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OPTIMIZATION OF TECHNOLOGICAL PARAMETERS IN THE PRODUCTION OF CEREAL BEVERAGES FORTIFIED WITH OMEGA-3 POLYUNSATURATED FATTY ACIDS

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The object of this study was cereal drinks fortified with Omega-3 polyunsaturated fatty acids: rice (product 1), oat (product 2), buckwheat (product 3). The purpose of the research was to optimize technological parameters in the production of such beverages.

A mathematical model was built in the form of three regression equations describing the influence of grinding size (K), roasting temperature (T), and roasting duration (t) on three output variables: oat, buckwheat, and rice protein content. Statistical analysis of the obtained equations showed that they are adequate in the selected area of planning: K=0.66–2.34 mm, T=133–217 °C, t=3.3–11.7 min.

Studies were conducted to determine quality indicators, chemical composition, biological and nutritional value of the developed cereal drinks, in comparison with the control version.

It has been established that the content of fatty acid composition of cereal drinks differs markedly. The minimum share of saturated fatty acids was established in product No. 3, without fortification – 10.43 %. The content of polyunsaturated fatty acids ranged from 82.09 % (product 1) to 89.57 % (product 3). The highest omega-3 content was found in product 2, with fortification – 1.34 %, and the lowest – in product 1, without fortification – 0.27 %.

The introduction of a filler in cereal drinks made it possible to add protein, thereby increasing the biological value. According to the content of essential amino acids, the devised product is characterized by a high content of essential amino acids, exceeding the FAO/WHO ideal protein scale, which allows us to draw a conclusion about the high biological value of the developed product.

The analysis of the mathematical model built established that an increase in the coarseness of grinding leads to a decrease in the protein content in the entire investigated range of values of this factor

Keywords: cereal drink, Omega-3, fortification, functional drink, amino acid score, fatty acid composition, optimization of technological parameters

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1. Introduction

A modern human abuses fast food and various fast foods, as a result of which s/he gets diseases of the gastrointestinal tract, a deficiency of trace elements, vitamins and biologically active substances in the body [1]. In order to solve the problems of meeting the needs of the population with functional products, it is necessary to expand the assortment and improve the quality of nutrition due to the use of domestic agricultural products, using new technological processing methods.

Under modern conditions, one of the ways to solve the problem of violation of the nutritional status is the development of new types of food products, for example, beverages using the grain of cereal crops. Thanks to its composition, rich in micronutrients, and the beneficial effect on the human body, cereal drinks are increasingly used for the prevention of various diseases [2].

More than 50 names of drinks made from vegetable raw materials of various categories are known. The most popular products of this category were cereal cocktails made from tolokna, talkan, jelly, coffee drinks, instant drinks from spelt wheat, and chicory. Marketing studies show that the market for beverages made from vegetable raw materials is 2÷5 % of the entire beverage market and is not sufficiently developed, although the population shows interest in such products [3].

In the intense rhythm of life, a person strives to minimize the time spent on cooking, however, the modern fashion trend for proper nutrition (PN) and a healthy lifestyle (HLS) causes a person to want to preserve his/her health. The demand for fortified products is growing, which causes the need for the emergence of new products, as a result of which the development of technologies for the production of functionally oriented healthy food products is relevant.

2. Literature review and problem statement

Functional nutrition is a concept that includes the development of theoretical foundations, production, sale, and consumption of functional food products. In Japan, England, the USA, Germany, France, and other countries, targeted national programs are being implemented to improve the health of the population by developing and organizing the production of food components that correct the biochemical composition of food products for mass consumption.

Having realized the potential of the cereal beverage market, in the USA, Canada, and Europe, even enterprises that previously produced traditional milk are switching to its production, and some livestock farms are turning into almond groves. The advantage of the production of cereal drinks is that it does not require keeping farm animals to obtain milk. There are many reasons for consuming cereal drinks, including various diseases.

The prerequisite for the development of technology for the production of cereal beverages is the overproduction of grain in the Republic of Kazakhstan (transitional stocks – an average of 2.5 million tons) and a narrow assortment of cereal beverages. In the Republic of Kazakhstan, cereal crops are produced in large quantities, but there is no production of plant-based beverages, although the production of plant-based milk is already widespread throughout the world. The use of local plant raw materials from different regions of the Republic of Kazakhstan in the production technology of cereal-based milk drinks is a relevant and promising direction in the food industry [4].

In [5], a technique of preparing vegetable milk from flax seeds was developed. It involves washing flax seed in water with a temperature of no more than 25 °C for 10–15 minutes. Next, grinding of wet flax seeds to a finely dispersed state with a particle size of no more than 50 microns is implied. Next, subsequent extraction in a solution of table salt with a concentration of no more than 0.6 % and a hydromodule of 1:8–1:10 by continuous mixing of the components for 45–50 minutes. The temperature should not exceed 30 °C. Further, the obtained pulp is divided into vegetable milk and seed mass. Plant milk is obtained from flax seeds, which have a high nutritional value, contain proteins, fats, and carbohydrates in an easily digestible form, and are characterized by the absence of toxic hazardous substances.

In [6], an acidified protein drink was developed, which is stable during storage due to the formation of a structured molecular network of gellan gum. In work [7], «Liquid oat base» was developed, which is used as a substitute for milk or a biologically active additive. The invention makes it possible to obtain a product based on oat raw materials with an increased protein content without the use of proteases and preserved or improved organoleptic indicators.

In work [8], a technique of obtaining vegetable milk is proposed, which includes grinding the seeds to a homogeneous powder by fourfold extraction of oil from ground seeds with hexane followed by removal of the hexane on a rotary evaporator. The disadvantage of the specified technique is that with a rather complex manufacturing technology, the resulting product has insufficiently high biological value.

There is a known technique of obtaining vegetable milk from hemp seeds, which can be used as an independent product, as well as in the production of combined milk drinks and in the production of special food [9]. The technique includes germination of seeds until the appearance of sprouts 1–2 mm in size, crushing to a homogeneous mass, extraction in hot water with a hydromodule of 1:3–1:5, and squeezing through a filter. The invention makes it possible to obtain vegetable milk of high nutritional value, containing easily digestible small peptide modified protein, free amino acids, soluble sugars, vitamins, macro- and microelements, as well as other biologically active substances. However, this technique of production uses raw materials that are not available for the Republic of Kazakhstan.

