free products/diets [13]. Sorghum is a cereal crop well adapted to low rainfall regions and has therefore become a staple crop for millions of people around the world. As with all cereals, the chemical composition and nutritional value of sorghum vary within and between cereal crops [14] [15].

Soriz (*Sorghum oryzoidum*) is a hybrid of sorghum that is characterized by glassy endosperm, similar to rice. It was obtained at the Institute for Scientific Research for Maize and Sorghum in the Republic of Moldova, by crossing Sudan grass (*S. sudanense*) and bicolor sorghum (*S. bicolor*) [16] [17]. The advantages of soriz are manifested in the production process, which does not require major investments: the plant is not pretentious to soil conditions, fertilizers and has tolerance to diseases and pests. It has high productivity per hectare: in favorable conditions, the productivity of soriz reaches 6 - 8 t/ha, and in some years, in the northern parts of the republic, the harvest reached 12 t/ha (Chirsanova, A., *et al.*). The chemical composition of whole grain grains attests a starch content—74.12%…82.0% d.m., protein—about 13.0% d.m., sugars—0.24% - 0.37% d.m., lipids—0.1%…0.5% d.m., ash—0.36% - 2.0% d.m. In the whole soriz, the dominant protein fractions belong to prolamins (56.0% of total protein), followed by glutelin (22.4%), globulins (7.3) and albumin (6.7) [18]. An important feature of soriz is the absence of gluten, which makes it an optimal alternative in the diversification of gluten-free products—a relevant and extremely current field of research, especially for the Republic of Moldova [19] [20]. The novelty of the research consists in the fact that soriz is a relatively new cereal for the Republic of Moldova, but which reaches new borders. Respectively, research on the impact of processing, hydrothermal treatments on the nutritional value of soriz is current and necessary.

2. Materials and Methods

Whole grains of soryz and hulled soryz "Alimentar 1", purchased at the Institute of Plant Protection and Organic Agriculture of the Academy of Sciences of Moldova, were used as research material. Hydrothermal treatment of whole grains and hulled grains was done in distilled water (Table 1).

The methods used in the research are presented in Table 2.

Table 1. Raw materials used for research and their protein content.

No.	Raw materials used for determinations	Proteins, %	Dry matter, %
1	Whole grains of soriz	13.13	87.6
2	Boiled whole grains (without prior hydration) Boiling time—115 ± 5 minutes	12.96	29.4
3	Whole grains cooked after pre-hydration Hydration time 8 hours. Boiling time—85 ± 5 minutes	11.9	33.6
4	Raw dehulling grains	12.88	87.2
5	Boiled dehulling grains Boiling time—40 ± 5 minutes	10.16	21.0

Table 2. Methods used for determining the analyzed indices.

Determined indices	Method of analysis/source
Moisture Determination	[21]
Protein Determination	Kjeldahl method [22]
Amino acids	Quantitative determination of amino acids was performed on the AAA-339 analyzer "Mikrotechna" (Czech Republic), by acid hydrolysis of proteins, in the presence of 6 M HCl, for 24 hours at 105˚C. (Kosarenko, T., D./Козаренко Т. Д., 1975)
Summary index of essential amino acids (SIEAA)	$SIEAA = \sqrt[8]{IC1 * IC2 * \cdots * IC8}$ CI—chemical index of the essential amino acid [23],
Chemical score index (CSI)	$CSI = \frac{\text{mg of EAA in 1 g test protein}}{\text{mg of EAA in 1 g reference protein (egg protein)}} \times 100$ [24] [25] [26].

3. Results and Discussions

The quality of the protein describes its characteristics in relation to its property to achieve defined metabolic actions [27] and is evaluated according to the ability of food constituent amino acids to meet the biological needs of the consumer [28]. Of the total amino acids, it was accepted that ten are essential amino acids for adults [24]. These amino acids cannot be synthesized by the human body from available materials and must be part of a healthy and balanced diet. However, the list of essential amino acids has been criticized [29], and the Food and Agriculture Organization (FAO) recommends addressing dietary amino acids as individual nutrients [30]. From a nutritional point of view, it is quite clear that some amino acids are absolute dietary needs if you want to maintain a normal growth [29]. Knowing the amino acid content, especially the essential ones, are important indicators in assessing the nutritional quality of traditional cereal products and those obtained from new sources of raw materials [31].

