Проведено аналіз основних методів підвищення харчової і біологічної цінності борошна пшеничного. Значну увагу приділено питанню корегуванню вмісту білку у борошні за рахунок внесення добавок. Підкреслено актуальність поліпшення амінокислотного складу білка борошна, обгрунтовано доцільність комплексних досліджень з розробки рецептур харчових систем зі збалансованим амінокислотним складом на основі пшеничного борошна та шротів олійних культур.

Експериментально визначено амінокислотний склад та розраховано біологічну цінність білків сировини для харчових систем – шротів соняшнику та сої. Науково обґрунтовано склад композиції шротів соняшникового і соєвого з поліпшеним амінокислотним складом. Встановлено, що за вмістом лейцина, лізина та суми сірковмісних амінокислот (метіонін, цистин) білок композиції шротів максимально наближений до еталонного. Скор ізолейцина, триптофана, фенілаланіна і тирозина в білку композиції шротів вище еталонного в 1,1–1,47 рази.

Розраховано амінокислотний склад та визначено біологічну цінність білку харчових систем, що містять у своєму складі 80–90 % борошна пшеничного та 10–20 % композиції шротів сої та соняшнику поліпшеного амінокислотного складу. Встановлено, що найбільшу біологічну цінність у порівнянні з борошном пшеничним має рецептура харчової системи, що містить 20 % композиції шротів і 80 % борошна пшеничного. У даній харчовій системі скор лімітованих амінокислот – лізину та сірковмісних (метіонін і цистин) – найбільш наближений до еталонного і становить 67,68 % та 70,12 %.

Експериментально визначено жирнокислотний склад і розраховано біологічну ефективність жирів розроблених харчових систем. Найбільш наближеною рецептурою до рекомендованого дієтологами співвідношення жирних кислот є харчова система із співвідношенням композиція шротів:борошно пшеничне 20:80.

Одержані рецептури харчових систем будуть корисними для використання в технологіях борошняних виробів з підвищеною біологічною цінністю

Ключові слова: борошно пшеничне, шрот соняшниковий, шрот соєвий, незамінні амінокислоти, скор, жирні кислоти, харчові системи

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DEVELOPMENT OF AMINO ACID BALANCED FOOD SYSTEMS BASED ON WHEAT FLOUR AND OILSEED MEAL

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1. Introduction

Human nutrition is the main factor in ensuring and improving health. For the proper functioning of the human body, about 600 essential nutrients are needed daily. Proteins – the most important component of the six main components of food should be present in the nutrition of every person every day. Protein – the main source of essential amino acids – plays the role of building material in the process of cell development and metabolism in the organism. Lack of proteins in the diet can lead to a decrease in the protective properties of the organism, disrupt digestion processes, blood formation, the activity of the central nervous system or weaken mental activity. It is well known that about half of the world's population lacks protein in the diet. The main source of dietary protein can be called not only fish and animals, but also plants, namely grain and oil crops [1].

At the same time, the nutrition of a significant part of the world's population is characterized by violations of the nutritional status, namely, a mismatch between the low level of energy consumption and the high level of consumption of high-calorie foods with a low content of essential substances [2]. Today, more than ever, this significant part of the population requires foods with a balanced amino acid and fatty acid composition to maintain their health. Such products can provide the human body with the necessary amount of essential macro- and micronutrients and, in addition, will not change the usual diet and lifestyle [3, 4].

Each country in the world has unique traditions and food culture. However, bread and bakery products from wheat flour are the components of the daily diet of most people. So, in Ukraine, the consumption of bread and bakery products accounts for about 11 % of total food consumption. At the same time, the volume of production of bread for wellness purposes is less than 0.5 % of the total output of bakery products. For comparison, in developed countries, this figure reaches 30 % [1]. The main component of the bread or bakery formulation is flour. The amino acid composition of the protein of wheat flour is not balanced. In wheat flour, of eight essential amino acids for an adult, six are limited, including such important ones as sulfur-containing methionine and cystine, and, as in other crops, lysine. If the diet contains enough lysine-rich foods (dairy products, meat, fish), the low lysine content in wheat bread may not cause anxiety. However, when the proportion of bread and other grain products in the diet increases, the question of how to increase the lysine content in bread becomes very important. Therefore, flour and products from it can be considered promising products for the enrichment of essential ingredients.

Fortification of bread with lysine can be carried out either by adding natural products rich in protein in general and lysine in particular to the flour, or by adding concentrates or pure preparations of lysine. Natural products have an advantage, because in addition to high protein content, they contain a significant amount of vitamins and minerals. Thus, using natural fortifiers for flour, it is possible to comprehensively enrich bread.

Among various natural products, soy flour, yeast, skimmed milk powder, cereal germ and sunflower or cotton meal cake deserve special attention due to the high lysine content. However, despite the high biological value, today the use of cake or meal cannot be called rational, because traditionally their main share goes to livestock feed and only 15 % goes to food industry enterprises [5].

Therefore, the solution to the problem of obtaining balanced amino acid composition of food systems based on wheat flour and oilseed meal is relevant. The resulting food systems and flour products from them can become not only competitive, but will also contribute to improving the health of the population.

2. Literature review and problem statement

An effective way to increase the nutritional and, in particular, biological value of wheat flour is to optimize its nutrient composition using promising types of additives that have a sufficient amount of essential substances and an acceptable cost [4]. Correction of the protein content in flour is achieved by the introduction of various natural additives, including oilseed meal. The addition of oilseed meal to wheat flour not only enhances the nutritional and biological value of the latter, but also improves the technological and organoleptic characteristics of flour products obtained from similar combined products [6–14].

In [6], the results on the use of hemp flour in bread production have been presented. The authors found that the introduction of hemp flour from 30 to 50 % of the total mass of flour contributed to the reduction of stale breadcrumbs; affected the color of the crumb, increasing the darkening index from 29.69 (standard bread) to 46.26 (50 % of the additive); increased the protein content to 13.38–19.29 g/100 g compared with wheat bread (11.02 g/100 g). For industrial production of bread, the authors recommended the introduction of hemp flour in wheat flour not higher than 30 %. But the use of this additive in flour can lead to an increase in the cost of the finished product – bread because of its high cost. The authors calculated the protein content in the finished product, but did not determine its amino acid composition, according to which the biological value or proximity of protein to the ideal should be calculated. Such a development of bread recipes with improved organoleptic characteristics can expand the range of flour products.