Our analysis revealed the presence of high-tech experience in the production of cereal drinks in the near and far abroad. The resulting product is distinguished by its originality of execution, as well as the use of vegetable raw materials: rice, coconut, soybeans, almonds with various additives and combinations. This leads to the need to choose optimal recipes and technological solutions for the production of cereal drinks.

3. The aim and objectives of the study

The aim of our research is to optimize the technological parameters in the production of new cereal drinks fortified with Omega-3 polyunsaturated fatty acids (PUFAs).

To achieve this goal, the following tasks were identified and solved:

– to build a mathematical model of the influence of technological parameters on the protein content of oats, buckwheat, and rice;

– to investigate the physical-chemical composition and organoleptic characteristics of cereal drinks fortified with Omega-3 PUFAs, using raw materials in the optimal ratio;

– to investigate the indicators of the biological value of cereal drinks fortified with Omega-3 PUFA;

– to investigate the regression equations that form the mathematical model of the process for the presence of optimums.

4. The study materials and methods

4. 1. Examined materials

As an object of the study, we used cereal drinks:

– rice drink fortified with Omega-3 polyunsaturated fatty acids – product 1;

– oatmeal drink fortified with Omega-3 polyunsaturated fatty acids – product 2;

– buckwheat drink fortified with Omega-3 polyunsaturated fatty acids – product 3.

The research base is laboratories at the Technology and Standardization Department of the Kazakh University of Technology and Business, as well as the Food Safety Research Institute at the Almaty Technological University (Republic of Kazakhstan).

4. 2. Methods for studying the quality indicators of new cereal beverages

Under laboratory conditions, the technology of cereal drinks fortified with Omega-3 PUFAs was devised. Studies have been carried out to determine the quality indicators, chemical composition, biological and nutritional value of the developed cereal drinks, in comparison with known technologies [10].

The features of the proposed methods and the results obtained in comparison with existing methods are that we used studies to determine the fatty acid, amino acid composition, physical-chemical parameters, organoleptic parameters of samples, and mathematical modeling methods.

The biological value of the samples was determined by the amino acid composition by calculating the amino acid score. The amino acid composition was compared with the amino acid composition of an ideal protein according to the FAO/WHO scale. This method is currently the most relevant and most accessible indicator for determining the usefulness of a protein.

Sensory indicators were determined in accordance with the regulatory documents characterizing the quality of the samples, as mandatory requirements that ensure the safety of life and health of the population. The nutritional value of cereal drinks was assessed according to standard research methods.

The mass fraction of moisture was determined by the drying method according to GOST 13586.5–2015.

The determination of the mass fraction of ash was carried out according to GOST R 54607.10–2017, based on the determination of the total ash remaining after burning and ashing a batch in a muffle furnace.

The determination of free nitrogen was performed by the Kjeldahl method with subsequent conversion to protein.

Acidity in cereal drinks was determined in accordance with GOST 6687.4–86. The method is based on titration with an alkali solution of all acidic substances after the release of the drink from carbon dioxide.

The determination of organoleptic indicators and readiness for consumption of the obtained cereal drinks were carried out according to GOST ISO 6658–2016.

The mass fraction of fat was determined by the Soxhlet method. The mass fraction of amino acids was determined on a Kapel 105 M capillary electrophoresis system.

The content of heavy metals was determined on a KVANT-Z.ETA-T spectrometer with electric atomization by atomic absorption spectroscopy (ASS) [11].

Fatty acid methyl esters were analyzed using a Shimadzu GC 2010 Plus gas chromatograph with a flame ionization detector (FID). Capillary column “CPSil 88 for FAME” (Agilent Technologies) 100 m long, 0.25 mm in inner diameter, 0.20 μm stationary phase film thickness [12].

4. 3. Methodology for planning the experiment

As a mathematical model of the process, regression equations were chosen for three output variables: protein content (B, d) of oats (y_1), buckwheat (y_2), and rice (y_3).

The following variables were chosen as input variables: grinding size (K, mm), roasting temperature (T, °C), roasting duration (t, min).

The intervals of variation of the input variables are given in Table 1.

Table 1

Intervals of variation of input variables

Factors	Code designation	x_i=–1,682 (star points)	x_i=–1 (lower level)	x_i=0 (main level)	x_i=+1 (upper level)	x_i=+1,682 (star points)
Grinding size, μm	x_1	0.66	1	1.5	2	2.34
Roasting temperature, °C	x_2	133	150	175	200	217
Roasting time, min	x_3	3.3	5	7.5	10	11.7

To construct the regression equations, a rotatable plan 2^3 was used. Estimates of the coefficients of the regression equations were calculated using the formulas:

$$a_i = \begin{cases} \dfrac{A}{N}\left[2\lambda_1^2(n+2)\big(0(y)\big) - 2\lambda_2\lambda_1\sum_{j=1}^{n}(jjy)\right],\ i=0, \\ \dfrac{\lambda_2}{N}(iy),\ i=1,2,\ldots,n, \end{cases} \quad (1)$$

$$a_{n+1} = \frac{A}{N}\left\{\begin{matrix} \lambda_2^2\left[(n+2)\lambda_1 - n\right](iiy) + \\ +\lambda_2^2(1-\lambda_1)\sum_{j=1}^{n}(jjy) - 2\lambda_1\lambda_2(0y) \end{matrix}\right\},$$

$$i=1,2,\ldots,n, \quad (2)$$

$$a_{2n+j} = \frac{\lambda_2^2}{N\lambda_1}(ily), \quad j=1,2,\ldots,k-2n. \quad (3)$$

The parameters of the plan, A, λ_1, λ_2, included in (1) to (3), were calculated using the formulas:

$$A = \frac{1}{2\lambda_1\left[(n+2)\lambda_1 - n\right]}, \quad (4)$$

$$\lambda_1 = \frac{2^{n-p}N}{\left(2^{n-p}+2\alpha^2\right)^2}, \quad (5)$$

$$\lambda_2 = \frac{N}{2^{n-p}+2\alpha^2}. \quad (6)$$

In addition, in formulas (1) to (3), the following notations are adopted:

$$(0y) = \sum_{j=1}^{N} y^j, \quad (7)$$

$$(iy) = \sum_{j=1}^{N} x_i^j y^j, \quad (8)$$

$$(ily) = \sum_{j=1}^{N} x_i^l x_l^j y^j. \quad (9)$$

All input and calculated parameters of the rotatable plan are given in Table 2.