In native soriz grains, the sum of non-essential amino acids is about 66% of their total protein (**Table 3**). Soriz grains are characterized by a high content of glutamic acid (302.0%), alanine (96.0%) and proline (90.01%), which is also characteristic for most cereals [4] [14] [31].

Dehulling is the mechanical method that involves separating the pericarp from germs, which often leads to the elimination or reduction of phytic acid, as well as some minerals and vitamins [32]. Dehulling of soriz grains led to an uneven change in amino acid content. As a result, the total amount of essential amino acids decreased by 19.8% compared to the native grain. Sulfur amino acid content values decreased by 2.7%, but aromatic amino acid values increased by 11.6%. Dehulling has also led to an increase in the share of glutamic acid and alanine amino acids that are rich in gluten proteins (especially prolamins), which are found in large quantities in soriz derivatives [18]. Dehulling does not change the content of these amino acids.

Hydrothermal treatment. Scientific studies have shown that hydrothermal treatment improves the bioavailability of micronutrients by reducing the content of phytic acid and phenolic substances [33] [34]. Boiling whole grains without prior hydration led to 34% loss of essential amino acids compared to native grains, and pre-hydration of the grains and subsequent boiling reduced essential amino acid losses by 8% compared to cooked grains without hydration. Whole grains and dehulled soriz grains are a considerable source of branched-chain amino acids (BCAAs) (leucine, isoleucine and valine). Leucine is not only a precursor for muscle protein synthesis, but can also play a role in regulating intracellular signaling pathways that are involved in the process of protein synthesis [35]. Branched amino acids are considered the most important amino acids in protein synthesis, which are attributed a detoxifying role in dealing with ammonia and in preventing muscle trophism. But, nevertheless, there are still many controversies and research is needed to elucidate this topic [36] [37]. The hydrothermal treatment had an insignificant impact on the content of these

Table 3. The impact of dehulling and hydrothermal treatment on the amino acid content of soriz.

	Amino acids	Whole grains of soriz	Boiled whole grains (without prior hydration)	Whole grains cooked after pre-hydration	Raw dehulling grains	Boiled dehulling grains
		mg amino acid/1g protein				
1	Lysine	14.80	12.33	14.4	9.2	7.0
2	Methionine	1.70	6.89	11.1	1.3	4.2
3	Cysteine	11.80	10.7	11.4	9.5	10.3
4	Threonine	23.2	20.0	16.53	16.1	18.7
5	Isoleucine	29.1	28.43	27.5	32.0	28.8
6	Leucine	122.50	115.47	121.5	124.0	130.3
7	Valine	44.00	42.6	40.77	43.4	42.7
8	Phenylalanine	46.0	44.5	45.6	52.0	46.9
9	Tyrosine	21.1	20.5	18.8	30.1	24.7
10	Tryptophan	7.01	5.4	6.5	3.8	3.0
11	Histidine	20.01	13.0	19.5	14.0	10.0
12	Arginine	30.01	25.0	35.0	29.0	14.0
13	Asparagine acid	66.26	77.0	64.5	70.0	68.0
14	Serin	44.00	37.7	43.0	38.0	38.0
15	Glycine	30.50	29.8	31.0	21.3	24.0
16	Alanine	96.00	104.5	97.4	104.0	113.0
17	Glutamic acid	302.00	302.0	299.5	313.3	328.0
18	Proline	90.01	105.0	93.0	89.0	88.4
19	Ammonia	4.0	3.4	3.3	5.1	3.0
		Totalizations				
20	ΣAA	1000	1000	1000	1000	1000
21	Nitrogen metabolism index	1004	1003.4	1003.3	1005.1	1003
22	Σnon-essential AA	658.78	693	685	678.6	683.4
23	Σessential AA	341.22	307	315	321.4	316.6
24	Σimmunoactive AA	594	598	580	601	622.6
25	Σglycogenic AA	303.96	311.6	292.8	292.1	304.4
26	Σketogenic AA	240.51	226.63	219.9	241.9	233.7
27	Σproteinogenic AA	1000	1000	1000	1000	1000
28	Σsulfur AA	13.5	17.59	22.5	10.8	14.5
29	Σaromatic amino acids AA	67.1	64.4	82.1	78.7	71.6

amino acids, although the ratio between them, for the researched samples, is far from ideal (2:1:1), namely: in whole grains it is 4:1:2.7.

