Enrichment of protein barley and triticale groats by adding chickpea

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Summary
An indicator of the proximity of protein to an ideal protein is the minimum score, which shows how much of it can be utilized by the human body. Obviously, the more of this protein in the product, the better. In nutrition, complementarity of proteins in terms of amino acids complementing each other is preferred. In spite of a decrease in total protein content, the reference protein of a mixture should increase, while the excess protein should be reduced. In two-component systems, we can limit ourselves to solving a system of two linear equations. In this study, we considered the possibility of increasing the nutritional value and usefulness of protein in cereals produced from triticale grain and barley, by adding a certain amount of cereals produced from chickpeas. The article describes the amino acid characteristics of triticale, barley and chickpea and calculation of their amino acid scores, as well as the ratio of the reference and excess proteins in a mixture. An algorithm was proposed for calculating optimum proportions of two proteins when they are mixed.

Keywords
triticale; chickpea; enrichment; protein; groats; amino acid

To date, areas facing the development of special foodstuffs as well as products and rations of „functional“ and „personalized“ nutrition, are relevant. The latter is based on the allelic polymorphism of individual “susceptibility genes” associated with fixation of certain food nutrients [1]. However, the issues of health-promoting nutrition remain also relevant, which aim at improving the dietary patterns, including in the disadvantaged population. Traditional cereal groats, in the form of porridge, constitute a significant part of our diet. However, their protein component is not only insufficient for adequate nutrition in terms of total content, but also is of poor quality.

Of 20 amino acids contained in proteins, which are required for a active life of humans, 9 are essential amino acids (EAA) that must be supplied by food. Non-essential amino acids (NEA) can be synthesized by the human body. Fixation of EAA by human body occurs in a certain proportion, in accordance with the profile of a reference (ideal) protein. Nutritional assessment of a protein can be based on comparison of its amino acid composition with a certain reference protein. The profile (amino acid composition) of a reference protein was reported by the Food and Agriculture Organization (FAO), based on many years of biomedical research [2]. The reference protein profile is periodically reviewed in view of evolving scientific evidence.

There are several indicators of the proximity of a protein to the reference one [3]. As an assessment of the biological value of a protein, the minimum score is most commonly used. The score of a particular amino acid is defined as the ratio of this amino acid content to the content of this amino acid in the reference protein. An amino acid with a minimum score is called the first limiting amino acid, and the minimum score defines the proportion of the reference protein in the

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total protein. If we multiply it by the total protein content, we shall obtain the share of the reference protein in the product, which satisfies the body's functional needs. The remaining part of protein (excess part) is utilized by the body, loading the liver and kidneys. From this point of view, it is desirable if the food product contains a maximum of reference protein and a minimum of excess protein.

Cereals are characterized by a low content of lysine, an amino acid responsible for proper functionality of the cardiovascular and immunity systems of the human body [4, 5]. In cereal products, lysine can be complemented by legumes, whose proteins, on the other hand, are characterized by low contents of methionine and cysteine, such as those of chickpea [6]. This approach is used in bakery and pasta production, for example [6, 7]. Chickpea proteins compare favourably with proteins of other leguminous crops, such as beans, peas or soybeans with low levels of antinutrients. Moreover, the usefulness of chickpea in food production is explained not only by its nutritional value, but also by specific properties of its proteins [8].

Barley, groats in the form of pearl barley and peeled barley porridge, are traditional in Russia. Groats from triticale (including the high-carotenoid species) were recently developed at the All-Russian Research Institute of Grain and its Processing Products (ARRIG, Moscow, Russia) [9].

Scientific hypothesis

In the case of complementarity of chickpea proteins with barley and triticale proteins, it is possible to improve the situation with the amino acid profile when creating a combined product. As this takes place, the amino acid profiles of the component proteins must be selected so that they complement each other, that is the protein quality increases when adding a moderate quantity of protein with a high content of essential amino acid is added to another protein for which this amino acid is a limiting one.