Table 2

Parameters of the rotatable plan

The number of points in the core of the plan	Number of star points	Number of experiments at the center of the plan	Total number of experimental points	Star shoulder	Calculation parameters			Number of factors	Number of plan generators
n_c	n_{sp}	n_0	N	α	λ_1	λ_2	A	n	p
8	6	6	20	1.682	0.856	1.46	0.455	3	0

Estimates of the variances of the coefficients of regression equations were calculated using the formula:

$$s_i^2=\begin{cases}2\frac{A}{N}\lambda_1^2(n+2)s^2,\ i=0,\\ \frac{\lambda_2}{N}s^2,\ i=1,2,...,n,\\ \frac{A}{N}\left[(n+1)\lambda_1-(n-1)\right]\lambda_2^2s^2,\ i=n+1,...,2n,\\ \frac{\lambda_2^2}{N\lambda_1}s^2,\ i=2n+1,...,k.\end{cases} \quad (10)$$

The sums of squared deviations of experimental errors were calculated using the formulas:

$$S_E=S_E(0)+S_E(1), \quad (11)$$

$$S_E(0)=\sum_{j=1}^{n_0}\sum_{i=1}^{\nu}\left(y_e^0-y_e^{2^{n-p}+2n+j,i}\right)^2, \quad (12)$$

$$S_E(1)=\sum_{j=1}^{2^{n-p}+2n}\sum_{i=1}^{\nu}\left(y_e^j-y_e^{ji}\right)^2, \quad (13)$$

where:

$$y_e^0=\frac{1}{n_0\nu}\sum_{j=1}^{n_0}\sum_{i=1}^{\nu}y_e^{2^{n-p}+2+j,i}. \quad (14)$$

The estimation of the variance of experimental errors was calculated by the formula:

$$s_e^2=\frac{S_E}{\varphi_2}, \quad (15)$$

where φ_2 is the number of degrees of freedom, calculated by the formula:

$$\varphi_2=\left(2^{n-p}+2n\right)(\nu-1)+\nu n_0-1. \quad (16)$$

The error of a single experiment was calculated by the formula:

$$s=\frac{s_e^2}{\nu}, \quad (17)$$

where ν is the number of parallel experiments at each point of the plan, ν=1 was taken.

The adequacy test was carried out in accordance with the Fisher criterion:

$$F=\frac{s_d^2}{s_e^2}\le F_{cv}, \quad (18)$$

where F_{cv} is the critical value of the F-distribution adopted for the significance level of 0.01;

s_d^2 – estimation of the variance of the inadequacy of the regression equations:

$$s_d^2=\frac{S_D}{\varphi_1}, \quad (19)$$

where φ_1 is the number of degrees of freedom, calculated by the formula:

$$\varphi_1=N-(1+k)-(n_0-1). \quad (20)$$

5. Results of optimization of technological parameters in the production of new cereal drinks fortified with Omega-3-PUFA

5. 1. Development of a mathematical model of the influence of technological parameters on the protein content of oats, buckwheat, and rice

Table 3 gives the results of experiments to determine the values of the output variables according to the implemented rotatable plan.

Table 3

Results of the implementation of the experimental plan

№	Input variables						Output variables		
	Normalized values			Natural values			Experimental values		
	x_1	x_2	x_3	K, mm	T, °C	t, min	y_1, g	y_2, g	y_3, g
1	2	3	4	5	6	7	8	9	10
1	–	–	–	1	150	5	10.5	10.8	6.8
2	–	–	+	1	150	10	9.7	11.2	7.1
3	–	+	–	1	200	5	10.3	10.4	6.6
4	–	+	+	1	200	10	9.9	10.5	6.5
5	+	–	–	2	150	5	9.2	9.8	6.1
6	+	–	+	2	150	10	9	9.7	6.2
7	+	+	–	2	200	5	9.3	9.5	6.1
8	+	+	+	2	200	10	9.1	9,6	6
9	–1.68	0	0	0.66	175	7.5	9.8	9.9	6.4
10	+1.68	0	0	2.34	175	7,5	9.1	9.7	6.5
11	0	–1.68	0	1.5	133	7.5	9.2	9.9	6.4
12	0	+1.68	0	1.5	217	7.5	9.3	9.8	6.1
13	0	0	–1.68	1.5	175	3.3	10.1	9.9	6.2
14	0	0	+1.68	1.5	175	11.7	9.9	10.1	6.8
15	0	0	0	1.5	175	7.5	9.7	10.3	6.7

The estimate S_E (0) calculated by formula (12) for n_0=6 is given in Table 4. The results of calculations of the sums of squared deviations S_E (1), S_E and an estimate of the variance of experimental errors s_e^2. are also there.

Table 4

Statistical estimates of the accuracy of the experiment

Output variables	Estimates			
	S_E (1)	S_E (0)	S_E	s_e^2
y_1	0	0.054683333	0.054683333	0.010937
y_2	0	0.185	0.185	0.037
y_3	0	0.113083333	0.113083333	0.022617

As a result of calculations using formulas (1) to (3), the coefficients of the regression equations in the normalized form are obtained, given in Table 5.

Table 5

Coefficients of regression equations

Output variable	Coefficient									
	a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
y_1	9.744	–0.363	0.027	–0.141	–0.109	–0.179	0.084	0.025	0.1	0.05
y_2	10.33	–0.338	–0.122	0.061	–0.141	–0.123	–0.071	0.087	–0.062	–0.0125
y_3	6.723	–0.178	–0.11	0.088	–0.101	–0.171	–0.083	0.075	–0.025	–0.075

The general structure of the equations is:

$$y_l = a_0^l + a_1^l x_1 + a_2^l x_2 + a_3^l x_3 + a_4^l x_1^2 + a_5^l x_2^2 + a_6^l x_3^2 + \\ + a_7^l x_1 x_2 + a_8^l x_1 x_3 + a_9^l x_2 x_3, \qquad (21)$$

where l is the number of the output variable: l=1, 2, 3

Table 6 gives the estimates of variance in the coefficients of the regression equations calculated by formula (10).

The results of checking the adequacy of the regression equations are given in Table 7.

Table 6

Estimates of variance in the coefficients of regression equations

Output variable	s^2	s_0^2	s_1^2	s_2^2	s_3^2
y_1	0.010937	0.038514118	0.025487	0.024789	0.033286
y_2	0.037	0.070839963	0.046879	0.045594	0.061223
y_3	0.022617	0.05538495	0.036651	0.035647	0.047866

Table 7

Results of checking the adequacy of regression equations

Output variable	S_D	φ_1	s_d^2	S_E	φ_2	s_e^2	F	F_{cv}
y_1	0.389	5	0.078	0.0547	5	0.0109	7.11	10.97
y_2	1.276	5	0.255	0.185	5	0.037	6.9	10.97
y_3	0.534	5	0.107	0.113	5	0.023	4.72	10.97

The results given in Table 7 allow us to conclude that the regression equations for all three output variables are adequate.