In [7], studies were presented on the production of biscuits from a mixture of wheat flour with the addition of different amounts of pumpkin seed flour, a by-product of pumpkin oil production. The authors of the study showed the possibility of reducing the cost of the final product through the use of a secondary product of production. Using the studies, it was found that the introduction of pumpkin seed flour into the product's recipe contributed to reducing the diameter, height and volume of biscuits, giving them a pleasant taste of fried pumpkin seeds, an unusual green color and a softer texture. The experiments of scientists [7] proved that the replacement of wheat flour with pumpkin seed flour to maintain high technological parameters of biscuits should not exceed 60 %. The work proposes the use of pumpkin seed flour as a functional and nutritious substitute for wheat flour. However, calculations and data that prove the biological and nutritional values of this type of flour and biscuits have not been given.

In [8], in the preparation of oatmeal cookies with functional properties, 30 % of wheat flour was replaced with partially fat-free almond flour and 100 % of soybean oil was replaced with almond oil. The resulting cookies were examined and compared with traditional oatmeal cookies. It was found that the new cookies have a fairly high humidity, fiber content, protein content and low calorie content. The authors noted that such a replacement not only allows you to get a product for wellness purposes, but also to prevent the formation of residual waste after oil extraction, which is interesting from an environmental point of view. The study does not explain why the replacement of wheat flour should be exactly 30 %. The authors, as in previous works, did not study the amino acid composition of almond flour protein and its direct effect on the total amino acid composition of a mixture of wheat and almond flour.

In contrast to [6–8], the authors of [3] scientifically substantiated the formulation of sunflower halva with the addition of a special-purpose protein-fat mixture. A special-purpose mixture based on flax and sesame seeds has a balanced composition of branched-chain amino acids (leucine, isoleucine, valine) in a ratio of 2:1:1, enriched with ω-3 polyunsaturated fatty acids. However, this study refers to a mixture of oilseeds that was used in a confectionery product such as halva, not flour.

The work [9] presents the results of studies regarding the addition of 20 to 50 % amaranth flour to wheat flour in the chapati technology (traditional bread in India). It was found that the content of amaranth flour improves the properties of the dough, reduces water absorption and stability of the dough, and also increases the total content of protein and trace elements in the final product. However, by adding amaranth flour to wheat flour, the total protein content in the final product can be increased by no more than 3–5 %. This can be explained by the fact that amaranth seeds, compared to soybean, sunflower, rape, and flax seeds, which have a protein content of 35 to 50 %, contain a small amount of protein, namely 12–19 %.

In [13], the results of studies on the use of coconut copra meal, which has a low content of lauric acid, to produce cookies, have been presented. The cookies obtained by the authors had good organoleptic properties. The authors predict that in the future copra meal may become a promising type of raw material for the confectionery industry. However, such an additive cannot contribute to an increase in the total protein content in the developed cookies, as it contains about 3.5 % protein.

The studies presented in [6–13] have been carried out using a mixture of wheat flour and flour of various oilseeds or their meal only with the aim of expanding the range of flour products and using secondary processing products, but not to obtain products with increased biological and nutritional value. Therefore, research on the development of food system formulations based on wheat flour, which will have a balanced amino acid composition, is promising. So, for example, in [14], the results of studies of bread production technology with the addition of 5 to 30 % of the developed "Omega-6" grain mix are presented. The composition of the grain mixture formulation includes grain and oil crops: sprouted corn (63 %), amaranth (1 %), flax seeds (15 %), sunflower seeds (2 %), pumpkin seeds (2 %), sesame seeds (2 %) wheat bran (15 %). According to the results of studies, it was found that the best organoleptic and physico-chemical properties were in a bread sample with the addition of 20 % of the grain mixture. The authors found that in the resulting sample the content of essential amino acids increased by about 56.6 %; magnesium – by 33.8 %; sodium – 7.3 %; potassium – by 10.2 %. The antioxidant activity in grain bread compared to control increased by 1.89 times. The number of microorganisms in experimental bread decreased by 50 %. According to the forecasts of the authors, the use of this "Omega-6" grain mixture in the technology of flour products will expand the range of bread with increased nutritional and biological value. However, the disadvantage of this grain mixture is its multicomponent nature and difficulty of obtaining some components.

Based on the foregoing, it is determined that today there are many developments of flour-based food systems that are aimed at solving such problems as improving the technological and organoleptic characteristics of flour products, reducing their cost or using secondary products. No studies have been found on improving the amino acid composition and increasing the biological value of wheat flour protein by using protein-rich supplements to produce amino acid-balanced nutritional systems. Therefore, conducting research in this direction is advisable.

3. The aim and objectives of the study

The aim of the work is to develop recipes for food systems with a balanced amino acid composition based on wheat flour and oilseed meal, in particular soy and sunflower.

The following tasks were set to achieve this aim:

– experimentally determine the amino acid composition and calculate the biological value of proteins of reasonably selected feedstock for food systems;

– scientifically substantiate the composition of the soybean and sunflower meal mixture with improved amino acid composition;

– scientifically substantiate the composition and determine the biological value of food systems based on wheat flour and soybean and sunflower meal mixture with improved amino acid composition;

– experimentally determine the fatty acid composition and calculate the biological effectiveness of fats of the proposed food systems.

4. Materials and methods for the development of amino acid balanced food systems based on wheat flour and oilseed meal

4. 1. Materials and equipment used in the experiment

The following materials were used for research:

– wheat flour according to DSTU 46.004;

– sunflower meal according to DSTU 4638;

– soybean meal according to DSTU 4593.

