The paper is devoted to solving the problem of the nutritional and biological value of rye-wheat bread by enriching it with non-traditional local plants raw materials – linseed flour and rice husk fiber. Rice husks are rarely used in bakery production, and in most cases remain unprocessed. However, this research defined the right ways for using them and set as a preliminary work in this field. The study has been carried out in two stages: firstly, linseed flour was added to the rye-wheat bread recipe in an amount of 5; 10; 15; 20 % to the weight of wheat flour. Secondly, dietary fiber was added to these experimental samples, prepared from rice husks without removing amorphous silicon dioxide in an amount of 0.3; 0.5; 0.7 % to the total mass of rye-wheat flour. The optimization of the ratios of the flour components with a simplex-lattice design was carried out and the rheological measurements of dough and bread were conducted on the farinograph and Chopin alveograph.

The study results experimentally found that mixtures of rye-wheat flour and linseed flour with the addition of fiber as "medium in strength" give bread with sufficient volume. The recipe optimization parameters indicated that rational percentage of fiber and linseed flour up to 0.5 % and 15 %, respectively allows increasing the nutritional and biological value of finished products, improves the crumb structure, gas-holding and water-holding capacity of bread, which in turn prevents the stale process and thereby increases the shelf life of finished products.

The obtained results allow us to suggest that, this recipe optimization model could be used in further research, as studies in this direction are limited

Keywords: rye-wheat bread, linseed flour, rice husk fiber, rheology, recipe optimization

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A STUDY OF THE POSSIBILITIES OF USING LINSEED FLOUR AND RICE HUSK FIBER AS AN ADDITIONAL SOURCE OF RAW MATERIALS IN THE BAKERY INDUSTRY

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1. Introduction

One of the main objectives of state policy in the field of nutrition is the production of food enriched with essential ingredients, special baby food, functionally oriented products, dietary (therapeutic and prophylactic) foods, public health, prevention of diseases caused by incomplete and unbalanced nutrition, development of biologically active food additives [1].

Improvement of the quality of flour products can be achieved by deeply studying the baking process, which is one of the main processing methods of bakery production and flour products. It represents a difficult process of heating damp colloidal capillary-porous semi-processed product leading to the change of its physical, microbiological and colloid-chemical properties [2].

Given that the nutritional and biological value of wheat flour, as the main raw material for bakery products, is low in the content of amino acids and minerals and vitamins, it becomes necessary to use products from other cultures in the preparation of dough to increase the nutritional value of finished products [3].

Second-grade flour from durum wheat, oatmeal, rice husk, etc. is a fiber-rich source and could be easily used for bread production [4]. The last one is mostly used because of its cellulose, lignin and mineral, ash content (including 92–97 % silicon dioxide). These substances are natural sorbents, removing toxins and radionuclides from the human body. The study of scientists also reported that rice husk also contains significant amounts of macro and micro elements and organic substances (70–85 %) [5].

According to modern doctrine, rice husk fiber (RHF) is a crucial food component in nutrition physiology and must be consumed every day to prevent cardiac illness and gut disorders. In this regard, it is advisable to enrich mass-consumption products with RHF to support vulnerable social groups with fulfilled diet. Therefore, bread and bakery products could be the main source for increasing nutritional value with RHF, due to their high consumption level and processing lines, even though they are more adaptable for modernization.

Moreover, there are other types of unconventional raw materials, such as linseed flour, which is mostly used for increasing the functional properties of bread and bakery products. The unique chemical content of linseed flour (LF), where lipids are 12–20 % (omega 3–8 %, omega 6–75 %, omega 9–15 %), RHF 40 % (including cellulose 7 %), proteins 30 %, carbohydrates 38 % (8 % digestible) enables to increase the nutritional and biological value of bread products [6].

Therefore, it is a relevant task to make bakery products from rye and wheat flour with the addition of LF and RHF. Besides this issue, it is crucial firstly to optimize the recipe of bakery products before production with relevant research steps.

2. Literature review and problem statement

The work of scientists published as a review paper demonstrated that RH is a natural sheath formed around rice grains during their growth. As a type of natural fiber obtained from agroindustry waste, RH can be used as a filler in composites in various polymer matrices. The advantages of naturally occurring fibers like their availability, cost, biodegradability, low density, high specific strength have motivated the scientific community to try to develop newer materials using these naturally occurring fibers, which also solves the problem of waste disposal. However, this work demonstrated RH nonfood characteristics [7].

Other studies illustrated the potential of converting RH amended with market refused fruit (market refused banana (B), honeydew (H) or papaya (P)) into vermicomposting using *Eudrilus eugeniae*, where the results reveal that vermicomposting is a feasible technology for bio-transforming RH into value-added material, namely vermicompost [8].

A review paper of another researchers attempts to understand the applicability of RH as a fiber with various polymers based on the recent research works. It also threw light on various modification techniques that can further enhance the mechanical properties by altering the chemical and physical properties of husk. The paper assisted in understanding the phenomenon associated with the manufacture of rice husk based bio-composite and provides critical insight into future rice husk applications [9].

Different researchers' team studied the possibilities of using RH with wheat flour in bread production. In this context, the objective of their experiment was to evaluate the loss of cooking mass, the color of the crust and crumb, and the specific volume of bread with the inclusion of different rice husk contents in its formulation. The results demonstrated no difference in specific volume and mass loss between the formulations. However, in relation to color, the luminosity parameter was largely affected, with a marked decrease in both crust and crumb, since there was a greater substitution of wheat flour by rice husks [10].

However, there are limited research works related to RHF addition to bread products. More studies were conducted on rice bran, which takes third place in the rice grain milling process.

There are other scientific works regarding linseed flour, which was selected by us as the second additive in bread production. Linseed (flaxseed) flour (LF) was used in the wok, where they studied the effect of LF on the rheological properties of wheat flour dough and bread characteristics. The results of the work demonstrated that LF significantly ($p<0.05$) increased dough water absorption, peak time, and mixing tolerance index, but decreased dough stability. Oven spring was significantly lower for all flaxseed treatments compared to the control. However, the loaf volume of bread made with 6 and 10 % LF did not differ significantly ($p<0.05$) from the control. The LF concentrations tested did not affect the specific volume of bread even though the water absorption values were higher for dough with LF. The bread containing flaxseed had darker crust color and a more yellow crumb color compared to the control bread, but the crumb structure was not negatively impacted [11].

Ample works have been done regarding LF; however, only with LF and wheat flour, or its replacement.

In this study, we used RHF as a functional additive, and the main reason for selecting rice husks is that the composition of this material includes cellulose, lignin and mineral ash, consisting of 92–97 % silicon dioxide, which are useful substances for the human body [12, 13].

Rice hull and rice bran fibers share similar compositions and physicochemical properties. Animal studies with the administration of rice hull fiber (3.75 or 5 % in the diet) for 3 months demonstrated significantly reduced fasting blood glucose concentrations by up to 22 % and blood total cholesterol concentrations by up to 18 % in male rats. Rice hull fiber also meets the growing demand for allergen-free sources of insoluble dietary fiber in the marketplace. Additionally, it has a light color, bland flavor, small particle size, and moderate water-holding capacity, which makes it a good choice for baking applications, extruded cereals, snacks, and other products where the fiber source should not compete with other ingredients for hydration [14].