5. 2. Study of the physicochemical composition and sensory quality indicators of the developed cereal drinks

Under laboratory conditions, a technology has been devised for cereal drinks fortified with Omega-3 PUFAs. Flaxseed flour was chosen as a drink fortification. Studies of the physicochemical parameters of cereal drinks were carried out, in comparison with the control variant, the results of which are given in Table 8.

Flaxseed flour, rich in PUFA content, was used as a fortification agent. PUFA promotes the excretion of cholesterol and supports the metabolism of proteins and fats in the body [13]. Flax seeds have a beneficial effect on the high protein content in the composition of drinks. Analysis of the research results showed that all samples of cereal drinks with the addition of flax are leading in terms of protein content compared to unfortified drinks. In terms of protein content in the drink, buckwheat with the addition of flax is the leader, which amounted to 3.89 %, and the lowest protein values were found in rice drink (1.86 %).

To improve the technological properties and organoleptic characteristics of new cereal drinks, the technology used flax seed flour and dry whey concentrate as an enriching component. Flaxseed flour is an enriching base for Omega-3 PUFAs, and whey powder concentrate adds a milky flavor and aroma to cereal drinks. Organoleptic indicators of experimental samples of cereal drinks are given in Table 9 and in Fig. 1.

a *b* *c*

Fig. 1. Prototypes of cereal drinks:
a – rice drink;
b – oatmeal drink;
c – buckwheat drink

Table 8

Physical-chemical parameters of cereal drinks

Name of indicators	Control sample No. 1 (rice drink)	Product 1		Control sample No. 2 (oatmeal drink)	Product 2		Control sample No. 3 (buckwheat drink)	Product 3	
		with flax	without flax		with flax	without flax		with flax	without flax
Mass fraction of moisture, %	92	94	92.24	91	93.68	92	92	90	93
Mass fraction of ash, %	0.12	0.13	0.05	0.25	0.33	0.21	0.20	0.24	0.12
Mass fraction of protein, %	0.2	1.86	1.49	1.0	3.02	2.49	1.0	3.89	1.95
Acidity, °T	1.6	1.5	1.7	2.0	1.9	2.1	1.8	1.7	1.9

Table 9

Organoleptic characteristics of prototypes of cereal beverages

Product name	Appearance and consistency	Taste	Aroma	Color
Rice drink enriched with Omega-3 PUFAs, sample No. 1	Consistency is homogeneous	Clean, full, full-bodied, without a pronounced grain flavor	The smell peculiar to rice drinks	White, with a cream tint, homogeneous throughout the mass
Oatmeal drink enriched with Omega-3 PUFAs, sample No. 2	Consistency is homogeneous, without suspensions	Clean, full, full-bodied, without a pronounced grain flavor	The smell peculiar to oatmeal drinks	With a creamy tint, uniform throughout the sample volume
Buckwheat drink enriched with Omega-3 PUFAs, sample No. 3	Consistency is homogeneous, without lumps	Clean, full, rich	The smell is pronounced, characteristic of a buckwheat drink	With a light yellow tint, uniform throughout the sample volume

The results of organoleptic studies indicate good consumer qualities of the samples. Under laboratory conditions, prototypes of cereal drinks were produced, and their extended tasting was carried out using the ranking method, i.e., with a description of complex organoleptic characteristics. A board of 11 people noted the good taste, color, aroma, and appearance of the developed cereal drinks.

The mineral composition of cereal drinks is given in Table 10.

Table 10

Mineral composition of cereal drinks, mg/l

Name of indicators	Control sample No. 1 (rice drink)	Product 1		Control sample No. 2 (oatmeal drink)	Product 2		Control sample No. 3 (buckwheat drink)	Product 3	
		with flax	without flax		with flax	without flax		with flax	without flax
Zinc (Zn)	1.12	0.81	1.78	1.3	0.34	1.47	2.24	3.74	1.84
Copper (Cu)	0.52	0.51	0.69	0.58	0.65	0.62	0.25	0.38	0.41
Iron (Fe)	4.23	4.60	6.46	3.38	4.17	4.85	4.12	6.49	3.37
Manganese (Mn)	1.85	1.91	3.44	1.98	2.07	2.55	1.1	1.70	1.05
Nickel (Ni)	2.75	2.81	4.12	3.5	4.87	2.68	2.18	2.62	3.01
Cobalt (Co)	0.63	0.77	1.20	н/о	н/о	н/о	1.04	1.07	1.13

Based on our data, it was found that the content of minerals in the developed cereal drinks increases due to the fortification of Omega-3 PUFAs.

5. 3. Studying the biological value of proteins and a complex of fatty acids in developed cereal drinks

It is important to emphasize that the fats of cereals contain a lot of polyunsaturated fatty acids – linoleic and linolenic. Based on the FAO/WHO, fat intakes are around 3 % for ω6 and 0.5 % for ω3, but up to 9 % ω6 and 2 % ω3 are recommended to combat heart disease.

The daily requirement for linoleic acid should be 6–10 g, the minimum – 2–6 g, and its total content in the fats of the diet – at least 4 **%** of the total calorie content. Therefore, the fatty acid composition of lipids in foods intended for human nutrition must be balanced. From 10–20 **%** – polyunsaturated, 50–60 **%** – monounsaturated, and 30 **%** saturated, some of which should be with an average chain length. This is ensured by using 1/3 vegetable and 2/3 animal fats in the diet. For the elderly and patients with cardiovascular diseases, the content of linoleic acid should be about 40 **%**, the ratio of polyunsaturated and saturated acids should approach 2:1, the ratio of linoleic and linolenic acids should be 10:1 [14].

According to the data from Table 11, the content of the fatty acid composition of cereal drinks varies markedly.

In a high-quality protein, not only the composition of essential amino acids must be balanced, but also a certain ratio of essential and non-essential amino acids, otherwise some of the essential ones will be misused. Studies of the amino acid composition of experimental samples of cereal drinks were carried out, represented in the form of diagrams (Fig. 2–7).