A mixture of oilseed meal is a mixture of sunflower meal dried in an oven at a temperature of 100–105 °C to a moisture content of 3.0–3.5 % and finely ground and soybean meal in different proportions. Grinding of the meal was carried out on a Glasser knife vertical grinder (Infel, RF) (rotation speed up to 10,000 rpm). Glasser knife vertical shredder allows to grind raw materials to a particle diameter of 150...200 microns. The resulting mixture has the consistency of flour.

Food systems based on wheat flour and oilseed meal mixture are a mixture of wheat flour and oilseed meal mixture. The resulting mixture has the consistency of flour.

4. 2. Method for determining the protein content in oilseed meal and wheat flour

The mass fraction of protein in oilseed meal and wheat flour was determined by the Kjeldahl method. The main stages of the analysis of protein content are ashing of the investigated raw materials; steam distillation of ammonia nitrogen resulting from ashing; titration of the resulting solution with ammonium borate, conversion of the nitrogen content to the protein content in the raw materials.

4. 3. Method of determining the amino acid composition of the proteins of oilseed meal and wheat flour

The amino acid composition of the proteins of sunflower meal and soybean meal was determined using ion exchange column chromatography. Amino acid analysis was performed on an LKB 4151 Alpha Plus amino acid analyzer (Sweden).

The main stages of the analysis of the amino acid complex of bound amino acids are the hydrolysis of the protein of raw materials and the subsequent quantitative determination of amino acids in the resulting hydrolyzate. The prepared sample was introduced into a cation exchange resin column. Buffer solutions with different pH values were sequentially passed through an ion-exchange column, during which the separation of amino acids occurred. The eluate that exited the ion exchange column reacted qualitatively with ninhydrin. The resulting mixture was sent to a photometer, where quantitative identification of amino acids was carried out. Amino acids were identified by comparing their retention time with the retention time of standards. The type of amino acid was characterized using the value of the peak retention time, the amino acid content was characterized using the value of the peak area.

4. 4. Methodology of determining the fatty acid composition of oilseed meal lipids and wheat flour lipids

Sample preparation for determining the fatty acid composition of oilseed meal lipids and wheat flour lipids was carried out according to DSTU ISO 5509. The resulting solution of fatty acid methyl esters was analyzed according to DSTU ISO 5508 by gas-liquid chromatography on a Shimadzu chromatograph (Japan). Fatty acids were identified by comparing their retention times with the retention times of standards. The fatty acid content was calculated as a percentage of their total.

4. 5. Methodology for determining the biological value of oilseed meal protein and wheat flour protein

An indicator of the biological value of a protein is the amino acid score. The amino acid score of oilseed meal protein and wheat flour protein was determined by comparing the content of each irreplaceable amino acid in the proteins of the test material to the content of the same amino acid in the so-called "ideal" reference protein (according to the FAO/WHO amino acid scale). A reference protein is a theoretical protein that is ideally balanced in amino acid composition. Accordingly, the rate of all amino acids in the reference protein is 100 %. The calculation of the amino acid scores of essential amino acids is carried out according to the formula (1):

$$\text{SCORE} = \left({}^{a_i}\!/_{a_b} \right) \cdot 100\ \% \qquad (1)$$

where a_i – amino acid content in a 100 g protein of the investigated raw materials; a_e – content of the same amino acid in a 100 g reference protein.

The amino acid, which has the lowest rate in the studied protein, is called limiting. It determines the degree of assimilation of the whole protein.

4. 6. Methodology of studying the effect of oilseed meal ratio on the amino acid composition of meal mixture protein

As a result of studies of the effect of the ratio of sunflower and soybean meal on the content of essential amino acids in the mixture of oilseed meal C_{EAA} (c_{sf}, c_{sb}), the following dependencies are obtained

$$C_{EAA}\left(c_{sf}, c_{sb}\right) = C_{EAA} \cdot c_{sf} + C_{EAA} \cdot c_{sb}, \qquad (2)$$

where C_{EAA} – content of the essential amino acid in the meal mixture protein; c_{sf} – mass fraction of sunflower meal protein in a meal mixture; c_{sb} – mass fraction of soybean meal protein in a meal mixture.

4. 7. Methods of developing food systems based on wheat flour and oilseed meal mixture

To obtain models of food systems with a balanced amino acid composition based on wheat flour and oilseed meal, we used a methodology based on the following principles [15]:

– in any set of protein-containing ingredients, there is a ratio that provides the most balanced amino acid composition with respect to a statistically sound reference protein;

– due to the introduction of additional fat-containing ingredients, it is possible to purposefully change the fatty acid composition of the product being developed;

– in any set of fat-containing ingredients, there is such a ratio in which the ratio between saturated, monounsaturated and polyunsaturated fatty acids corresponds to the value that is set as much as possible.

The calculation for determining the amino acid content in food systems based on wheat flour and a mixture of sunflower and soybean meals of improved amino acid composition is performed according to the formula (3):

$$A_i = \frac{\sum_{i=1}^{n} a_{ik} p_k x_k}{\sum_{k=1}^{n} p_k x_k}, \qquad (3)$$

where A_i – mass fraction of the i-th amino acid in the protein of the model food system, %; a_{ik} – mass fraction of the i-th amino acid in the protein in the k-th ingredient, %; p_k – mass fraction of protein in the k-th ingredient, % (p_{flour}=10.34; p_{mixture}=40.5); x_k – mass fraction of the k-th ingredient, %.

For the development of food systems based on wheat flour and oilseed meal composition, the following ratio was selected: 80–90 % of wheat flour and 10–20 % of a mixture of oilseed meal with improved amino acid composition. The range of variation in the ratio of components in the modeling of food systems was 1 %. Since in the considered range of ratios of the components of food systems, the variation interval during mathematical modeling was 1 %, eleven prescription compositions were obtained as a result of modeling food systems by amino acid composition.

4. 8. Methods for determining the biological effectiveness of fats in food systems

For each of the obtained food systems, the fatty acid composition has been experimentally determined and analyzed, namely, the ratio between saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) has been found.