Another beneficial characteristic of rice husk is that its raw materials are quickly renewable and environmentally friendly [15, 16].

The studies of the addition of RHF and LF to wheat flour, their interaction, optimization of its recipe were not carried out previously. So, we encountered several problem formulations during the product recipe optimization process. Solutions to these problems are indicated in the following sections of the study.

3. The aim and objectives of the study

The main aim of this work is to study the possibilities of using LF and RHF as an additional source of raw materials in the bakery industry besides wheat flour, with the optimization of their recipe and increasing their nutritional properties.

To achieve the aim, the following objectives have been set:

– to study the main rheological characteristics of dough, produced with adding rice husk fiber and linseed flour;

– to assess the physicochemical properties of flour mixtures, produced with adding rice husk fiber and linseed flour;

– to optimize the recipe of bread for producing it from wheat linseed flour and rice husk fiber.

4. Materials and methods of research

For this study, RHF (as a powder), a mixture of peeled rye flour and first-grade wheat bakery flour, ST linseed flour (LLP 0504400092–84–03–2020), samples of yeast dough from a rye-wheat mixture prepared with sourdough, and baked products from it, samples of yeast dough from a rye-wheat mixture prepared with additives of dietary RHF and products baked from it were used. Samples of yeast dough from rye-wheat and linseed flour mixture, prepared with RHF additives, baked products from it were used in the present study.

Linseed flour was obtained from Garnec company (Russia) with 334 kcal per 100 g energetic value. The nutritional value of the products was as follows: proteins – 12.6 %, fats – 2.6 %, carbohydrates – 40 %. A mixture of peeled rye flour (Endaks company, Russia) with the energetic value – 294 kcal per 100 g of product, where proteins – 10.7 %, fats – 1.9 %, carbohydrates – 58.5 % and first-grade wheat bakery flour was purchased from LLP SevEsilZerno (Kazakhstan) with required nutritional content (proteins – 10.6 %, fats – 1.3 %, carbohydrates – 73.2 %). RHF was delivered from a peasant farm (Kostanay city, Kazakhstan) and its chemical composition and basic properties were studied at the Institute of Combustion Problems (Almaty, Kazakhstan). The results are as follows: proteins – 8.75 %, fats – 0.38 %, water – 4.87 %, ash – 11.86 %, pentozan – 4.52 %, cellulose – 39/12 %, lignin – 27.8 %.

Preparation of rye-wheat bread samples.

The rye-wheat bread samples were produced as follows: the dough was prepared from peeled rye flour, first-grade wheat flour, water, yeast, sourdough, salt, malt, sugar, vegetable oil, fermented, cut, proofed and baked. As a supplemental material to the dough, carbonated RHF (without removing amorphous silicon dioxide) and linseed flour (LF) were added.

Rheological measurements on the farinograph.

The studies of dough's rheological properties were carried out on two devices, namely Farinograph-TS (Brabender, UK) and structural meter (NPO Radius Moscow, Russia).

The first method is based on measuring and registering the consistency of the dough formation process, its development, and changes in its consistency during kneading (from flour and water) according to normative documents requirements (RF SSt 51404–99) [11].

For the determination on the structural meter, the following modes were used:

– 1 mode – determination of elongation and elasticity in deformation;

– 2 mode – determination of adhesive properties;

– 7 mode – determination of relaxation time according to the given force.

Determination of dough's deformation elasticity and plasticity.

The initial value of the exponent that determines the elasticity of deformation and viscosity is P_0=0.5 H (viscous layer). The indicator then shows the speed value of the variable as V=100 mm/min. The indicator then displays the strength of the sample during the experiment. When it reaches P=100 H, the force stops and gives a signal. The value of the variable is detected as H_1. The indicator moves downward at a predetermined speed. When the force value is reached, a signal (H_2) is issued and the value of the variable is recorded. The table will move to the previous position at maximum speed. The indicator displays the value and number of H_1.

The results are processed by the following equations:

$$\text{Relative plasticity} = \frac{\Delta H_{planned} * 100}{\Delta H_{total}}, \quad (1)$$

$$\text{Relative elasticity} = \frac{\Delta H * 100}{\Delta H_{total}}, \quad (2)$$

$$\Delta H_{elast} = \left(\Delta H_{total} - \Delta H_{planned}\right). \quad (3)$$

Determination of dough's adhesive properties.

The test dough is placed in the chamber on a moving plate. The plate with the electric motor raises the chamber with the dough until it touches the sensing element disk. When determining the adhesion properties, the pre-bonding stress to which the sample is loaded is set by the plastine speed as V=100 mm/min, P=100 H to create the bonding strength, an important value of the initial stress is set as P_0=0.5 H. Then the pause value set at t=100 sec appears on the indicator. At the end of the mode, the indicator shows the sample strength and the corresponding movement value. The adhesive pressure is determined by the following equations:

$$\sigma_{adh} = \frac{\left(P_{rej} - P_{con}\right)}{F}, \quad (4)$$

where P_{rej} – breaking force, H; P_{con} – connection force, H; F – disk space, Pa.

Determination of the dough's relaxation time according to the given force.

To determine the relaxation time of the dough at a given force, the following values are given: P_0=0.5 H, V=100 mm/min, creating a force of P=100 H. The indicator records the load and force values. At the end of the mode, the indicator shows P, H and relaxation time (seconds).

Rheological measurements on the Chopin alveograph.

Measurements were conducted according to RF SSt 51415–99 on the Chopin alveograph (GBS Technologies, Kazakhstan). To assess the effect of flax flour on the rheological properties of the dough, 5, 10, 15, 20 % linseed flour mixtures with replacing wheat flour were prepared. To these experimental samples, dietary RHF in the amount of 0.3; 0.5; 0.7 % to the total mass of flour was added. As a control, rye-wheat flour (a ratio of 60:40) was used. The bread quality was assessed 4–6 hours after baking by organoleptic and physicochemical indicators (SSt 31807–2018) [12].

Optimization of the ratios of the flour components with a simplex-lattice design.

When solving multifactual extremal problems, an approximate mathematical model of the process is obtained, which connects all the considered factors.

It is required to obtain some representations of the response function due to a number of facts, for example:

$$\eta = \phi(x_1, x_2, \ldots, x_n), \tag{5}$$

where η – optimization criterion (response) by which the process under study is assessed; $x_1, x_2, \ldots, x_n$ – independent variables (facts) that can be varied.

The geometric image of the response function (5) is called the response surface in fact space. The response function can be approximated by a polynomial view

$$\eta = \beta_0 + \sum^n \beta_i x_i + \sum^n_{i<j} \beta_{ij} x_i x_j + \sum^n \beta_{ii} x_i^2 + \ldots, \tag{6}$$

where β_0, β_i, β_{ij}, β_{ii}, ... – theoretical coefficients of regression, by the values of which the degree of influence of the relevant facts can be judged.

As a result of the experiment, the regression coefficients β0, β_i, β_{ij}, β_{ii}, ... are obtained, which are estimates of the theoretical coefficients. After this, equation (6) takes the form

$$y = b_0 + \sum^n b_i x_i + \sum^n_{i<j} b_{ij} x_i x_j + \sum^n b_{ii} x_i^2 + \ldots, \tag{7}$$

where y – calculated value of the optimization criterion.