Table 11

Fatty acid composition of cereal drinks, %

Name of indicators	Product 1		Product 2		Product 3	
	with flax	without flax	with flax	without flax	with flax	without flax
ΣEFAs	17.91	14.15	14.69	15.63	17.67	10.43
ΣMUFAs	42.1	45.7	45.1	44.3	46.52	49.73
ΣPUFAs	39.99	40.15	40.21	40.07	35.81	39.84
Oleic (C18:1)	42.1	45.7	45.1	44.3	46.52	47.84
ω6	38.74	39.88	38.87	39.45	34.51	39.52
ω3	1.25	0.27	1.34	0.62	1.30	0.32
ω6/ω3	3.23	0.67	3.44	1.57	3.76	0.81

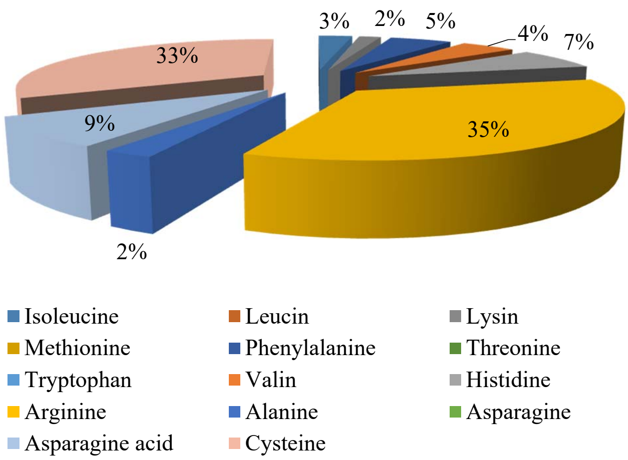

Fig. 2. Content of amino acids in non-fortified Product 1, g/100g

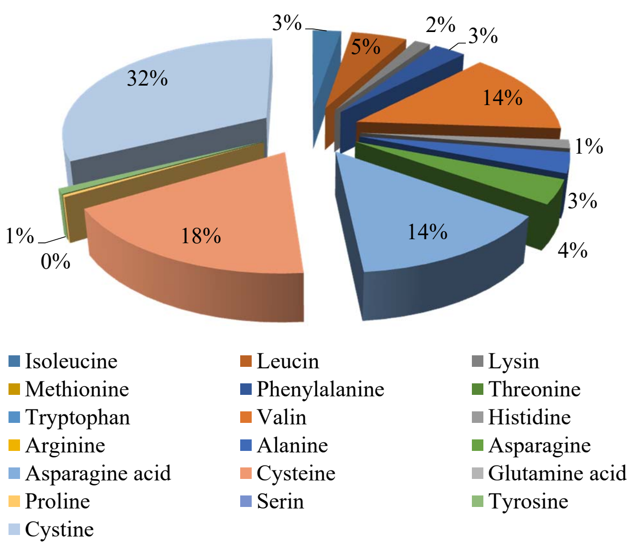

Fig. 3. Content of amino acids in fortified Product 1, g/100g

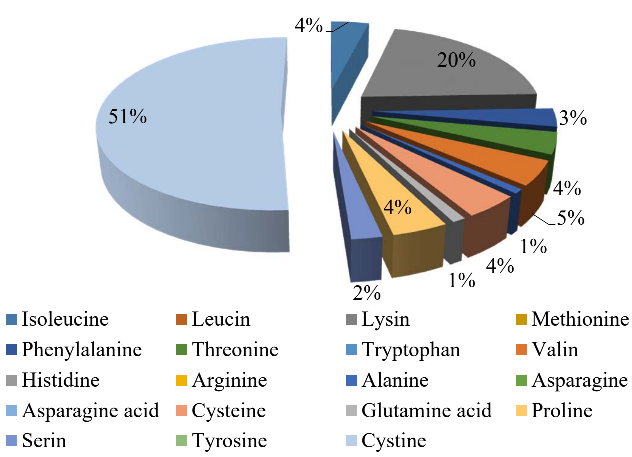

Fig. 4. Content of amino acids in non-fortified Product 2, g/100 g

It should be noted that in terms of amino acid composition, oats are one of the most balanced cereal crops. The amino acid composition of oats is closest to muscle protein, which makes it a particularly valuable product [15]. Rice proteins are highly digestible and have a better aminogram compared to other cereals since they contain essential amino acids in large quantities [10, 16].