MATERIAL AND METHODS

As a component of porridge, barley groats (from barley in accordance with GOST 5784-60 [10]), were used. These were obtained in a store in Moscow, Russia. Chickpea groats from chickpea of the „Vektor" variety of 2015 harvest were provided by the Federal Scientific Center of Legumes and Groat Crops (Streletsky village, Oriol Region, Russia).

The procedure of the production of chickpea groats in laboratory conditions included the following steps: crushing of grains in a hammer mill (Bühler, Braunschweig, Germany) with a working sieve of 5 mm, glazing of the shell and flour on the air separator (Bühler) and selection of the fraction "passage 1.5 mm – gathering 2 mm" on the laboratory air separator of grain VSZ (LTK Grainlab, Krasnodar, Russia).

Mixing the cereals was carried out in a laboratory paddle mixer, manufactured in the workshop of the ARRIG.

Tab. 1 provides the amino-acid profile of reference protein as recommended by FAO, triticale, barley and chickpea grains[2].

Amino acid scores were calculated based on recommendations given in FAO report [2]. The calculation results are shown in Tab. 2.

To determine the ratio of components in the mixture, various methods can be used, for example, method of direct search for the maximum of the first limiting amino acid of a mixture by varying proportions. In this case, the algorithm for calculating the percentage of the reference (ideal) protein in the mixture can be presented as follows [11]:

Tab. 1. Amino-acid composition of reference protein and protein of cereal crops.

Indicators	Content in relation to protein [%]			
	Reference	Chickpea	Triticale	Barley
Total protein	100.0	25.0	10.5	10.0
Lysine	5.5	7.2	3.5	3.5
Methionine + cystine	3.5	2.1	3.4	3.6
Isoleucine	4.0	4.3	3.7	4.6
Leucine	7.0	7.9	6.9	5.1
Threonine	4.0	4.0	2.8	2.5
Phenylalanine + tyrosine	6.0	8.6	7.1	8.2
Tryptophane	1.0	1.0	1.0	1.2
Valine	5.0	5.3	4.2	3.7

Tab. 2. Amino acid scores of protein of chickpea, triticale and barley.

Indicators	Chickpea	Triticale	Barley
Amino acid score (non-dimensional quantity)			
Lysine	1.3	0.6	0.6
Methionine + cystine	0.6	1.0	1.0
Isoleucine	1.1	0.9	1.2
Leucine	1.1	1.0	0.7
Threonine	1.0	0.7	0.6
Phenylalanine + tyrosine	1.4	1.2	1.4
Tryptophane	0.9	1.0	1.2
Valine	1.1	0.8	1.2
Content in product			
Reference protein [%]	15.2	6.7	6.3
Excess protein [%]	9.8	3.8	3.7

1. The values of total protein B_1 and scores of its EAA (C_{i1}) shall be set for the first component of the mixture:

$$\{C_{i1}, i = \overline{1,n}\} \quad (1)$$

2. The values of total protein B_2 and scores of its EAA (C_{i2}) shall be set for the second component of the mixture:

$$\{C_{i2}, i = \overline{1,n}\} \quad (2)$$

3. The values of the first component X shall be set.
4. Total protein of the mixture (B) shall be calculated:

$$B = X(B_1 - B_2) + B_2 \quad (3)$$

5. Amino acid scores of EAA of the protein of the mixture (C_i) shall be calculated:

$$\{C_i, i = \overline{1,n}\} \quad (4)$$

$$C_i = \frac{X(C_{i1}B_1 - C_{i2}B_2) + C_{i2}B_2}{X(B_1 - B_2) + B_2} \quad (5)$$

6. The minimum score of the mixture $C_{\min}$ and appropriate amino acid shall be determined:

$$C_{\min} = \min\{C_i, i = \overline{1,n}\} \quad (6)$$

7. The percentage of convertible protein (K) in the mixture shall be calculated:

$$K(X) = C_{\min}B \quad (7)$$

8. The percentage of excess protein is

$$I(X) = B - K(X) \quad (8)$$

9. By varying X, one will find

$$C = \max[\min[C_i(X)]] \quad (9)$$

There may be a way to use any subprogram of extremum seeking.