Before planning and conducting an experiment, you should choose an optimization criterion, i.e. the parameter by which the investigated object is evaluated and which connects facts in the mathematical model. After the optimization criterion (parameter) is selected, it is necessary to select, as possible, all the factors influencing its value, and for the facts, they indicate the range of values.

There are several methods of mathematical planning of an experiment, among which it is most convenient to describe the technological models of the process of grinding wheat, rye and pea grain with sufficient accuracy.

In this regard, in the future, a second-order rotational plan (Box's plan) is considered, which provides an optimal ratio of input factors affecting the process of grinding the optimum material.

When processing the experimental results and studying the response functions, we used an equation of the second kind (7).

The calculation of regression coefficients for the second-order rotational plan was carried out by the following formulas:

$$b_0 = a_1 \sum_1^n y_u - a_2 \sum_1^k \sum_1^n x_{iu}^2 y_u, \tag{8}$$

$$b_1 = a_3 \sum_1^n x_{iu} y_u, \tag{9}$$

$$b_y = a_4 \sum_1^{n_z} x_{iu} x_{ju} y_u, \tag{10}$$

$$b_y = a_5 \sum_1^n x_{iu}^2 y_u + a_6 \sum_1^k \sum_1^n x_{iu}^2 y_u - a_7 \sum_1^n y_u, \tag{11}$$

where a_1–a_7 are the coefficients, the values of which are chosen taking into account the number of factors.

The hypothesis about the adequacy of the model was checked using Fisher's criterion:

$$F = \frac{S_{ad}^2}{S_{\{y\}}^2}, \tag{12}$$

where S_{ad}^2 – adequacy variance; $S_{\{y\}}^2$ – reproducibility variance.

The adequacy variance is determined from the expression:

$$S_{ad}^2 = \frac{S_R - S_E}{f_{ad}} = \frac{\sum_1^N (y - y_p)^2 - \sum_1^{n_0} (y_{0j} - y_0)^2}{N - \lambda - (n_0 - 1)}, \tag{13}$$

where $\bar{y}$ – individual observation results;

y_p – the criterion value calculated by the regression equation;

N – the number of experiments taken into account when evaluating the regression coefficients;

λ – the number of coefficients of the equation;

n_0 – the number of repetitions of the zero experiment.

The reproducibility variance is determined from the expression:

$$S_{\{\bar{y}\}}^2 = \frac{\sum_1^{n_0} (y_{0j} - \bar{y}_0)^2}{n_0 - 1}, \tag{14}$$

where y_{0j} – the result of a single observation at the zero point;

$\bar{y}_0$ – the result of the experiment at the zero point (arithmetic mean);

n_0 – the number of observations at the zero point.

The model is adequate if, at a given significance level of 5 %, the number of degrees of freedom for more than 5 and less than 5 variances, $F_p<F_t$. The value of F_t is found from the application.

To assess the significance of the recession coefficients, we use the following equations:

$$s_{\{b_0\}}^2 = a_8 s_{\{y\}}^2, \tag{15}$$

$$s_{\{b_1\}}^2 = a_9 s_{\{y\}}^2, \tag{16}$$

$$s_{\{b_u\}}^2 = a_{10} s_{\{y\}}^2, \tag{17}$$

$$s_{\{b_y\}}^2 = a_{11} s_{\{y\}}^2, \tag{18}$$

where, $s_{\{b_0\}}$, $s_{\{b_1\}}$, $s_{\{b_{ii}\}}$, and $s_{\{b_{ij}\}}$ – respectively, the quadratic errors in determining the coefficients b_0, b_i, b_{ii} and bij; $s_{\{y\}}^2$ – error of the mean over parallel observations; a_8, a_9, a_{10}, a_{11} – coefficients whose values are chosen taking into account the number of factors.

Statistical analysis.

The experiments were conducted in triplicate. Statistical analysis was performed using Statistical Package of Microsoft Excel. Data were expressed as mean±standard deviation of triplicate determinations and were compared using Fisher's test at $p<0.05$ significance level.

5. Results of studying the possibilities of using linseed flour and rice husk fiber as an additional source of raw materials

5. 1. Determination of the rheological characteristics of dough, produced with adding RHF and linseed flour

The dough is a watered colloidal complex – a polydispersity, which has a certain internal structure and is very peculiar, continuously changing its rheological properties.

Depending on the type, speed and duration of deformation, the dough can behave either as an ideally elastic body, or as a viscous one, or as a combination of these properties, that is, referring to elastic-viscous materials.

The dough has both the properties of a solid and a liquid, so it must have a certain ratio of viscous and elastic properties. These kinds of rheological properties of combined dough (rye-wheat flour with rice husk and linseed flour mixtures) were assessed with various devices, and its relative plasticity, relative elasticity, relaxation time and adhesive pressure were determined. The results are presented in Table 1.

The adhesion pressure of the dough with 5–20 % LF increases by 146–158 kPa, and in samples with 0.3 % RHF powder, depending on the amount of added LF, it increases by 144–150 kPa, 0.5 % – 140–147 kPa, 0.7 % to 138–144 kPa. The control sample showed a pressure of 145 kPa. The decrease in the dough adhesion pressure in the samples with the addition of dietary RHF compared to the samples without additives is explained by the increase in the moisture content in the dough obtained from rice bran. Rice bran powder also increases the moisture content of the dough, which in turn reduces the stickiness of the rye wheat flour dough with LF. This is due to the fact that LF and RHF improve the water absorption of the flour, harden the glue and reduce the viscosity of the dough, reducing the amount of free water in the dough. The pattern of changes in the properties of this dough can be seen in Fig. 1 below.

Table 1

Rheological properties of dough from a mixture of rye and wheat, flax flour with the addition of RHF

LF content to the mass of first-grade wheat flour, %	Relative ductility, %	Relative elasticity, %	Relaxation time, *F*=const, s	Adhesive pressure, kPa, 100 s
1	2	3	4	5
Control	78.5	6.5	272	145
5	79.0	6.0	268	146
10	80.0	5.3	263	148
15	78.0	5.0	260	151
20	75	4.4	254	158
0.3 % dietary RHF from rice husks to the total mass of flour				
5	80	6.7	270	144
10	81	6.2	265	145
15	80	6.0	263	148
20	78	5.7	259	150
0.5 % dietary RHF from rice husks to the total mass of flour				
5	81	7.0	273	140
10	83	6.7	270	142
15	82	6.3	267	145
20	80	6.0	260	147
0.7 % dietary RHF from rice husks to the total mass of flour				
5	79	7.5	280	138
10	80	7.1	277	141
15	78	6.8	273	143
20	77	6.4	268	144