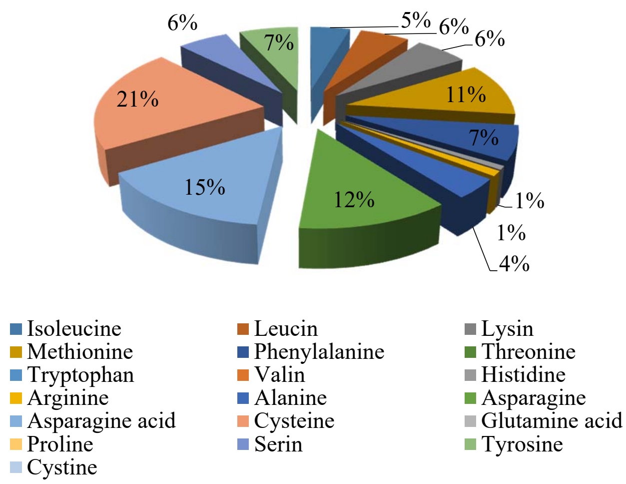

Fig. 5. Content of amino acids in fortified Product 2, g/100 g

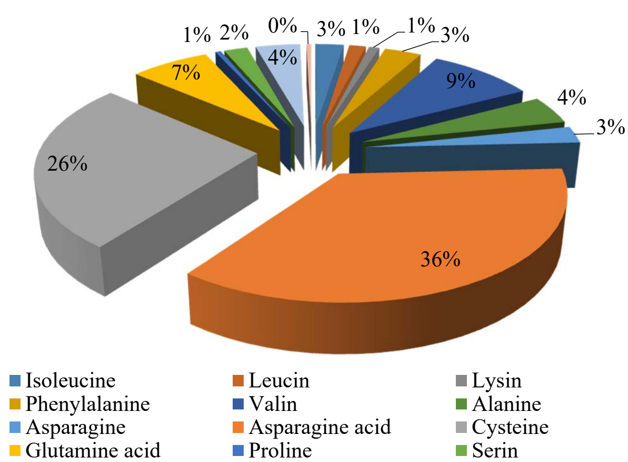

Fig. 6. Content of amino acids in non-fortified Product 3, g/100 g

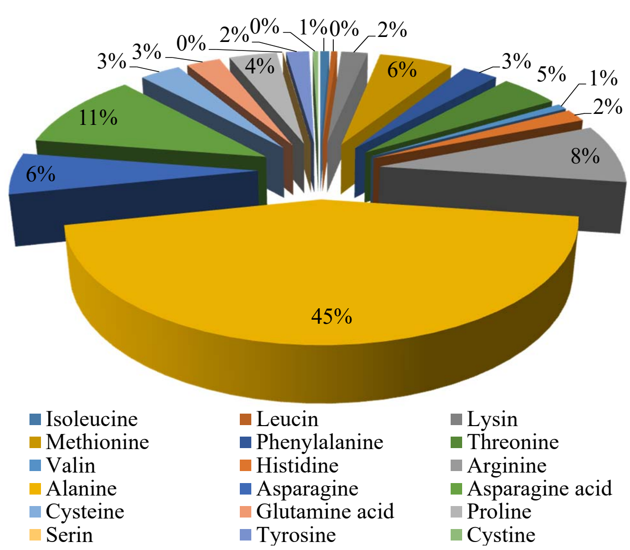

Fig. 7. Content of amino acids in fortified Product 3, g/100 g

The biological value of the protein component of the samples was determined by the amino acid composition by calculating the amino acid score. It is customary to calculate the biological value of proteins by their amino acid composition. The calculation is carried out in comparison with the amino acid composition of the "ideal" protein. This method for determining the biological value of a protein is called the chemical or amino acid score method. For an adult, the FAO/WHO amino acid scale is used as the "ideal protein".

The introduction of a filler into cereal drinks made it possible to enrich the protein composition, thereby increasing the biological value of the product. Product compliance with FAO/WHO requirements (ideal protein formula) is shown in Fig. 8–10.

Based on the analysis (Fig. 8) of the biological value of the cereal fortified product No. 1, the content of methionine+ cysteine and valine increased compared to the unfortified product No. 1.

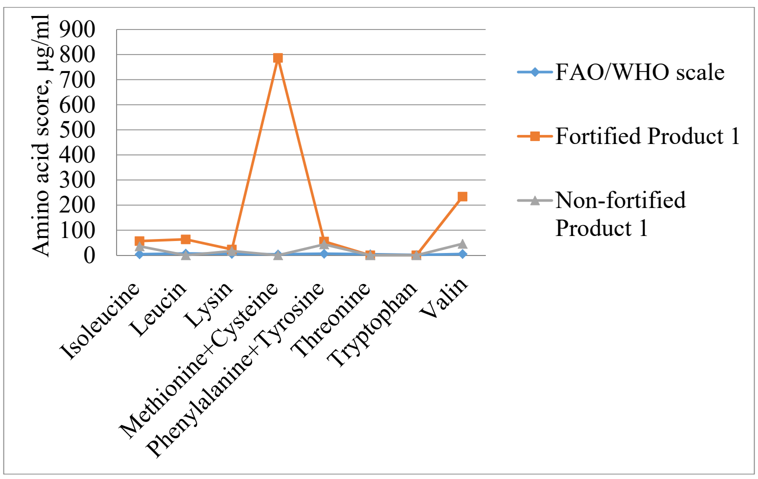

Fig. 8. Comparison of the amino acid score of product 1 according to the FAO/WHO scale, µg/ml

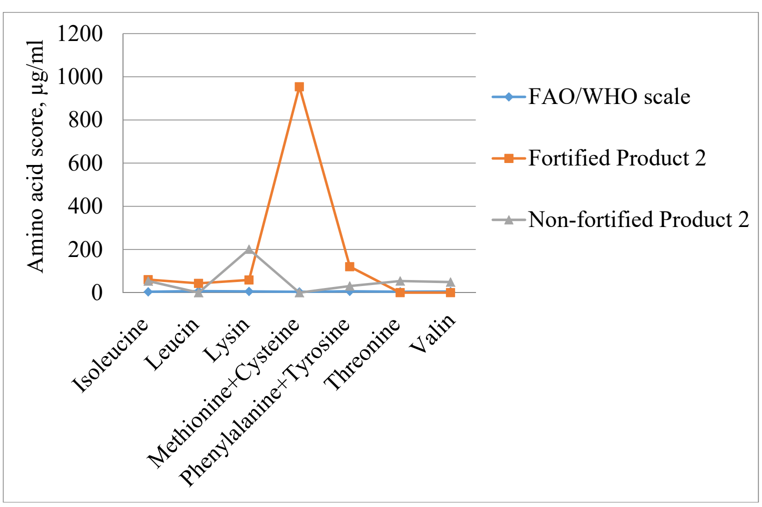

Fig. 9. Comparison of the amino acid score of product 2 according to the FAO/WHO scale, µg/ml

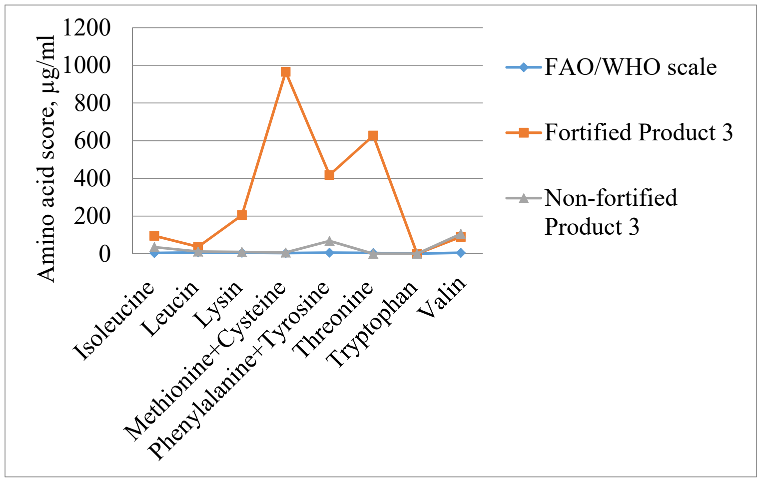

Fig. 10. Comparison of the amino acid score of product 3 according to the FAO/WHO scale, µg/ml

The content of isoleucine, leucine, and phenylalanine+tyrosine was at the same level and did not exceed 100 (µg/ml). In product No. 2, the content of methionine+cystine and lysine increased compared to the unfortified product No. 2, and the content of other amino acids increased slightly. In product No. 3, the amount of lysine, threonine, phenylalanine-tyrosine increased by 1000 (µg/ml) due to fortification with flaxseed flour, the content of isoleucine and valine slightly increased compared to the control variant.