To calculate the proportions and convertible protein of the mixture of two components, a simpler algorithm can be used:

1. The protein content in each component is set (B_1 and B_2).
2. The minimum amino acid score of the protein of the first component ($C_{i1\min}$) is found as well as the amino acid score of appropriate EAA in the second component (C_{i2}).
3. The minimum amino acid score of the protein of the second component ($C_{j2\min}$) is found as well as the amino acid score of appropriate EAA in the first component (C_{j1}).
4. The mass fraction of the first component of the mixture is designated X.
5. The proportions of the mixture are taken in such a way that contents of reference proteins in the mixture, calculated by limiting EAA of the first and second components, are equal:

$$B_1C_{i1\min}X + B_2C_{i2}(1 - X) = \\ = B_1C_{j1}X + B_2C_{j2\min}(1 - X) \quad (10)$$

On re-arrangements and determining X, the maximum fraction of the first component of the mixture ($X_{\max}$) is obtained

$$X_{\max} = \frac{1}{1 + \frac{B_1(C_{i1\min} - C_{j1})}{B_2(C_{j2\min} - C_{i2})}} \quad (11)$$

The convertible protein content in the mixture, depending on the mass fraction of the component, is equal to K calculated according to Eq. 12 or Eq. 13.

$$K = B_1C_{i1\min}X_{\max} + B_2C_{i2}(1 - X_{\max}) \quad (12)$$

$$K = B_1C_{j1}X_{\max} + B_2C_{j2\min}(1 - X_{\max}) \quad (13)$$

These calculations can be used if the limiting amino acids of the components do not match.

Considering that ratio in Eq. 14 is greater than 0 and $0 < X < 1$, it is possible to calculate the proportions and scores of proteins of the mixture.

$$\frac{B_1\left(C_{i1\min} - C_{j1}\right)}{B_2\left(C_{j2\min} - C_{i2}\right)} > 0 \qquad (14)$$

It is advisable to recount the scores of all essential amino acids of the mixture, since it is possible that the second limiting amino acid of one of the components has become limiting.

To facilitate the calculations, it is possible to write a calculation programme using the mathematical package MathCad (Mathsoft, Cambridge, Massachusetts, USA).

Statistical analysis

To analyse the parameters of the product, statistical analysis of the obtained data was conducted and the reliability of the obtained data was evaluated by T-test, using SPSS Statistics, version 20.0 (IBM, Armonk, New York, USA). To describe the ordered sample, we used statistical functions of the average arithmetic value and the average standard error. Graphical interpretation of the results was made by using Microsoft Excel (Microsoft, Redmond, Washington, USA).

RESULTS AND DISCUSSION

Tab. 2 shows complementarity of proteins (synergistic effect) of triticale and barley with chickpea protein. Parameters of the protein and the mixture, depending on the chickpea content, are shown in Fig. 1 and Fig. 2. Data of typical tests are presented, each value being an average of at least five determinations. We selected the value of reliability $p = 0.04$. As can be seen, the extremum of a minimum score of triticale groats takes place when adding 0.197 kg·kg^{-1} of chickpea groats, while in case of barley groats this takes place when adding 0.292 kg·kg^{-1} of chickpea groats. With the component ratio in a mixture corresponding to the extremum, a protein (though incomplete $C_{\min} < 1$) with an optimum profile of amino acids. is obtained. The total protein, as well as its reference part, increases with increasing the percentage of chickpea. When $C_{\min}(X_{\max}) > 1$, the equation $C_{\min}(X) = 1$ has two solutions ($X_{\min}$ and $X_{\max}$), and in the interval of the proportion of adding the first component $X_{\min} < X < X_{\max}$, the mixture's protein is complete. However, the mixture should not only be useful, but it also should conform with dietary habits. For this purpose, the proportion of chickpea added to the mixture is evaluated from the culinary, taste point of view and, for baking, an optimum of 0.10 kg·kg^{-1} (10 %) was found [7]. The addition of chickpea in the range preferred in culinary use (up to 30 %) has the effect in the growth of total and ideal protein, while reducing the excess protein.