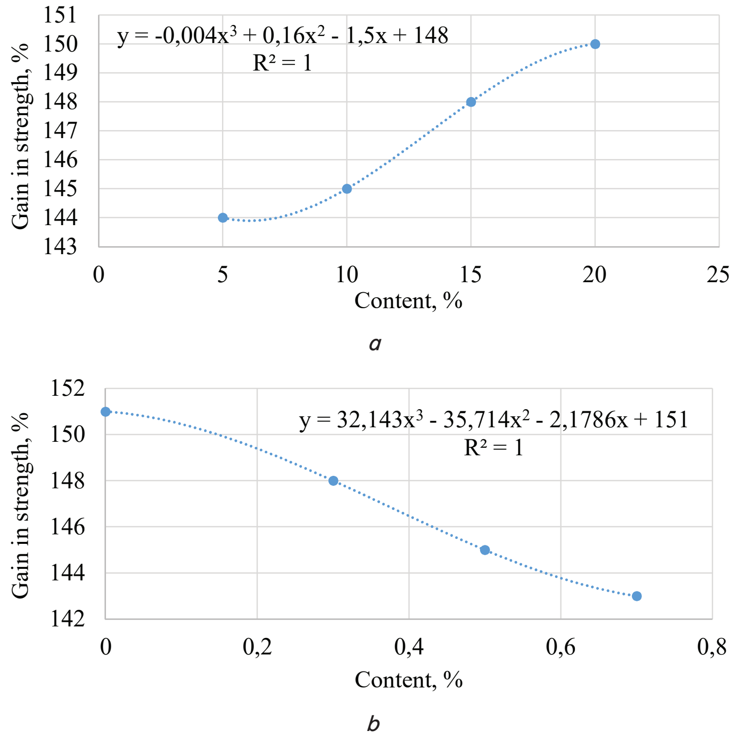

Fig. 1. Adhesive properties of rye-wheat dough: *a* — with linseed flour; *b* — with rice husk fiber

The study of the rheological properties of the dough using the farinograph allows obtaining data on the nature of formation dynamics of the dough, accumulation of potential energy of elastic deformation at the initial stage of kneading and its consumption in the future.

The initial stage of rheological studies of flour on the farinograph is to determine the amount of water that must be added in order to obtain dough of the required consistency (500 units). The results obtained characterize the water absorption capacity of flour and the effect of various additives on this indicator.

There is a change in the relative elasticity and ductility of the dough in accordance with this pattern. Samples with LF had decreased elasticity and increased ductility, while dough samples with dietary RHF had a higher percentage of elasticity and decreased ductility. This has a positive effect on the structural and mechanical properties of bread dough, its ability to retain its shape.

It is known that the volume, elasticity and some other indicators of bread made from wheat and rye flour are determined by gluten proteins. It is obvious that replacing a part of flour with other prescription components will inevitably lead to a change in the rheological properties of the dough and finished products [17–19]. Alveograms of the dough with the addition of LF and RHF and the results of their processing showed a positive result for the dough made from rye-wheat flour. The dough from a mixture of rye and wheat flour is closer to rye than to wheat flour in properties, so it is prepared similarly to rye.

The results of the study on the effect of rice husk and LF powder on the dough quality by alveograms are shown in Table 2.

The addition of LF reduced the dough elasticity, as evidenced by the indicator *P*. When adding 0.3–0.7 % RHF to the flour mixture, the dough elasticity improves, depending on LF dosage.

Table 2

Alveographic parameters of the dough from a mixture of rye and wheat, LF with the addition of RHF

LF content to the mass of first-grade wheat flour, %	*P*, dough elasticity, mm	*L*, dough extensibility, mm min	*P/L* elasticity to tensile ratio	W, specific work of deformation of the dough, erg	Inflation index *G*, cm^3
1	2	3	4	5	6
Control	164	73	2.25	2.25	19
5	168	40	3.4	4.20	14
10	170	90	1.67	1.89	21.1
15	176	171	0.5	1.03	36.5
20	178	260	0.68	0.68	35.8
0.3 % dietary RHF from rice husks to the total mass of flour					
5	152	29	8	5.24	17.0
10	158	54	2.37	2.93	16.3
15	161	93	1.19	1.73	21.4
20	163	161	1.01	1.01	28.2
0.5 % dietary RHF from rice husks to the total mass of flour					
5	128	23	4.41	5.57	12
10	134	48	0.8	2.79	28.8
15	149	53	7.84	2.81	29.7
20	160	152	0.77	1.05	29.9
0.7 % dietary RHF from rice husks to the total mass of flour					
5	130	19	8.58	6.84	9.7
10	136	38	0.91	3.58	26.1
15	140	44	0.72	3.18	27.4
20	153	102	0.81	1.50	31.6

The amount of LF to the weight of wheat flour in the dough increased its extensibility (index *L*) compared to the control. The dough extensibility when adding LF in the flour mixture was 40–260 mm according to the options, while the control sample was 73 mm.

The inflation index of dough with linseed flour and rice husk fiber is given in Fig. 2.

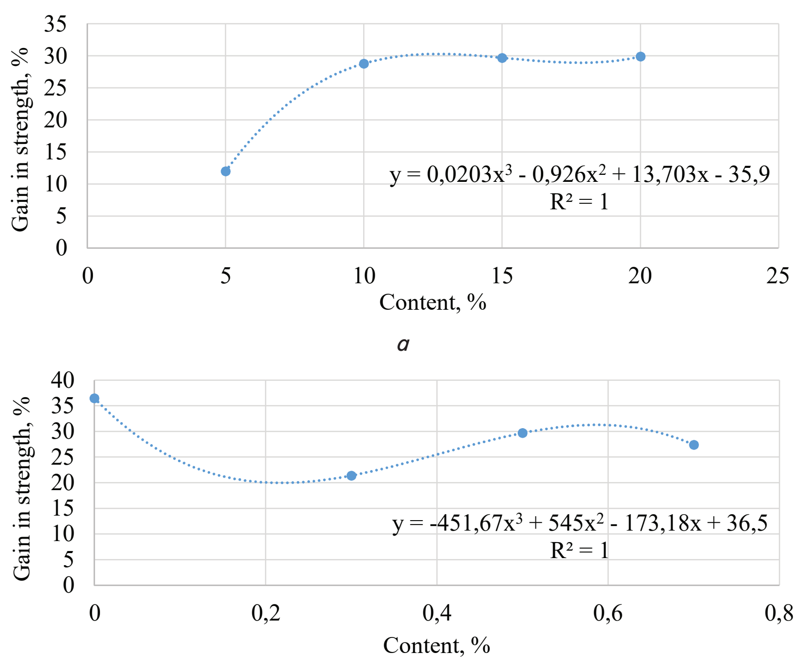

Fig. 2. Inflation index of dough: *a* – with linseed flour; *b* – with rice husk fiber *G*, cm^3

The inflation index is the arithmetic mean of the scale inflation indices corresponding to the abscissa of the dough rupture and is equal to the square root of the volume of air (in cubic centimeters) required to inflate the bubble before it bursts (excluding the volume of air required to separate the test sample from the fixed surface).

5. 2. Physicochemical indicators of flour mixtures, produced with adding RHF and linseed flour

The properties of bread such as organoleptic and physicochemical indicators were assessed 4–6 hours after production according to the SSt 31807–2018 requirements [12].

From the results of the study, the effect of RHF (0.3; 0.5; 0.7 % to the mass of first-grade wheat flour) on the quality of the dough and finished bread indicates that the 0.5 % RHF addition is the most optimal dosage.

As the LF addition increases from 15 to 20 %, the organoleptic indicators such as elasticity, porosity structure, and crusts deteriorate when using RHF, but they are much better in comparison with samples without RHF. Physicochemical indicators of bread with an increase in the LF content from 5 to 15 % to the mass of first-grade wheat flour when using RHF are improved in comparison with similar samples without RHF.