The calculation for determining the content of fatty acids (SFA, MUFA or PUFA) in food systems is performed according to the formula (4):

$$L_i = \frac{\sum_{i=1}^{n} l_{ik} q_k x_k}{\sum_{k=1}^{n} q_k x_k}, \qquad (4)$$

where L_i – mass fraction of the i-th fatty acid in the fat of the simulated food system, %; l_{ik} – mass fraction of the i-th fatty acid in the fat of the k-th ingredient, %; q_k – mass fraction of fat in the k-th ingredient, % (q_{flour}=1.48; $q_{mixture}$=2.13); x_k – mass fraction of the k-th ingredient, %.

To assess the quality of the fat component of food systems, a biological efficiency coefficient was used, which in accordance with [18] indicates the degree of fat absorption and the matching of their fractional composition to the needs of the body. To calculate the biological effectiveness of fats of various food products, the concept of reference fat is used, that is, a hypothetical product that contains PUFA, SFA, and MUFA in the required proportion.

The score for fatty acids of fat in food systems has been defined as the ratio of the content of certain fatty acids of a product to their content in a hypothetically "ideal" fat:

$$\mathrm{SCORE}_{Fi} = \frac{l_i}{l_0}, \quad (5)$$

where l_i – mass fraction of the i-th fatty acid in fat, g/100 g; l_0 – mass fraction of the i-th fatty acid in "ideal" fat, g/100 g.

For conditional "ideal" fat, the following condition holds:

$$\mathrm{SCORE}_{SFA}=\mathrm{SCORE}_{MUFA}= =\mathrm{SCORE}_{PUFA}=1. \quad (6)$$

The fat absorption degree is described by the dependence:

$$\psi = \frac{3 \cdot \mathrm{SCORE}_{Fi\,\min}}{\sum_{i=1}^{3} \mathrm{SCORE}_{Fi}}, \quad (7)$$

where $\mathrm{SCORE}_{Fi\,\min}$ – minimum score of the i-th fraction of fatty acids of fat; SCORE_{Fi} – score of each i-th fraction of fatty acids of fat.

It should be noted that the utilization rate of "ideal" fat ψ=1 [16].

The biological effectiveness of the feedstock (oilseed meal, their mixture and wheat flour), as well as food systems in accordance with formulas (5) and (7) was calculated according to two requirements:

– for nutrition of a healthy person, where, according to [18], the ratio of fatty acids SFA: MUFA: PUFA is 23.0: 69.0: 8.0, respectively;

– for therapeutic nutrition, where, according to [19], the ratio of fatty acids SFA:MUFA:PUFA is 33.3: 33.3: 33.3, respectively.

4. 9. Experimental design and statistical processing of research results

Mathematical methods were applied to plan the experiment and process the data using the Microsoft Office Excel 2003 software packages (USA). The studies were carried out in triplicate. For a given degree of probability P=95 %, the relative error did not exceed:

– 0.5 % in determining the protein content in raw materials;

– 2 % in determining the amino acid composition of raw materials;

– 0.5 % in determining the fatty acid composition of oilseed lipids.

5. Results of the development of amino acid balanced food systems based on wheat flour and oilseed meal

5. 1. Determination of amino acid composition and calculation of the biological value of raw materials proteins

The amino acid composition of the essential amino acids of proteins of sunflower and soybean meals, wheat flour (Fig. 1), as well as the indicator of their biological value (SCORE, %), which was calculated by the formula (1) (Fig. 2), have been experimentally determined. The data have been compared with the amino acid composition of the reference protein described in [16].

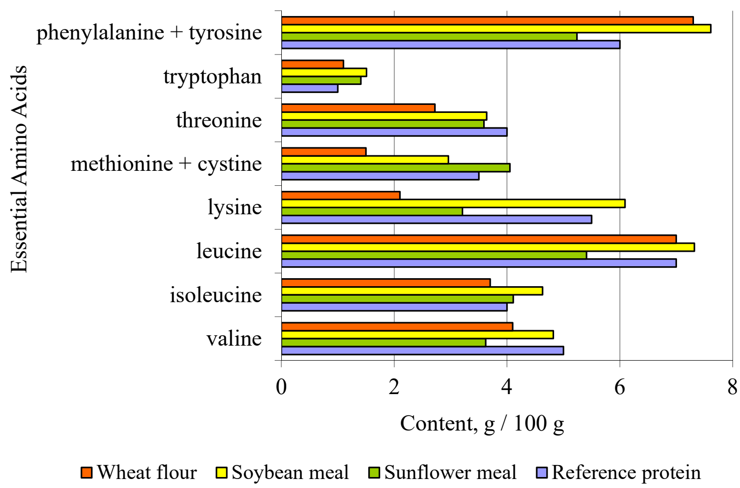

Fig. 1. Amino acid composition of essential amino acids of raw protein for food systems

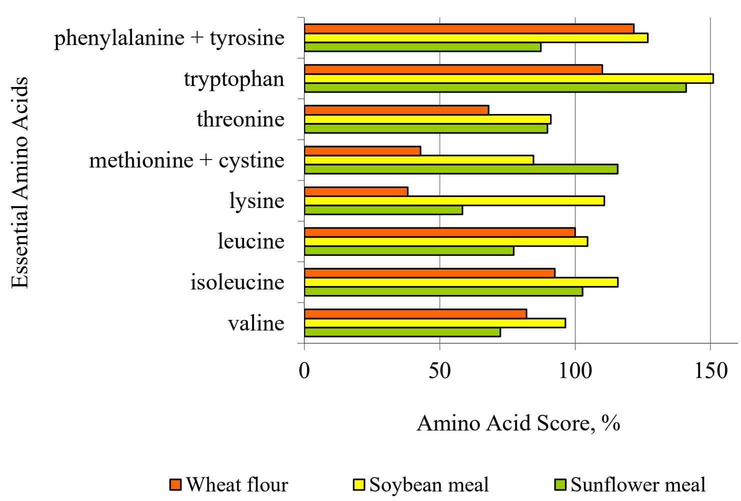

Fig. 2. Biological value of raw proteins for food systems

Comparing the content of individual amino acids in the wheat flour protein with the amino acid formula of the reference protein, it was found that there is a sharp disproportion of essential amino acids. Thus, if the score of leucine reaches 100.00 %, the score of phenylalanine+tyrosine – 121.67 %, the score of tryptophan – 110.00 %, and the score of valine, isoleucine is quite high and is 82.00 and 92.50 %, respectively, the rate of lysine, methionine and threonine is only 38.18, 42.86 and 68.00 %. In contrast, soybean meal protein, unlike wheat flour protein, contains a sufficient amount of all essential amino acids, except for the amount of sulfur-containing (methionine and cystine). The lack of limiting essential amino acids in soy protein can be avoided by adding sunflower meal protein, in which a sufficient amount of these amino acids is present. Analysis of the amino acid composition of sunflower meal protein indicates a lack of certain amino acids. It is especially poor in lysine, the content of which in soybean meal is significant.