Hydrothermal treatment beneficially changed the ratio of the amino acids tryptophan: lysine: methionine (optimal, being considered the ratio of 1:3:3) from a ratio of 1:2.1:0.2 (in whole grains) to 1:2.3:1.3 (in boiled grains without hydration), 1:2.2:1.7 (in hydrated grains then boiled) and 1:2.3:1.4 (in hulled and boiled grains).

In boiled whole grains the ratio of these amino acids proved to be more balanced compared to the rest of the samples, surpassing whole grains such as sorghum (1:1.01:1.36), millet (1:1.78:1.3) and wheat (1:0.91:0.55). In dehulled soriz, the ratio of the respective amino acids was closer to the rice groats (1:2.5:1.3), but more balanced compared to the wheat groats (1:1:1.1) [38].

Summary index of essential amino acids. One of the methods used to determine the biological value of proteins is to determine the summary index of essential amino acids. The summary index of essential amino acids for native grains was 69.4, for grains cooked without hydration-56.6, and for those cooked with pre-hydration-68, which indicates that boiling grains, after prior hydration, is a more efficient method in maintaining an optimal ISAE. The summary index of essential amino acids (ISAE) for raw hulled grains was 58.3, and for cooked hulled grains-56.5. However, this method does not allow the determination of the limiting amino acid in relation to the standard protein, the amount of which depends on the complete assimilation of others.

Chemical score index (*CSI*). The most common method of determining biological value is to calculate the CSI. The index is expressed as a percentage and shows the ratio of the content of the essential amino acid to the same amino acid in the standard protein (Lopez and Mohiuddin). The modification of the amino acid content in the hydrothermal treatment of whole grains and dehulled grains of soriz also conditioned the change of their CSI (**Table 4**).

Table 4. The impact of dehulling and hydrothermal treatment on the CSI of the soriz.

AA esențiali	Whole grains of soriz	Boiled whole grains (without prior hydration)	Whole grains cooked after pre-hydration	Raw dehulling grains	Boiled dehulling grains
Lysine	27	22	26	17	13
Methionine & Cysteine	39	50	64	31	41
Threonine	58	50	41	40	47
Isoleucine	73	71	69	80	72
Leucine	175	165	174	177	186
Valine	88	85	81	87	85
Fhenylalanine & Tyrosine	112	117	107	137	123
Tryptophan	70	54	65	38	30

The quality of the protein when peeling the grains depends, to a large extent, on the yield of the peeled grains. Essential amino acids make up 34% of the total number of amino acids.

The amino acid score is the most limiting amount of amino acid in the food protein, expressed as a percentage of that amino acid present in a reference protein [39] [40] [41].

Dehulling unevenly modifies the CSI of soriz grains, namely: decreases the CSI values for lysine by 10%, methionine by 8%, threonine by 18%, tryptophan by 32%, but increases the CSI values for isoleucine by 7.0% and phenylalanine 25% for dehulling grains. The CSI values for leucine and valine practically do not change after dehulling. For both native grains and soriz derivatives, the limiting amino acid remains lysine, which is characteristic of most cereals except corn, in which the limiting amino acid is tryptophan [42].

The limiting amino acid remains lysine. The value of this amino acid determines the biological value and the degree of assimilation of the protein. According to the calculations obtained, pre-hydration of grains with subsequent boiling can be considered a more effective method, compared to grains cooked without hydration, in order to reduce the loss of amino acids.

Hydrothermal treatment of whole grains and dehulled soriz grains differently altered the CSI of proteins. However, these remain medium quality proteins, the limiting amino acid of which is lysine (CSI = 26-for hydrated and boiled grains and CSI = 13-for hulled and boiled grains) [43] [44] [45].

4. Conclusions

Soriz proteins contain all the essential amino acids, the limiting one being lysine.

Peeling and hydrothermal treatment led to an uneven change in the amino acid content and, respectively, the CSI value in the researched samples.

The obtained results attest that the method of boiling grains with pre-hydration had a positive effect on the CIS of the following amino acids: lysine, methionine and cysteine, leucine and tryptophan.

For threonine and branched-chain amino acids, this method of hydrothermal treatment has led to higher amino acid losses compared to cooked grains without hydration.

The obtained results confirm that the nutritional quality of the soriz grain proteins and derivatives obtained, evaluated according to the CSI, is low. Therefore, their association with other foods such as eggs, meat, fish, milk, whose protein is well balanced in essential amino acids is justified.

The obtained results will be able to be used in the capitalization of the mouse for the design of gluten-free products, for the rational formulation of therapeutic diets and in investigations on the relationships between diet, health and disease.