5. 3. Optimization of the amount of additives for the preparation of rye-wheat bread

When planning the experiment, the numbers and conditions for conducting experiments were chosen that were necessary and sufficient to solve the problem with the required accuracy. The studied dependent variable Y is called the optimization parameter, and the independent variables X_i acting on it are called factors. As X_i factors for rye-wheat bread recipe optimization, the following factors were selected:

– X_1 – the amount of LF, %;
– X_2 – the amount of dietary RHF, %;
– Y_1 – water absorption capacity, %;
– Y_2 – dough formation time, min;
– Y_3 – dough stability, min;
– Y_4 – degree of dough liquefaction 10 minutes after the start of DS;
– Y_5 – dough dilution rate 12 minutes after maximum DS (ICC);
– Y_6 – water absorption capacity, %.

As a result of the experiment, a mathematical model (19) is constructed, which is a certain response function (Fig. 3–8) of independent variables – factors, and in each of the experiments, the response of the optimization parameter is realized.

$$Y = F(X_1, X_2, \ldots, X_n). \quad (19)$$

The study of the response surfaces of mathematical models of farinographic and alveographic parameters, as well as the rheological properties of the dough depending on the amount of LF and dietary RHF, showed some differences (Tables 3–5).

The water absorption capacity of the dough has a minimum value of Y_1=40 % with the amount of flax flour from 14.5 % (x_1=–0.1) to 16.5 (x_2=0.25). The influence of RHF amount on the water absorption capacity of the dough is minimal, i.e. no significant changes (20)

$$Y_1 = 35.02 - 45.334x_1 - \\ -5.889x_2 - 9x_1x_2 + 250.71x_1^2 + 5.446x_2^2. \quad (20)$$

It was also found that the relaxation time of the dough is also affected by LF and dietary RHF powder. Relaxation time is reduced due to the small amount of glue in the samples with LF. According to the data obtained, the change in relaxation time was significantly reduced in samples with dietary RHF powder. This proves that the relaxation time of the dough is significantly improved compared to the relaxation time of the dough with 5–20 % LF. This also showed that the dietary RHF gives the dough strength and cohesive properties, which contributes to the improvement of the structural and mechanical properties of rye-wheat flour dough.

With an increase in LF amount in the range under consideration, the degree of dough liquefaction 10 minutes after the start of DS decreases from 80 EF to 20 EF, and the effect of RHF amount is minimal (Fig. 4) (21).

$$Y_4 = 35.015 - 28.285x_1 - 3.9x_2 - \\ -3.75x_1x_2 + 14.567x_1^2 + 5.72x_2^2. \quad (21)$$

The dough elasticity increases from 130 mm to 1,600 mm with an increase in LF amount and with an increase in RHF amount, on the contrary, it decreases with the same values of dough elasticity (Fig. 5) (22).

$$z = 148.24 - 7.669x_1 - 9.449x_2 - \\ -4x_{12} + 0.313x_1^2 + 2.062x_2^2. \quad (22)$$

The dough elongation has a minimum value of 35 mm/min in the following range: with the amount of flax flour from 11 % to 14 % and with the amount of food RHF from 0.58 % to 0.7 %.

The specific work of deformation of the dough has a maximum value of 140 erg with an amount of flax flour of 15 % and an amount of food RHF of 0.5 % (Fig. 6) (23).

$$z = 144.8 - 1.01x_1 + 0.425x_2 - \\ -0.04x_1x_2 + 71.407x_1^2 + 71.282x_2^2. \quad (23)$$

The minimum ratio of elasticity to extensibility of the dough is achieved with the amount of flax flour from 18.5 % and with the amount of food RHF from 0.58 % (Fig. 7, 8) (24), (25).

$$z = 53.22 - 43.292x_1 + 18.566x_2 - \\ -10.75x_1x_2 + 30.618x_1^2 + 6.126x_2^2. \quad (24)$$

Table 3

Dependences of farinographic parameters of the dough on the amount of LF and dietary RHF

Coefficient	Water absorption capacity, %	Dough formation time, min	Dough stability, min	Degree of dough liquefaction 10 minutes after the start of DS	Dough dilution rate 12 minutes after maximum DS (ICC)	Farinograph quality number FQN, mm
b_0	35.02	6.74	6.102	35.015	35.02	74.813
b_1	–45.334	–1.326	5.657	–28.285	–45.334	–15.863
b_2	–5.889	–0.524	0.929	–3.9	–5.889	1.061
b_{12}	–9	–0.05	0.875	–3.75	–9	–3
b_{11}	250.71	–1.761	2.353	14.567	25.071	–25.946
b_{22}	5.446	–1.311	0.179	5.72	25.446	0.046
B_0	502.92	–12.39	15.67	268.35	502.92	–135.97
B_1	–34.652	1.873	–2.13	–21.26	–34.65	29.46
B_2	–530.58	30.91	–12.96	–106.26	–530.58	49.14
B_{12}	–9	–0.05	0.875	–3.75	–9	–3
B_{11}	1.003	–0.07	0.094	0.583	1.003	–1.04
B_{22}	636.14	–32.78	4.478	143.01	636.14	1.16
F_t	8.75	7.52	5.17	8.7	8.7	8.6

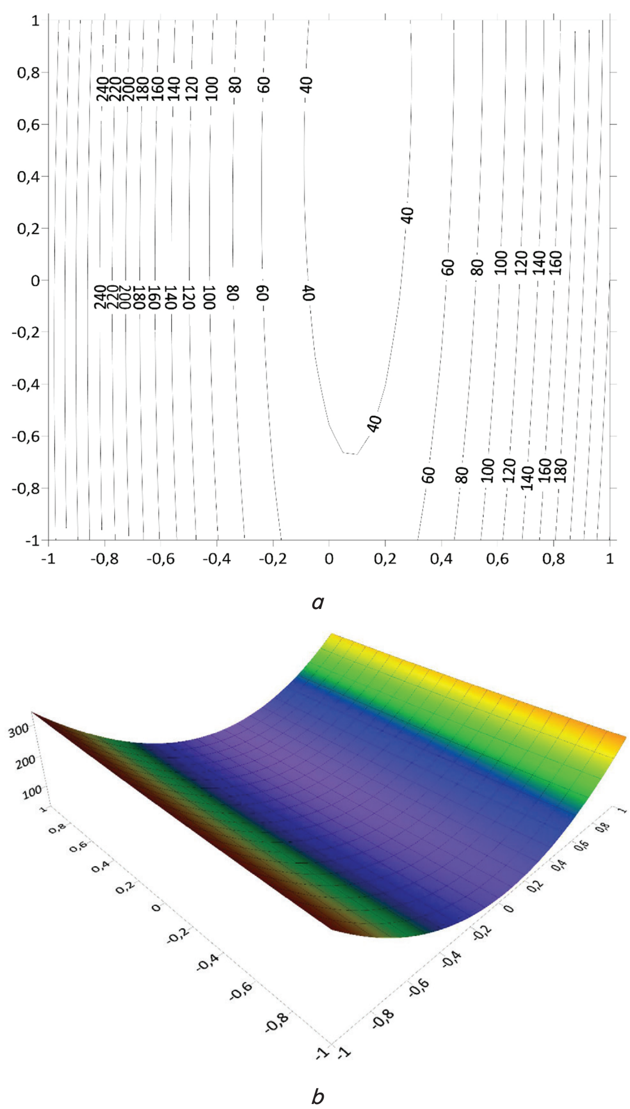

Fig. 3. Dependence of the water absorption capacity of the dough on the amount of linseed flour and dietary rice husk fiber: *a* – 2D surface; *b* – 3D surface

$$z = 0.784 - 0.368x_1 + 0.389x_2 - -0.315x_1x_2 + 0.199x_1^2 + 0.279x_2^2. \quad (25)$$