It is possible to compensate for the lack of the above-mentioned limiting amino acids in wheat flour and to bring their content closer to the indicators of the reference protein using the calculation method.

5. 2. Development of a composition of oilseed meal with improved amino acid composition

As can be seen from Fig. 1, 2, lysine is the limiting amino acid of sunflower meal and wheat flour (score 58.36 and 38.18 %, respectively), and the sum of sulfur-containing amino acids (methionine and cystine) is the limiting amino acid of soybean meal and again wheat flour (84.57 and 42.86 %, respectively). Based on the analysis of the data presented in Fig. 1, 2, the influence of the ratio of sunflower and soybean meal on the content of limiting amino acids in their composition is investigated.

Solving the problem of creating a composition of soybean and sunflower meal with improved amino acid composition, using data on the content of these amino acids in the proteins of sunflower meal, soybean and reference protein (Table 1), according to equation (2), described in paragraphs. 4.6, a system of two equations is compiled:

$$\begin{cases} C_{Lys} = 3.21 \cdot c_{sf} + 6.53 \cdot c_{sb} \\ C_{Met+Cys} = 4.70 \cdot c_{sf} + 2.96 \cdot c_{sb}, \end{cases} \quad (8)$$

where C_{Lys} is the lysine content in the protein of the meal composition, it is equal to the lysine content in the reference protein (5.50 g/100 g); $C_{Met+Cys}$ – the content of the sum of methionine and cystine in the protein of the meal composition, it is equal to the content of the sum of methionine and cystine in the reference protein (3.50 g/100 g).

Solving the system of equations (8), we determined the mass fraction of sunflower and soybean meal proteins in the meal composition of improved amino acid composition, which is close to the amino acid composition of the reference protein due to the greater content of lysine, methionine and cystine. Accordingly, the mass fraction of sunflower meal protein in the meal composition is 0.31, and soybean meal protein is 0.69.

Based on the analysis of the data presented in Fig. 1, 2, the following equations (9)–(14) are compiled to calculate the composition of essential amino acids in a reasonable composition of meal:

$$C_{Val} = 3.62 \cdot c_{sf} + 4.82 \cdot c_{sb}, \quad (9)$$

$$C_{Ile} = 4.11 \cdot c_{sf} + 4.63 \cdot c_{sb}, \quad (10)$$

$$C_{Leu} = 5.41 \cdot c_{sf} + 7.32 \cdot c_{sb}, \quad (11)$$

$$C_{Tre} = 3.59 \cdot c_{sf} + 3.64 \cdot c_{sb}, \quad (12)$$

$$C_{Trp} = 1.41 \cdot c_{sf} + 1.51 \cdot c_{sb}, \quad (13)$$

$$C_{Tyr+Phe} = 5.24 \cdot c_{sf} + 7.61 \cdot c_{sb}, \quad (14)$$

where C_{Val} – valine content in the protein of the meal composition; C_{Ile} – isoleucine content in the protein of the meal composition; C_{Leu} – leucine content in the protein of the meal composition; C_{Tre} – threonine content in the protein of the meal composition; C_{Trp} – tryptophan content in the protein of the meal composition; $C_{Tyr+Phe}$ – the content of the sum of phenylalanine and tyrosine in the protein of the meal composition.

According to the formulas (9)–(14), the content and score of essential amino acids of the protein composition of sunflower and soybean meal were calculated, the results are presented in Table 1.

Table 1

Amino acid composition and biological value of protein of the sunflower and soybean meal composition

Essential amino acids	Content in the reference protein, g/100 g	Content, g/100 g	SCORE, %
Valin	5.00	4.45	88.96
Isoleucine	4.00	4.47	111.72
Leucine	7.00	6.73	96.11
Lysine	5.50	5.50	100.00
Methionine+cysteine	3.50	3.50	100.00
Threonine	4.00	3.62	90.61
Tryptophan	1.00	1.48	147.9
Phenylalanine+tyrosine	6.00	6.88	114.58
Amount of essential amino acids	36.00	36.62	

As shown in Table 1, the total protein content in the composition increased. However, to assess the physiological value, not only the protein content is important, but also its full value, which is characterized by the content of essential amino acids and their quality, which is determined by the value of the score. Comparing the amino acid score of the meal composition and the reference protein, it was found that for amino acids such as leucine, lysine and the amount of sulfur-containing (methionine+cystine), it is as close as possible to the reference. For such amino acids as isoleucine, tryptophan and the amount of phenylalanine with tyrosine, the score is 1.1–1.47 times higher than the reference.

Based on the fact that 100 g of sunflower meal contains 37 g of protein, and 100 g of soybean meal – 47 g, to obtain a composition of sunflower and soybean meal of improved amino acid composition, their rational ratio is 1:1.76 or as a percentage of 36:64 %. At this ratio, the amino acid composition of the protein of the meal mixture is closest to the reference. The obtained meal composition was used for the development of food systems of high biological value based on wheat flour.

5. 3. Scientific substantiation of the composition and determination of the biological value of food systems based on wheat flour and the composition of sunflower and soybean meal with improved amino acid composition

The ratio of components of food systems based on wheat flour and the composition of sunflower and soybean meal with improved amino acid composition is justified based on the technological features of wheat flour and its mixtures according to research [3–10]. The calculation of the amino acid composition of the protein of food systems containing 90–80 % of wheat flour and 10–20 % of the composition of soybean and sunflower meal of the improved amino acid composition was performed according to formula (3). The results of the calculation are given in Table 2.