Funding

This research was funded by postdoctoral grant "Contribution regarding nutritional eradication of gluten consumption diseases" nr. 21.00208.5107.06/PD, running at Technical University of Moldova, https://utm.md/.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Oghbaei, M. and Prakash, J. (2016) Effect of Primary Processing of Cereals and Legumes on Its Nutritional Quality: A Comprehensive Review. *Cogent Food & Agriculture*, **2**, Article ID: 1136015. https://doi.org/10.1080/23311932.2015.1136015

[2] Laskowski, W., Górska-Warsewicz, H., Rejman, K., *et al.* (2019) How Important Are Cereals and Cereal Products in the Average Polish Diet? *Nutrients*, **11**, Article No. 679. https://doi.org/10.3390/nu11030679

[3] Pickard, R.S. and McKevith, B.J. (2005) The Role of Cereals in the Diet. In: Cauvain, S.P., Salmon, S.S. and Young, L.S., Eds., *Using Cereal Science and Technology for the Benefit of Consumers*, Woodhead Publishing, Sawston, 89. https://doi.org/10.1533/9781845690632.4.89

[4] McKevith, B. (2004) Nutritional Aspects of Cereals. *Nutrition Bulletin*, **29**, 111-142. https://doi.org/10.1111/j.1467-3010.2004.00418.x

[5] Abiola Oso, A. and Omotayo Ashafa, A. (2021) Nutritional Composition of Grain and Seed Proteins. In: Carlos Jimenez-Lopez, J., Ed., *Grain and Seed Proteins Functionality*, IntechOpen, London. https://doi.org/10.5772/intechopen.97878

[6] Gil, A.M. and Bock, J.E. (2020) Techniques for Analyzing Wheat Proteins. In: Cauvain, S.P., Ed., *Breadmaking*, Woodhead Publishing, Sawston, 81-108 https://doi.org/10.1016/B978-0-08-102519-2.00003-7

[7] Price, R.K. and Welch, R.W. (2013) Cereal Grains. In: Caballero, B., Ed., *Encyclopedia of Human Nutrition*, Academic Press, Cambridge, 307-316. https://doi.org/10.1016/B978-0-12-375083-9.00047-7

[8] Siddiqi, R.A., Singh, T.P., Rani, M., Sogi, D.S. and Bhat, M.A. (2020) Diversity in Grain, Flour, Amino Acid Composition, Protein Profiling, and Proportion of Total Flour Proteins of Different Wheat Cultivars of North India. *Frontiers in Nutrition*, **7**, Article No. 141. https://doi.org/10.3389/fnut.2020.00141

[9] D'Mello, J.P.F. (1993) Amino Acid Supplementation of Cereal-Based Diets for Non-Ruminants. *Animal Feed Science and Technology*, **45**, 1-18. https://doi.org/10.1016/0377-8401(93)90068-U

[10] Lasztity, R. and Hidvégi, M. (1985) Amino Acid Composition and Biological Value of Cereal Proteins: Proceedings of the International Association for Cereal Chemistry Symposium on Amino Acid Composition and Biological Value of Cereal Proteins Budapest, Hungary, 31 May-1 June 1983. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-5307-9

[11] Pal, R.S., Bhartiya, A., ArunKumar, R., Kant, L., Aditya, J.P. and Bisht, J.K. (2016) Impact of Dehulling and Germination on Nutrients, Antinutrients, and Antioxidant Properties in Horsegram. *Journal of Food Science and Technology*, **53**, 337-347. https://doi.org/10.1007/s13197-015-2037-3

[12] Amudha Senthil, S.P. (2015) Effect of Hydrothermal Treatment on the Nutritional and Functional Properties of Husked and Dehusked Buckwheat. *Journal of Food Processing & Technology*, **6**, Article No. 461.

https://doi.org/10.4172/2157-7110.1000461

[13] Niro, S., D'Agostino, A., Fratianni, A., Cinquanta, L. And Panfili, G. (2019) Gluten-Free Alternative Grains: Nutritional Evaluation and Bioactive Compounds. *Foods*, **8**, Article No. 208. https://doi.org/10.3390/foods8060208

[14] Rhodes, D.H., Hoffmann, L., Rooney, W.L., Herald, T.J., Bean, S., Boyles, R., *et al*. (2017) Genetic Architecture of Kernel Composition in Global Sorghum Germplasm. *BMC Genomics*, **18**, Article No. 15. https://doi.org/10.1186/s12864-016-3403-x