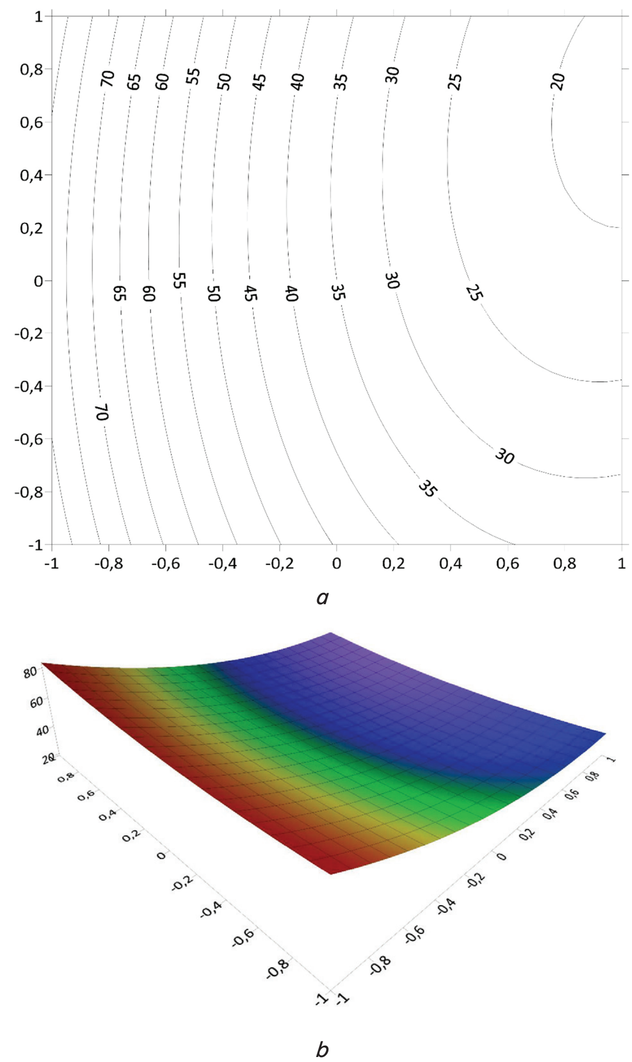

Fig. 4. Dependence of the degree of dough liquefaction after 10 minutes: *a* – 2D surface; *b* – 3D surface

Table 4

Dependences of the alveographic parameters of the dough on the amount of LF and dietary RHF

Coefficient	Dough elasticity, mm	Dough extensibility, mm/min	Elasticity to tensile ratio	Specific work of deformation of the dough	Inflation index G, sm^3
1	2	3	4	5	**6**
b_0	148.24	53.22	0.784	144.8	144.8
b_1	7.669	43.292	–0.368	–1.01	3.73
b_2	–9.449	–18.566	–0.389	0.425	2.357
b_{12}	4	–10.75	0.315	–0.04	–1.6
b_{11}	0.313	30.618	0.199	–71.407	–57.66
b_{22}	2.062	6.126	0.279	–71.282	–62.16
B_0	194.55	202.99	8.76	–941.7	–791.75
B_1	–0.84	–22.71	–0.47	85.51	70.74
B_2	–158.8	–84.73	–13.653	1784.78	1589.8
B_{12}	4	–10.75	0.315	–0.04	–1.6
B_{11}	0.013	1.225	0.008	–2.856	–2.31
B_{22}	51.55	153.15	6.981	–1782.05	–1554.1
F_p	7.74	8.63	3.2	5.67	5.97

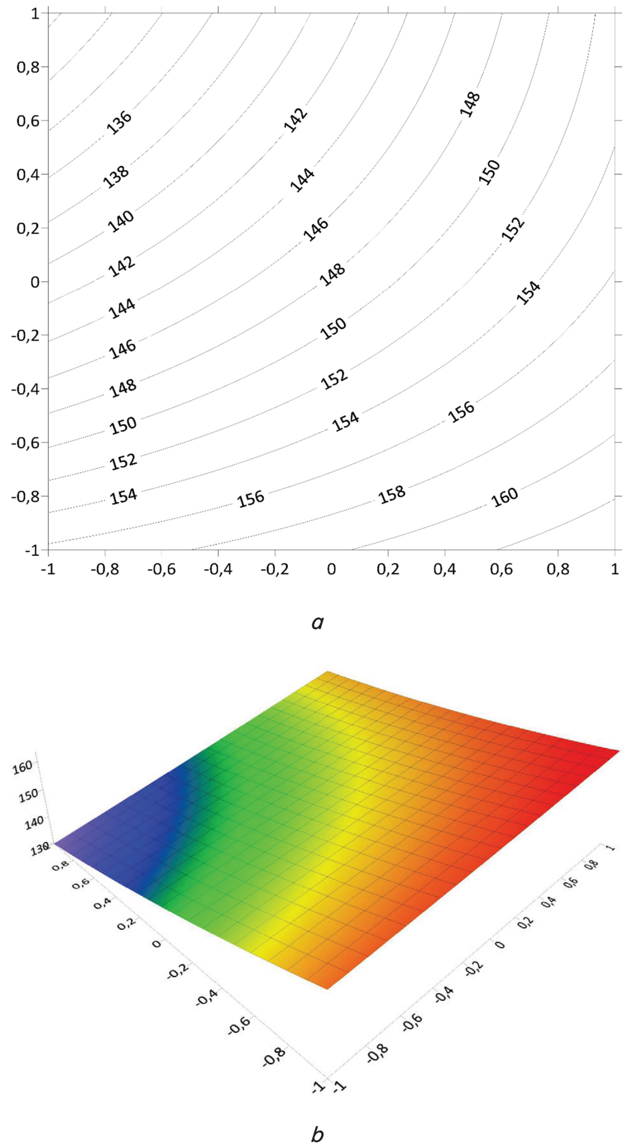

Fig. 5. Dependence of dough elasticity on the amount of linseed flour and rice husk fiber: *a* — 2D surface; *b* — 3D surface