Tasting assessment of barley porridge (groats No. 2) with the addition of chickpea groats at 0.05 kg·kg^{-1} (5 %), 0.10 kg·kg^{-1} (10 %), 0.15 kg·kg^{-1} (15 %), 0.20 kg·kg^{-1} (20 %) and 0.25 kg·kg^{-1} (25 %) showed that all samples had a pleasant appearance, solid consistency, there was no off-odour or taste characteristic of leguminous crops. A photograph of the porridge with addition of 0.10 kg·kg^{-1} (10 %) of chickpea groats is shown in Fig. 3.

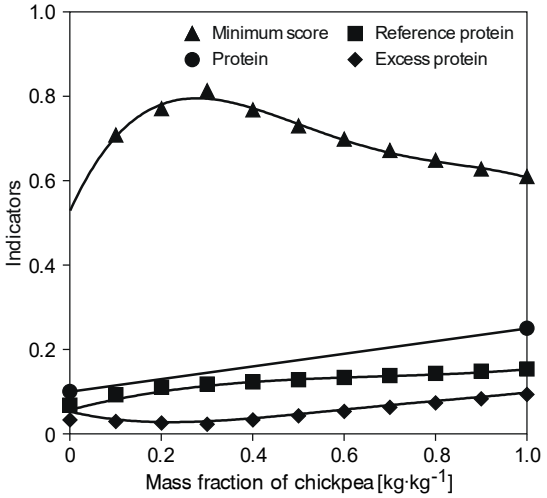

Fig. 1. Dependence of parameters of protein and mixture on the peeled barley and chickpea contents.

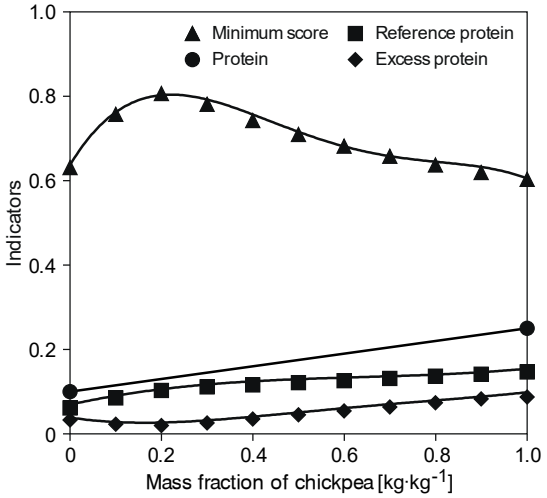

Fig. 2. Dependence of parameters of protein and mixture on the triticale and chickpea contents.

Fig. 3. Appearance of the peeled barley porridge with the addition of 10 % of chickpea groats.

CONCLUSION

At present, there is an acute shortage of food products with a balanced composition, primarily regarding the content of essential amino acids. Animal complete proteins are inaccessible for many people. Plant proteins are cheaper but incomplete. The creation of the combined plant foodstuffs with a balanced composition, primarily in terms of the essential amino acid content, offers at least a partial solution to the problem of a deficiency in complete protein. In this study, partial compensation of lysine deficiency in grain products from triticale and barley was proposed. The considered approach to the formation of an effective mixture of groats from triticale, barley and chickpea led to a product with an increased total protein and increased percentage of ideal protein, with decreased percentage of excess protein. An algorithm was proposed for calculating optimum proportions of two proteins when they are mixed. The methodology allows for creating the grain mixtures with an optimum amino acid profile of protein.

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