[15] Carcea, M. (2020) Nutritional Value of Grain-Based Foods. *Foods*, **9**, Article No. 504. https://doi.org/10.3390/foods9040504

[16] Galaiev, O.V., Shevchuk, G.I., Dudchenko, V.V. and Syvolap, I.M. (2011) Molecular Genetic Analysis of Soriz Genome (*Sorghum oryzoidum*). *Cytology and Genetic*, **45**, Article No. 208. https://doi.org/10.3103/S0095452711040049

[17] Siminiuc, R. and Ţurcanu, D. (2020) The Impact of Hydrothermal Treatments on Technological Properties of Whole Grains and Soriz (*Sorghum oryzoidum*) Groats. *Food and Nutrition Sciences*, **11**, 955-968. https://doi.org/10.4236/fns.2020.1110067

[18] Siminiuc, R., Cosciug, L., Popescu, L. and Viorica, B. (2012) The Effect of Dehulling and Thermal Treatment on the Protein Fractions in Soryz (*Sorghum oryzoidum*) Grains. *The Annals of the University Dunarea de Jos of Galati Fascicle VI*: *Food Technology*, **36**, 97-102. http://www.ann.ugal.ro/tpa/Anale%202012/vol%201/9_Siminiuc%20et%20al.pdf

[19] Siminiuc, R. and Ţurcanu, D. (2020) Certain Aspects of Nutritional Security of People with Gluten-Related Disorders. *Food and Nutrition Sciences*, **11**, 1012-1031. https://doi.org/10.4236/fns.2020.1111072

[20] Chirsanova, A., Reşitca, V., Siminiuc, R., *et al*. (2021) Innovative Food Products. Tehnica-UTM, Chisinau, Republic of Moldova. https://zenodo.org/record/5563412

[21] Horwitz, W. and AOAC International (2006) Official Methods of Analysis of AOAC International, 18th Edition, AOAC International, Gaithersburg.

[22] Helrich, K. and Association of Official Analytical Chemists, (1990) Official Methods of Analysis of the Association of Official Analytical Chemists. 15th Edition, Association of Official Analytical Chemists, Arlington.

[23] Borisenko, A.A. (2012) Моделирование, разработка и оптимизация продуктов здорового питания: монография. СевКавГТУ, Ставрополь.

[24] Joint FAO/WHO/UNU Expert Consultation on Energy and Protein Requirements (1985) Energy and Protein Requirements: Report of a Joint FAO/WHO/UNU Expert Consultation. World Health Organization, Geneva; WHO Publications Center USA [distributor], Albany.

[25] Shivakumar, N., Minocha, S. and Kurpad, A. (2018) Protein Quality & Amino Acid Requirements in Relation to Needs in India. *Indian Journal of Medical Research*, **148**, 557-568. https://doi.org/10.4103/ijmr.IJMR_1688_18

[26] Ihekoronye, A.I. (1988) Estimation of the Biological Value of Food Proteins by a Modified Equation of the Essential Amino Acid Index and the Chemical Score. *Food/Nahrung*, **32**, 783-788. https://doi.org/10.1002/food.19880320818

[27] Millward, D.J., Layman, D.K., Tomé, D. and Schaafsma, G. (2008) Protein Quality Assessment: Impact of Expanding Understanding of Protein and Amino Acid Needs for Optimal Health. *The American Journal of Clinical Nutrition*, **87**, 1576S-1581S. https://doi.org/10.1093/ajcn/87.5.1576S

[28] Nosworthy, M.G. and House, J.D. (2017) Factors Influencing the Quality of Dietary Proteins: Implications for Pulses. *Cereal Chemistry Journa*l, **94**, 49-57. https://doi.org/10.1094/CCHEM-04-16-0104-FI

[29] Reeds, P.J. (2000) Dispensable and Indispensable Amino Acids for Humans. *The Journal of Nutrition*, **130**, 1835S-1840S. https://doi.org/10.1093/jn/130.7.1835S

[30] Joye, I. (2019) Protein Digestibility of Cereal Products. *Foods*, **8**, Article No. 199. https://doi.org/10.3390/foods8060199

[31] Espinoza-Herrera, J., Martínez, L.M., Serna-Saldívar, S.O. and Chuck-Hernández, C. (2021) Methods for the Modification and Evaluation of Cereal Proteins for the Substitution of Wheat Gluten in Dough Systems. *Foods*, **10**, Article No. 118. https://doi.org/10.3390/foods10010118