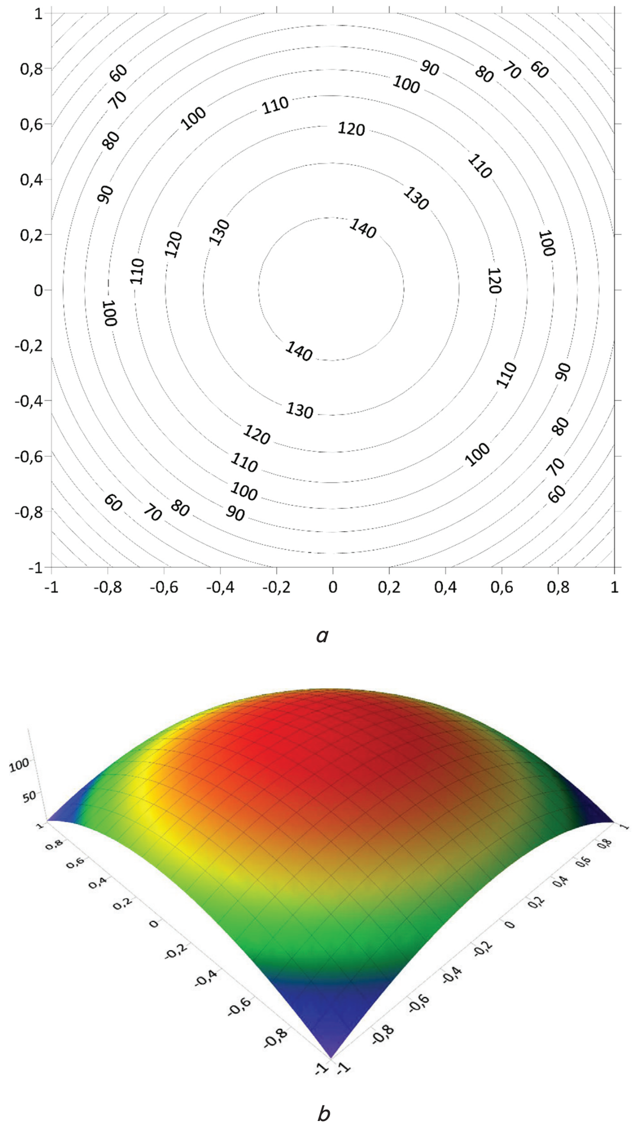

Fig. 6. Dependence of the specific work of deformation of the dough on the amount of linseed flour and dietary rice husk fiber: *a* — 2D surface; *b* — 3D surface

Table 5

Dependences of the rheological properties of the dough on the amount of LF and dietary RHF

Coefficients	Relative ductility, %	Relative elasticity, %	Relaxation time, F=const, s	Adhesive pressure, kPa, 100 s
1	2	3	4	5
b_0	81.619	6.081	266.26	144.83
b_1	–0.837	–0.577	–4.703	2.061
b_2	–1.312	0.663	5.1	–2.311
b_{12}	0.25	0.275	–0.75	–0.5
b_{11}	–0.11	–0.065	–1.553	0.579
b_{22}	–2.834	0.085	1.446	0.08
B_0	70.58	8.17	257.07	146.39
B_1	–0.16	–0.175	1.297	–0.033
B_2	60.55	–2.938	0.583	–6.046
B_{12}	0.25	0.275	–0.75	–0.5
B_{11}	–0.004	–0.003	–0.062	0.023
B_{22}	–70.86	2.128	36.164	–1.993
F_p	4.52	5.27	5.88	2.54

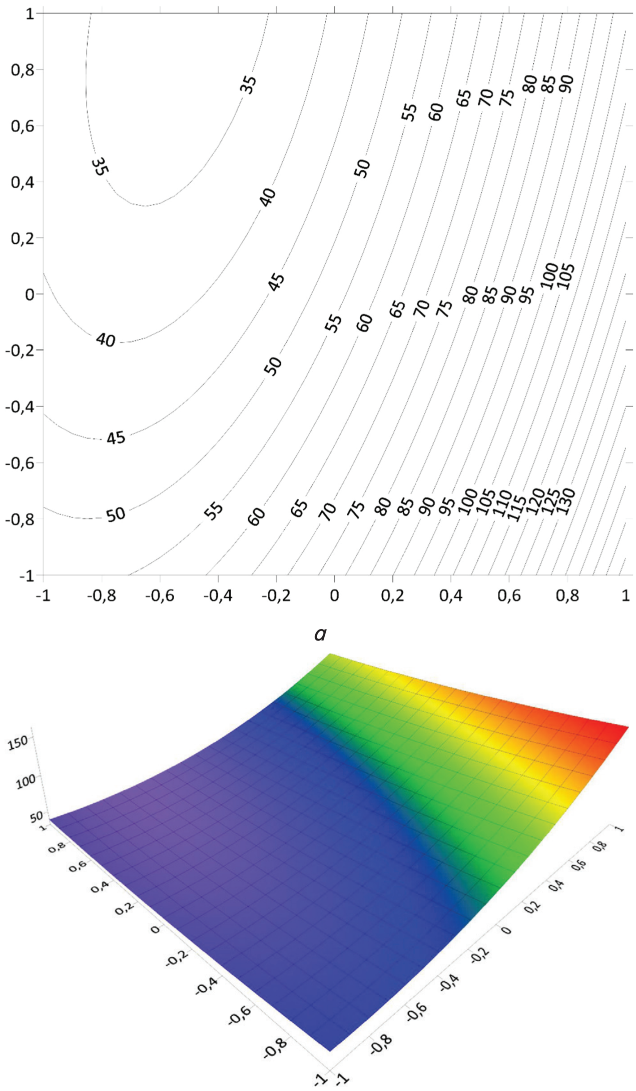

Fig. 7. Dependence of dough extensibility on the amount of linseed flour and rice husk fiber: *a* – 2D surface, *b* – 3D surface

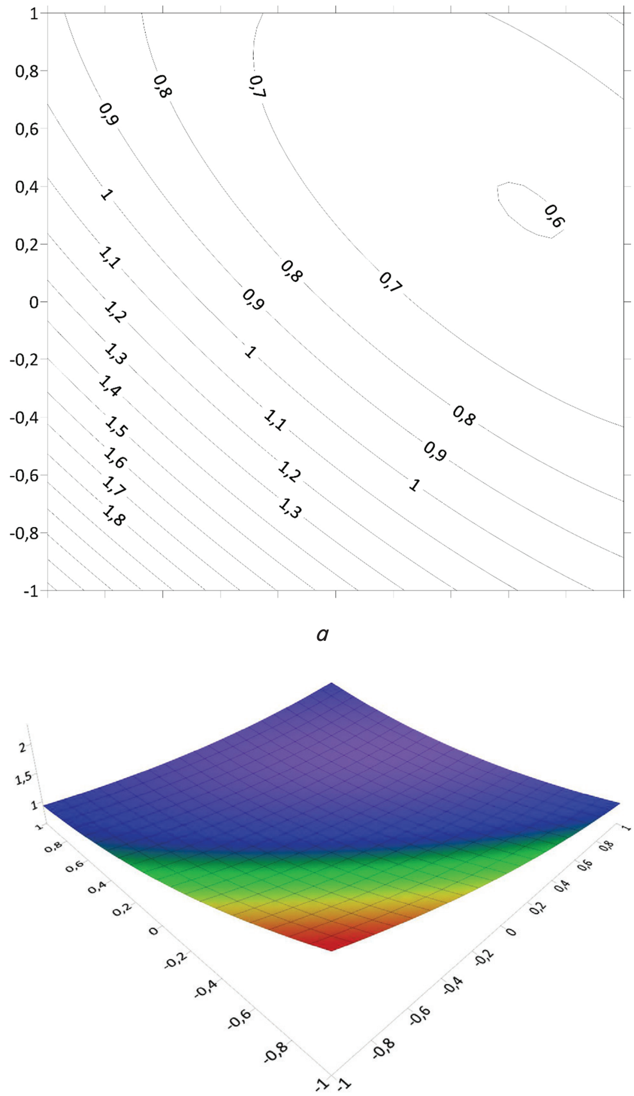

Fig. 8. Dependence of the elasticity to extensibility ratio of the dough on the amount of linseed flour and rice husk fiber: *a* – 2D surface; *b* – 3D surface