To determine and analyze the biological value of food systems, the amino acid rate of their proteins was calculated. The results of the calculation are given in Table 3.

Table 2

Amino acid composition of proteins of food systems

Indicator	Ratio of components (meal composition/wheat flour), %										
	10/90	11/89	12/88	13/87	14/86	15/85	16/84	17/83	18/82	19/81	20/80
Essential amino acids:	Amino acid content, g/100g										
Valine	4.28	4.29	4.30	4.32	4.33	4.34	4.35	4.36	4.37	4.38	4.39
Isoleucine	4.00	4.02	4.05	4.07	4.08	4.11	4.13	4.14	4.16	4.18	4.20
Leucine	7.04	7.04	7.04	7.05	7.05	7.05	7.05	7.06	7.06	7.06	7.06
Lysine	3.08	3.16	3.23	3.30	3.37	3.43	3.49	3.55	3.61	3.67	3.72
Methionine+cystine	2.08	2.12	2.16	2.21	2.25	2.28	2.32	2.36	2.39	2.42	2.45
Threonine	3.04	3.07	3.09	3.12	3.14	3.16	3.18	3.20	3.22	3.24	3.25
Tryptophan	1.24	1.25	1.26	1.27	1.28	1.28	1.29	1.30	1.31	1.32	1.32
Phenylalanine+tyrosine	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29	7.29
The sum of essential amino acids	32.04	32.24	32.43	32.61	32.78	32.95	33.11	33.26	33.41	33.56	33.70
Protein	Protein content, %										
	13.03	13.30	13.58	13.85	14.12	14.40	14.67	14.94	15.21	15.49	15.76

Table 3

Amino acid score of proteins of food systems

Ratio of the components of the meal composition/wheat flour), %	Score of essential amino acids, %							
	Valine	Isoleucine	Leucine	Lysine	Methionine+cystine	Threonine	Tryptophan	Phenylalanine+tyrosine
10/90	85.52	100.00	100.54	**56.02**	**59.35**	76.08	123.56	121.57
11/89	85.79	100.58	100.58	**57.40**	**60.62**	76.71	124.61	121.56
12/88	86.05	101.14	100.62	**58.73**	**61.85**	77.31	125.62	121.56
13/87	86.31	101.68	100.66	**60.00**	**63.03**	77.88	126.59	120.79
14/86	86.55	101.91	100.69	**61.22**	**64.16**	78.44	127.52	121.54
15/85	86.78	102.69	100.73	**62.40**	**65.25**	78.97	128.41	121.54
16/84	87.00	103.16	100.76	**63.54**	**66.29**	79.48	129.28	121.53
17/83	87.22	103.62	100.79	**64.63**	**67.30**	79.98	130.11	121.52
18/82	87.43	104.07	100.83	**65.68**	**68.28**	80.46	130.91	121.52
19/81	87.63	104.49	100.86	**66.70**	**69.22**	80.92	131.68	121.51
20/80	87.82	104.91	100.89	**67.68**	70.12	81.36	132.43	121.51

Comparing the score of individual amino acids in the protein of food systems with the introduction of 10–20 % of the composition of meal in wheat flour (Table 3) with the score of essential amino acids of wheat flour (Fig. 1, 2), it was found that such a sharp disproportion between essential amino acids does not exist. Indeed, the amino acid score of lysine, methionine+cystine and threonine in food systems as well as wheat flour remains less than 100 % and these amino acids will be lacking in foods based on the developed food systems. However, in comparison with wheat flour in pure form, the content of these amino acids is increased by 1.1–1.8 times and is, respectively, 56.02–67.68 % (lysine), 59.35-70.12 % (methionine+cystine), 76.08–81.36 % (threonine). The score of valine, isoleucine and leucine remains quite high and is 85.52–87.82 %, 100.00–104.91 % and 100.54–100.89 %. The excess of phenylalanine (121.57–121.51 %) and tryptophan (123.56–132.43 %) remains. Thus, comparing the amino acid scores of food systems, which are given in Table 3, it is found that the formulation containing 20% of the composition of meal and 80 % of wheat flour has the greatest biological value. In this food system, the score of limited amino acids – lysine and sulfur-containing (methionine and cystine) – is closest to the reference and is 67.68 % and 70.12 %. That is, the developed food systems have a higher biological value compared to wheat flour. It should be noted that due to the technological features of wheat flour, according to [3–10] it was not possible to increase the content of oilseed meal composition in food systems in order to further increase the biological value.

5. 4. Determination of fatty acid composition and calculation of biological efficiency of fats of the proposed food systems

The fatty acid composition of samples of food systems was studied. For each of the food systems, according to formula (4) the analysis of fatty acid composition was carried out, the results are given in Table 4.

Table 4

Fatty acid composition of food systems

Fatty acids, their ratio	Ratio of components of food systems (meal composition/wheat flour), %										
	10/90	11/89	12/88	13/87	14/86	15/85	16/84	17/83	18/82	19/81	20/80
	Fatty acid composition, g/100 g										
Σ SFA	21.27	21.16	21.06	20.95	20.85	20.75	20.64	20.54	20.44	20.34	20.24
Σ MUFA	15.59	15.72	15.86	15.99	16.12	16.25	16.38	16.50	16.63	16.76	16.88
Σ PUFA	63.14	63.11	63.09	63.06	63.03	63.01	62.98	62.95	62.93	62.90	62.88
SFA:MUFA:PUFA	1.37:1:4.05	1.35:1:4.01	1.33:1:3.98	1.31:1:3.94	1.29:1:3.91	1.28:1:3.88	1.26:1:3.85	1.24:1:3.81	1.23:1:3.78	1.21:1:3.75	1.2:1:3.73

According to Table 4, it is found that the developed food systems have a high content of polyunsaturated fatty acids. However, this may not be a disadvantage of the developed food systems, because most of the world's population lacks these nutrients in food [17]. In addition, products made from flour are always consumed in combination with other foods that are rich in saturated fatty acids. The closest recipe to the ratio according to the recommendations of nutritionists is the food system with a ratio of meal composition: wheat flour of 20:80.