5. 4. Investigation of regression equations for the presence of optimums

To determine the presence of optimums, an analysis of regression equations was carried out, the coefficients of which are given in Table 5, by canonical transformation of the response surface [17]:

– calculation of the coordinates of the stationary point x^* by solving the matrix equation:

$$\begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} x_1^* \\ x_2^* \end{pmatrix} = -\begin{pmatrix} a_1 \\ a_2 \end{pmatrix}, \qquad (22)$$

obtained from the condition of finding the extremum:

$$\frac{\partial y_i}{\partial x_i} = 2a + 2Ax^* = 0, \qquad (23)$$

where:

$$y_i = a_0 + 2a^T x + x^T Ax, \qquad (24)$$

In formula (24), the following designations are adopted: a is the column matrix of coefficients of equations with linear terms, the components of which are divided by 2, A is the matrix of coefficients in front of the nonlinear terms of the equation:

– calculation of the value of the output variable at a stationary point from the equation:

$$y_i{}^* = a_0 + 2a^T x^* + x^{*T} A x^*; \quad (25)$$

– converting the response surface to a canonical view

$$y_i - y_i{}^* = \lambda_1 \xi_1^2 + \lambda_2 \xi_2^2, \quad (26)$$

where λ_1, λ_2 are the eigenvalues of the matrix A, the sign ratio of which determines the form of the response surface.

The canonical transformation procedure was preceded by the procedure of fixing the input variable x_1 at three levels: $x_1=-1$; $x_1=0$; $x_1=+1$. This has made it possible to carry out an analysis by reducing the dimensionality of the factor space, while evaluating the patterns of change in the position of the response surface with a change in x_1 over the entire variation interval.

Table 12 gives the results of calculating the output variables at the optimal points and eigenvalues.

Table 12

Response surface analysis results

Output variable	y^*	λ_1	λ_2
y_1	$x_1=-1$		
	9.968983	–0.18852	0.093096
	$x_1=0$		
	9.763206	–0.18852	0.093096
	$x_1=+1$		
	9.32435	–0.18852	0.093096
y_2	$x_1=-1$		
	10.80828	–0.13777	–0.05625
	$x_1=0$		
	10.52291	–0.13777	–0.05625
	$x_1=+1$		
	9.995954	–0.13777	–0.05625
y_3	$x_1=-1$		
	7.114392	–0.17243	–0.08115
	$x_1=0$		
	6.937922	–0.17243	–0.08115
	$x_1=+1$		
	6.616112	–0.17243	–0.08115

From Table 12 it follows that for the output variable y_1 the response surface takes the form of a hyperbolic paraboloid ($\lambda_1<0$, $\lambda_2>0$, $|\lambda_1| \neq |\lambda_2|$) with a saddle point. This is also demonstrated by the visualization shown for $x_1=0$ (Fig. 11).

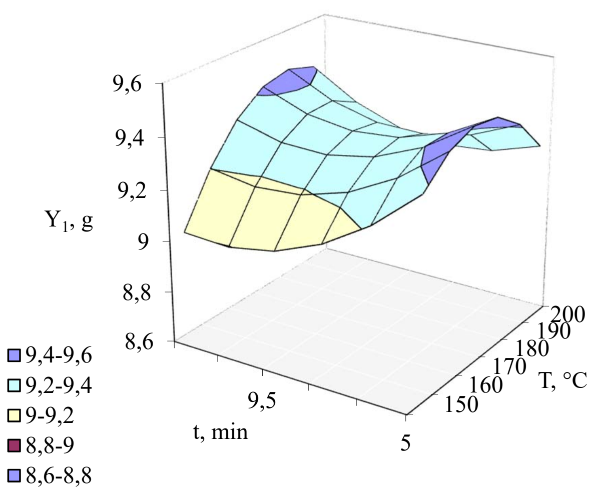

Fig. 11. Response surface $y_1=f(T, t)$ at $K=1.5$ mm

For output variables y_2 and y_3, the response surface takes the form of an ellipsoid ($\lambda_1<0$, $\lambda_2<0$, $|\lambda_1| \neq |\lambda_2|$). This is also demonstrated by the visualization shown for $x_1=0$ (Fig. 12, 13).

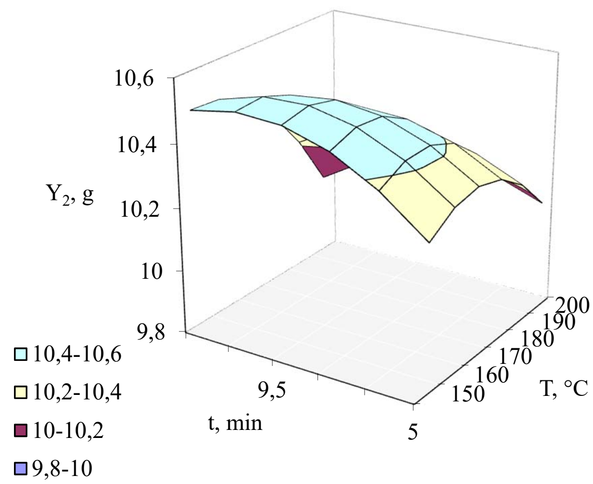

Fig. 12. Response surface $y_2=f(T, t)$ at $K=1.5$ mm

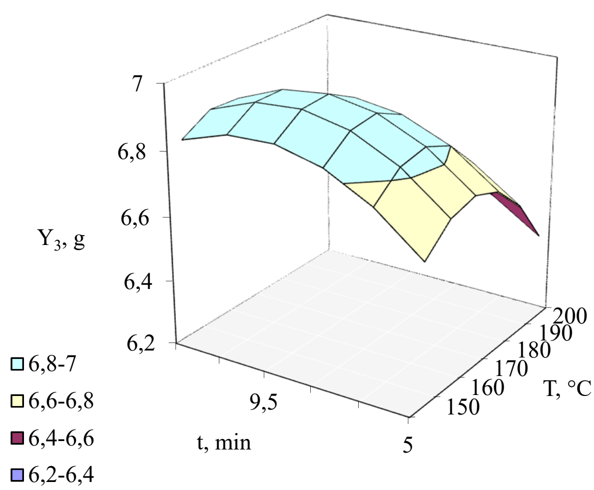

Fig. 13. Response surface $y_3=f(T, t)$ at $K=1.5$ mm

The results of the analysis of response surfaces based on the canonical transformation make it possible to evaluate the behavior of the output variable in the entire cloud of variation of the input variables.