[32] Krishnan, R. and Meera, M.S. (2018) Pearl Millet Minerals: Effect of Processing on Bioaccessibility. *Journal of Food Science and Technology*, **55**, 3362-3372. https://doi.org/10.1007/s13197-018-3305-9

[33] Krishnan, R., Dharmaraj, U. and Malleshi, N.G. (2012) Influence of Decortication, Popping and Malting on Bioaccessibility of Calcium, Iron and Zinc in Finger Millet. *LWT-Food Science and Technology*, **48**, 169-174. https://doi.org/10.1016/j.lwt.2012.03.003

[34] Taylor, J.R. and Duodu, K.G. (2015) Effects of Processing Sorghum and Millets on Their Phenolic Phytochemicals and the Implications of This to the Health-Enhancing Properties of Sorghum and Millet Food and Beverage Products. *Journal of the Science of Food and Agriculture*, **95**, 225-237. https://doi.org/10.1002/jsfa.6713

[35] Wolfe, R.R. (2017) Branched-Chain Amino Acids and Muscle Protein Synthesis in Humans: Myth or Reality? *Journal of the International Society of Sports Nutrition*, **14**, Article No. 30. https://doi.org/10.1186/s12970-017-0184-9

[36] Holeček, M. (2018) Branched-Chain Amino Acids in Health and Disease: Metabolism, Alterations in Blood Plasma, and as Supplements. *Nutrition & Metabolism*, **15**, Article No. 33. https://doi.org/10.1016/B978-0-12-391909-0.50003-7

[37] Engelking, L.R. (2015) Amino Acid Modifications. In: Engelking, L.R. (Author), *Textbook of Veterinary Physiological Chemistry*, Academic Press, Cambridge, 12-17

[38] Bregendahl, K., Roberts, S.A., Kerr, B. and Hoehler, D. (2008) Ideal Ratios of Isoleucine, Methionine, Methionine Plus Cystine, Threonine, Tryptophan, and Valine Relative to Lysine for White Leghorn-Type Laying Hens of Twenty-Eight to Thirty-Four Weeks of Age. *Poultry Science*, **87**, 744-758. https://doi.org/10.3382/ps.2007-00412

[39] Rajarathnam, S. and Shashirekha, M.N. (2003) Mushrooms and Truffles: Use of Wild Mushrooms. In: Caballero, B., Ed., *Encyclopedia of Food Sciences and Nutrition*, Academic Press, Cambridge, 4048-4054. https://doi.org/10.1016/B0-12-227055-X/00813-0

[40] Han, F., Moughan, P.J., Li, J., Stroebinger, N. and Pang, S. (2021) The Complementarity of Amino Acids in Cooked Pulse/Cereal Blends and Effects on DIAAS. *Plants*, **10**, Article No. 1999. https://doi.org/10.3390/plants10101999

[41] Boye, J., Wijesinha-Bettoni, R. and Burlingame, B. (2012) Protein Quality Evaluation Twenty Years after the Introduction of the Protein Digestibility Corrected Amino Acid Score Method. *British Journal of Nutrition*, **108**, S183-S211. https://doi.org/10.1017/S0007114512002309

[42] Lopez, M.J. and Mohiuddin, S.S. (2021) Biochemistry, Essential Amino Acids. StatPearls Publishing, Treasure Island.

[43] Han, F., Han, F., Wang, Y., Fan, L., Song, G., Chen, X., *et al.* (2019) Digestible Indispensable Amino Acid Scores of Nine Cooked Cereal Grains. *British Journal of Nutrition*, **121**, 30-41. https://doi.org/10.1017/S0007114518003033

[44] Cervantes-Pahm, S.K., Liu, Y. and Stein, H.H. (2014) Digestible Indispensable Amino Acid Score and Digestible Amino Acids in Eight Cereal Grains. *British Journal of Nutrition*, **111**, 1663-1672. https://doi.org/10.1017/S0007114513004273

[45] Fanelli, N.S., Bailey, H.M., Guardiola, L.V. and Stein, H.H. (2021) Values for Digestible Indispensable Amino Acid Score (DIAAS) Determined in Pigs Are Greater for Milk than for Breakfast Cereals, but DIAAS Values for Individual Ingredients Are Additive in Combined Meals. *The Journal of Nutrition*, **151**, 540-547. https://doi.org/10.1093/jn/nxaa398