The results of the calculation of the biological efficiency of raw materials for food systems, in accordance with formulas (5) and (6), according to the requirements for nutrition of a healthy person and for therapeutic nutrition, are given in Table 5 and Table 6, respectively.

Analyzing the data in Tables 5, 6, both in the case of nutrition of a healthy person, and in the case of therapeutic nutrition, the utilization rate of fats is the highest in sunflower and soybean meal, in wheat flour – the lowest. This, in turn, confirms the feasibility of developing food systems based on wheat flour with the addition of meal composition.

The results of the calculation of the biological efficiency of food systems, in accordance with formulas (5) and (7), according to the requirements for nutrition of a healthy person and for therapeutic nutrition, are given in Table 7 and Table 8, respectively.

Table 5

Biological efficiency of raw materials for food systems, according to the requirements for nutrition of a healthy person

Raw materials	Contents						Fat utilization rate, ψ
	SFA		MUFA		PUFA		
	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	
Sunflower meal (*S*)	11.19	0.49	26.25	0.38	62.56	7.82	0.13
Soybean meal (*So*)	16.08	0.70	23.30	0.34	60.62	7.58	0.12
Meal composition (*S*:*So*=37:63)	14.27	0.62	24.39	0.35	61.34	7.67	0.12
Wheat flour	22.39	0.97	14.18	0.21	63.43	7.93	0.07

Table 6

Biological efficiency of raw materials for food systems according to the requirements for medical nutrition

Raw materials	Contents						Fat utilization rate, ψ
	SFA		MUFA		PUFA		
	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	
Sunflower meal (S)	11.19	0.34	26.25	0.80	62.56	1.90	0.79
Soybean meal (So)	16.08	0.49	23.30	0.71	60.62	1.84	0.70
Meal composition (S:So=37:63)	14.27	0.43	24.39	0.74	61.34	1.86	0.73
Wheat flour	22.39	0.68	14.18	0.43	63.43	1.92	0.43

Table 7

Biological efficiency of food systems according to the requirements for nutrition of a healthy person

Ratio of components (meal composition/wheat flour), %	Contents						Fat utilization rate, ψ
	SFA		MUFA		PUFA		
	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	
10/90	21.27	0.92	15.59	0.23	63.14	7.89	0.0750
11/89	21.16	0.92	15.72	0.23	63.11	7.89	0.0756
12/88	21.06	0.92	15.86	0.23	63.09	7.89	0.0763
13/87	20.95	0.91	15.99	0.23	63.06	7.88	0.0770
14/86	20.85	0.91	16.12	0.23	63.03	7.88	0.0777
15/85	20.75	0.90	16.25	0.24	63.01	7.88	0.0784
16/84	20.64	0.90	16.38	0.24	62.98	7.87	0.0791
17/83	20.54	0.89	16.50	0.24	62.95	7.87	0.0797
18/82	20.44	0.89	16.63	0.24	62.93	7.87	0.0804
19/81	20.34	0.88	16.76	0.24	62.90	7.86	0.0811
20/80	20.24	0.88	16.88	0.24	62.88	7.86	0.0817

Table 8

Biological efficiency of food systems according to the requirements for therapeutic nutrition

Ratio of components (meal composition/wheat flour), %	Contents						Fat utilization rate, ψ
	SFA		MUFA		PUFA		
	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	g/100 g fat	SCORE, %	
10/90	21.27	0.64	15.59	0.47	63.14	1.91	0.4677
11/89	21.16	0.64	15.72	0.48	63.11	1.91	0.4716
12/88	21.06	0.64	15.86	0.48	63.09	1.91	0.4758
13/87	20.95	0.63	15.99	0.48	63.06	1.91	0.4797
14/86	20.85	0.63	16.12	0.49	63.03	1.91	0.4836
15/85	20.75	0.63	16.25	0.49	63.01	1.91	0.4875
16/84	20.64	0.63	16.38	0.50	62.98	1.91	0.4914
17/83	20.54	0.62	16.50	0.50	62.95	1.91	0.4950
18/82	20.44	0.62	16.63	0.50	62.93	1.91	0.4989
19/81	20.34	0.62	16.76	0.51	62.90	1.91	0.5028
20/80	20.24	0.61	16.88	0.51	62.88	1.91	0.5064

Analyzing the data in Tables 7, 8, both in the case of nutrition of a healthy person, and in the case of therapeutic nutrition, the coefficient of fat use is the highest in the sample of the food system with the ratio of meal composition: wheat flour of 20:80.

6. Discussion of research results on the development of amino acid-balanced food systems based on wheat flour and oilseed meal

Systematization and analysis of the results of studies of the protein content and, accordingly, amino acid composition of raw protein for food systems based on wheat flour (formula (1), Fig. 1) indicate a relatively low biological value of oilseed meal and wheat flour, taken separately, due to the disproportion of the content of such essential amino acids as lysine, methionine and cystine compared to their content in the reference protein. However, the ratio of the selected raw materials is a factor in regulating the biological value of the food system due to the presence of complementary scores of limiting amino acids. In addition, it should be noted that the advantage of using the proposed oilseed meal in the technology of wheat flour enrichment is that the meal belongs to the so-called by-products and is characterized by relatively low cost characteristics.

For the possibility of enrichment of wheat flour in order to increase its biological value, the composition of sunflower and soybean meal with improved amino acid composition has been scientifically substantiated. The meal ratio was calculated according to the system of equations (8) provided that there are no limiting essential amino acids in the composition, which are present in each component separately (Fig. 1, 2). So, according to formulas (9)–(14), the content of other essential amino acids is calculated. The developed composition can be used as a separate product, the biological value of which is close to the biological value of the reference protein (Table 1).