6. Discussion of results of the study on optimizing the composition of cereal drinks fortified with Omega-3 polyunsaturated fatty acids

Our regression equations (Table 5) are adequate (Table 7), therefore, they allow further analysis to identify optima. It is important to emphasize that the quality indicators of cereal drinks depend on the content of protein substances, which reduce blood glucose levels and increase the feeling of satiety. The composition of cereal drinks and the recipe determine the texture of the product and organoleptic characteristics. Other factors such as grain grinding methods, flour particle size, and flour processing may also have an effect.

According to the results of studies into the physicochemical parameters of cereal drinks, it was found that the highest protein content was shown in buckwheat and oatmeal drinks fortified with flaxseed flour. Changes in the ash content in the composition of buckwheat and oat drinks range from 50 % to 63 %, where the maximum belongs to drinks containing flax. In a rice drink, the maximum ash content belongs to the drink without the addition of flax. The mass fraction of moisture in all studied samples varies from 90 to 94 %. The acidity of the drinks varied from 1.6 to 2.1 °T (Table 5).

Despite the fact that minerals occupy only a small proportion in the product, they play an important role in terms of the nutritional value of the product. As a result of the study, the results were obtained for determining the mineral composition, which is within the limits with the data of control samples.

According to the results of the study, the content of the fatty acid composition of cereal drinks varies markedly. The minimum proportion of saturated fatty acids is established in product No. 3, without fortification – 10.43 %. The content of polyunsaturated fatty acids ranged from 82.09% (product 1) to 89.57 % (product 3). The highest content of Omega-3 was found in product 2, with fortification – 1.34 %, and the lowest – in product 1, without fortification – 0.27 % (Table 8).

Based on the FAO/WHO, fat intakes are around 3 % for ω6 and 0.5 % for ω3, but up to 9 % ω6 and 2 % ω3 are recommended to combat heart disease. The ratio of ω6 to ω3 in the developed product 1 shows the following: without fortification – 0.67 %, after fortification – 3.23 %, which indicates the correct ratio of ω6 to ω3. In product 2, without fortification – 1.57 %, after fortification it was – 3.44 %, in this variant, after fortification of the drink, the content of ω3 increased by 1.87 %. Product 3, without fortification – 0.81 %, after fortification amounted to – 3.76 %, shows that fortification has a positive effect on the ratio ω6/ω3 and the content of ω3 has become higher by 2.95 %.

Based on the data obtained, it can be concluded that the fortification has a positive effect on the ratio ω6/ω3 and the content of ω3 has become higher by 2.95 %. Fortification of experimental samples with flax seeds had a positive effect on the content of Omega-3, as well as on the ratio ω6/ω3. The ratio of ω6 to ω3 in the developed products has reached optimal values.

The biological value of the samples was determined by the amino acid composition by calculating the amino acid score. The introduction of a filler into cereal drinks made it possible to enrich the protein component of the drink, thereby increasing the biological value. In terms of the content of essential amino acids, the developed product is characterized by a high content of essential amino acids, exceeds the FAO/WHO ideal protein scale, which allows us to conclude that the developed product has a high biological value.

In terms of protein content, all samples of fortified cereal drinks are in the lead compared to samples without fortification, it can be concluded that flax flour favorably affects the high protein content in the composition of drinks. As follows from Table 12, the oat protein content has maxima in the roasting temperature region close to the center of the range of variation, and this conclusion is valid for both time levels – lower and upper. At the same time, an increase in the grinding size from 1 mm to 2 mm leads to a decrease in the amount of protein.

The protein content of buckwheat and rice have maxima within the planning area, however, just as in the case of the protein content of oats, an increase in the grind size leads to a decrease in the protein content.

The limitation of the study is that only the determination of the grinding size, temperature, and duration of roasting was considered; our results are adequate only in the selected planning area, limited by the ranges of variation of these factors (Table 1). Going beyond these areas may lead to inadequate results and requires additional research. Of interest may also be studies of the moisture-binding capacity of raw materials and the rheological parameters of cereal drinks.

At this stage, the main drawback of the reported studies is the lack of microbiological research into storage capacity and safety indicators of finished products, which can become another direction for further development of the study.

7. Conclusions

1. Based on the implementation of the rotatable plan, a mathematical model has been built in the form of three regression equations that describe the effect of grinding size (K), roasting temperature (T), and roasting duration (t) on three output variables: protein content of oats, buckwheat, and rice. Statistical analysis of the obtained equations showed that they are adequate in the chosen planning area: K=0.66–2.34 mm, T=133–217 °C, t=3.3–11.7 min.

2. Based on the analysis of physicochemical and sensory indicators of the quality of cereal drinks, it was established that when flaxseed flour was added to the formulation as an enricher of Omega-3 PUFAs, the protein content increased. In an oat drink – 0.53 %, buckwheat – 1.94 %, and rice – 0.37 %.

Based on the analysis of the mineral composition, it can be concluded that the content of zinc (Zn) in the buckwheat drink increased by 3.74 % compared to the control variant (1.84 %), due to fortification with flax flour. Similarly, in terms of the content of Fe and Mn – with the addition of flax, their content was, respectively, 51.9 % and 61.8 %. In products 1 and 2, the mineral composition is close to the control sample, respectively, with the exception of nickel (Ni), where the leading positions belong to an oatmeal drink with the addition of flax (4.87 %).

3. It was found that the minimum proportion of saturated fatty acids in product No. 3 without fortification was 10.43 %. The content of polyunsaturated fatty acids ranged from 82.09 % (product 1) to 89.57 % (product 3). The highest content of Omega-3 was found in product 2, with fortification – 1.34 %, and the lowest – in product 1, without fortification – 0.27 %. In terms of the content of essential amino acids, the developed product is characterized by a high content of essential amino acids, exceeds the FAO/WHO ideal protein scale, which allows us to conclude that the developed product has a high biological value.

4. By analyzing the obtained regression equations by canonical transformation, the response surface was investigated. It has been established that the response surface describing the content of oat protein in the considered factor space takes the form of a hyperbolic paraboloid with a saddle point. At the same time, the protein content has maxima in the roasting temperature region close to the center of the variation range, and this conclusion is

true for both time levels – lower and upper. Increasing the grind size leads to a decrease in the amount of protein. The response surfaces describing the protein content of buckwheat and rice take the form of ellipsoids with maxima inside the planning area. However, an increase in the grind size leads to a decrease in the protein content.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

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