Analysis of the amino acid composition and biological value of food systems based on wheat flour with different contents of the developed composition of oilseed meal (Tables 2, 3) allows us to state the following:

– protein content in the compositions of oilseed meal is much higher than that in wheat flour – 40.5 % vs. 10.34 % (paragraph 4.7), which, in turn, contributes to the nutritional and biological value of the developed food systems (Table 2);

– increasing the content of meal composition in food systems from 10 to 20% entails an increase in the biological value of the finished product by increasing the score of limiting amino acids from 38.18 % to 67.68 % for lysine and from 42.86 % to 70.12 % for the sum of methionine and cystine;

– increasing the content of meal composition in food systems can be only up to 20 % without deteriorating the technological characteristics of the product. We assume that with a further increase in the content of meal additives, there may be a decrease in the gluten content in the food system;

– further increase in the content of meal composition in food systems will make some adjustments in the technological process of both production and application of food systems.

Systematization and analysis of the results of studies of the fat content, as well as fatty acid composition of fats from raw materials and food systems (formula (4), Table 4), allows us to state the following:

– the fat content in the composition of oilseed meal is higher than in wheat flour – 2.13 % vs. 1.48 % (paragraph 4.8), which, in turn, contributes to the nutritional value of the developed food systems;

– the developed food systems have a fairly high content of polyunsaturated fatty acids – 62.88–63.14 g per 100 g of fat (Table 4). This fact is advantageous in terms of nutritional characteristics, but is unfavorable in terms of storage conditions, which also makes some adjustments to the production technology.

The calculation and analysis of the so-called biological efficiency of the developed food systems (Tables 5–8) revealed certain patterns:

– biological efficiency of raw materials for food systems according to the requirements for both nutrition of a healthy person (Table 5) and for therapeutic nutrition (Table 6) confirms the feasibility of adding meal composition to food systems;

– the utilization rate of fats is the highest in the sample of the food system with the maximum content of meal composition both under the condition of nutrition of a healthy person (Table 7) and under the condition of therapeutic nutrition (Table 8).

This, in turn, confirms the feasibility of developing food systems based on wheat flour with the addition of meal composition.

The results of the research can be developed in such sectors of the food industry as bakery, confectionery, sports nutrition, as well as in the processing of vegetable raw materials into protein products (isolates, concentrates, low-fat flour, etc.). It is through the use of the developed food systems that the problem of increasing the biological value of plant protein products can be solved.

The task of further research is to substantiate the compositions of meal of other oilseeds for adding to wheat flour in order to improve the amino acid composition and increase the biological value of the latter.

Difficulties in implementing the results of the study may be related to the management of the food industry. The investment of additional funds, even insignificant, in the purchase of the necessary equipment and the lack of tangible results affect the position of those who have to make decisions about the development of technology and expanding the range of health products.

7. Conclusions

1. The amino acid composition of wheat flour, soybean meal and sunflower meal was experimentally determined. It was determined that soybean meal protein contains the highest amount of lysine in comparison with wheat flour protein (score 110.73 % vs. 38.18 %). It was found that soybean meal protein is deficient only in sulfur-containing amino acids methionine and cystine (score 84.57 %). Sunflower meal protein, as well as wheat flour protein, has a low content of lysine (score 58.4 %), but a high content of sulfur-containing amino acids (score 115.71 %). It was determined that in wheat flour protein, the limiting amino acids are threonine (score 68.00 %) and sulfur-containing methionine and cystine (score 42.86 %). Due to the presence of complementary scores of limiting amino acids, it can be argued that the protein mixture of sunflower and soybean meal may have an amino acid composition that is as close as possible to the ideal protein, and in food systems based on wheat flour will improve their amino acid composition and, consequently.

2. The mixture of sunflower and soybean meal, the amino acid composition of which is as close as possible to that in the reference protein, is scientifically substantiated. The score of the five essential amino acids of the composition, with the exception of valine (88.96 %), threonine (90.61 %) and leucine (96.11 %) is 100 % or higher. The ratio of components in the composition is as follows: sunflower meal: soybean meal=36:64. The introduction of meal in this ratio into the flour should reduce the amino acid deficiency of the protein of the resulting food systems.

3. Food systems with improved amino acid composition and, accordingly, increased biological value in comparison with wheat flour are scientifically substantiated. The flour content in them is 90–80 %, the content of meal composition is 10–20 %. The amino acid composition and biological value of each obtained food system are determined. It was found that the total protein content increased from 10.34 % (for flour) to 13.03...15.76 % (for the food system depending on the proportion of meal composition). It was found that the total amino acid content in food systems compared to flour increased by 1.08–1.14 times depending on the proportion of meal composition. It was found that the content of limited amino acids, namely lysine, increases in food systems in comparison with wheat flour by 1.46–1.77; the amount of methionine and cystine by 1.39–1.64; threonine by 1.12–1.2 times. It was found that the score of limited amino acids (lysine – 67.68 %, the amount of methionine and cystine – 70.12 %, threonine – 81.36 %) in the developed food systems is the highest at the ratio of wheat flour: meal composition=80:20.

4. The fatty acid composition of raw materials and actually obtained food systems has been experimentally determined. It is found that depending on the share of meal composition in food systems, the content of saturated fatty acids is in the range of 20.24...21.27 %; monounsaturated – 15.59...16.88 %; polyunsaturated – 63.14...62.88 %. The resulting food systems were found to have elevated levels of polyunsaturated fatty acids. It is found that the most approximate recipe according to the requirements for both healthy food and therapeutic nutrition is a food system with a ratio of meal composition: wheat flour as 20:80, respectively. The coefficient of fat utilization of food systems was found (0.075...0.0817 according to the requirements for nutrition of a healthy person; 0.4677...0.5064 according to the requirements for therapeutic nutrition). The highest coefficient of fat utilization (0.0817 and 0.5064, respectively, according to the requirements for nutrition of a healthy person and for therapeutic nutrition) is observed in the food system with a ratio of meal mixture: wheat flour of 20:80. Based on the obtained results, it can be stated that the introduction of a balanced meal mixture to flour in the amount of 20 % improves the amino acid composition and biological value of protein, improves the fatty acid composition, assimilation of the resulting food system. However, it is necessary to continue further research on the impact of this food system on the technological and organoleptic characteristics of bakery products.

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