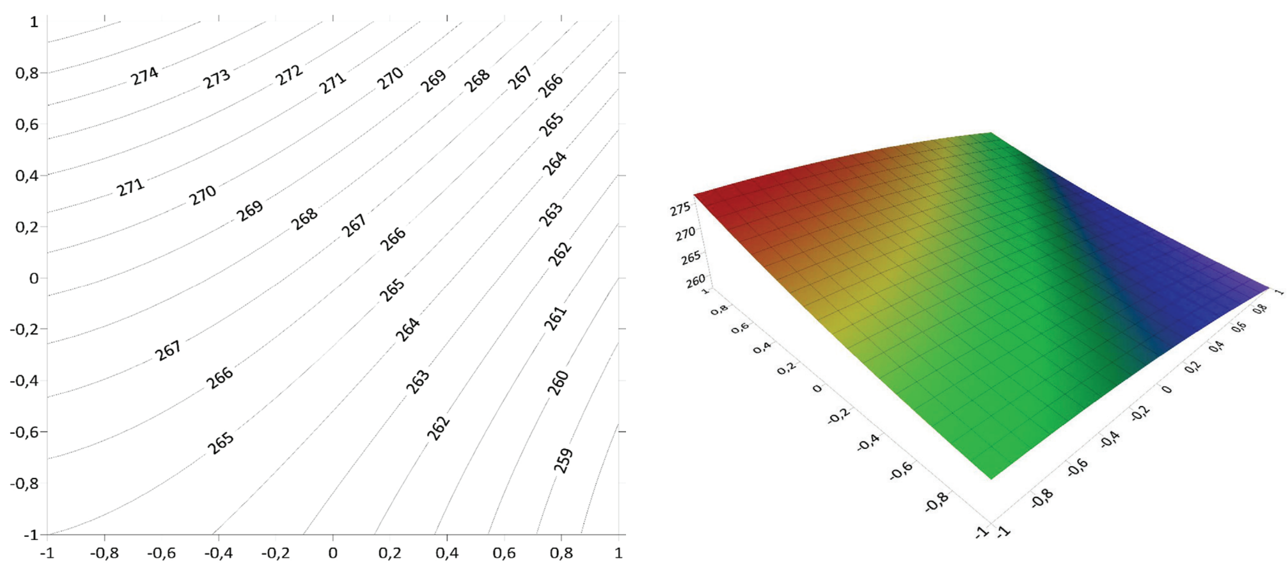

Fig. 9. Dependence of relaxation time on the amount of linseed flour and rice husk fiber: *a* – 2D surface; *b* – 3D surface

Relaxation time decreases to 258 s with an increase in the amount of flaxseed meal and increases to 274 s with an increase in the amount of dietary RHF (Fig. 9) (26).

$$z = 266.26 - 4.703x_1 + 5.1x_2 - -0.75x_1x_2 + 1.553x_1^2 + 1.446x_2^2. \quad (26)$$

The optimization revealed that the most suitable composition of bread would be 0.5 % rice husk fiber and 15 % linseed flour substitution. There are significant differences between the specific volume results of the optimized bread and the control sample.

Based on the results presented in the work, we can assume that the introduction of complex improvers into the dough has a positive effect on the rheological quality indicators of dough.

6. Discussion of the results of studying the possibilities of using linseed flour and rice husk fiber as an additional source of raw materials in the bakery industry

To obtain dough for producing bakery products from rye and wheat flour, new recipe optimization was used in this work, which makes it possible to use linseed flour and rice husk fiber as an additional source of raw materials.

The fundamental contrast between optimized bread recipes and existing analogues is the bakery products from rye and wheat flour with the addition of linseed flour and rice husk fiber as a functional and quality increasing additive.

In this study, the introduction of LF and RHF into the rye-wheat flour mixture led to significant changes in the dough properties.

The organoleptic assay results presented that as the LF addition increases from 15–20 %, organoleptic indicators such as elasticity, porosity structure, and crusts deteriorate when using RHF.

The results of rheological properties of combined dough presented that; the adhesion pressure of dough with the addition of LF (15 %) and RHF (0.5 %) improves the water absorption of the flour, hardens the glue and reduces the viscosity (Fig. 1). Besides, it also reduces the amount of free water in the dough.

The elasticity properties of dough with RHF also presented a higher percentage of elasticity and decreasing ductility (Table 2), while the inflation index of dough with LF increased, and with RHF reduced with increasing addition percentage.

The study of the surface responses of mathematical models (Tables 3–5) of farinographic and alveographic parameters, as well as the rheological properties of the dough depending on the amount of LF and dietary RHF, illustrated that the effect of RHF amount on the water absorption capacity of the dough is minimal. The relaxation time of the dough with RHF addition was lower compared to LF addition. However, this result determines that RHF gives strength and cohesive properties to the dough. At the same time, the degree of liquefaction of the dough with RHF also demonstrated minimal changes and the same scenario was with LF. The elongation of the dough in both droughts was with no significant changes.

The results display that the weight loss during the baking with RHF addition did not differ, as can be seen in Table 1. Those results are promising, considering that higher water accumulation is related to higher microbial degradation, and thus, lower shelf life. Several works report that fibers, beyond the fundamental role in water retention in bakery products, tend to decrease specific volume [8, 9].

Based on the study results, it is possible to recommend the introduction of 15 % LF and 0.5 % RHF into the rye and wheat flour mixture, which increased several rheological and quality properties of the product. Therefore, a new direction in the production of bakery products with LF and RHF can be developed.

The advantages of our developed recipe in comparison with the investigated ones are as follows:

– increased water holding capacity of products;

– the use of natural food additives, whose production, in turn, affects the waste-free production of rice hulls;

– expansion of the range of bakery products.

The dissimilarity among the studied recipe equivalents is that the bakery products based on the proposed recipe will have high rheological properties. Moreover, the products are produced from natural and functional additives, which could be beneficial for consumers.

Despite all these achievements, there are several issues related to recipe creation and dough production, such as limitations of studies conducted in this direction, the difficulty of obtaining fiber from rice hulls, as it is rarely used in the food industry in Republic of Kazakhstan.

For the further development of our research, we have planned a study aimed at investigating the microbiological and chemical indicators of the obtained products based on the developed formulation.

7. Conclusions

1. In this study, the main rheological characteristics of dough, produced with adding rice husk fiber and linseed flour were assessed. As a result, the addition of linseed flour and rice husk fiber did not affect the weight loss when baking. Thus, rice husk fiber with linseed flour is a promising ingredient for bakery, which can contribute to the desired food security.

2. The study of physicochemical properties of flour mixtures, produced with adding rice husk fiber and linseed flour presented that 0.5 % fiber is an optimal dosage.

3. Optimization of the recipe of bread for producing it from wheat linseed flour and rice husk fiber presented that the influence of the amount of RHF and LF on the water absorption capacity, the degree of dough liquefaction was minimal. At the same point, the elasticity, relaxation time increased with RHF addition. The elongation of the dough levels up with both additives. According to the study results, our recipe optimization model with the addition of linseed flour and rice husk fiber can be used in further research related to these fields, as studies in this direction are limited.

References

1. Baiysbayeva, M., Iskakova, G., Izembayeva, A., Batyrbayeva, N., Dikhanbayeva, F., Daribayeva, G. (2021). Development of technology for macaroni products based on flour of grain crops and ion-zoned water. Eastern-European Journal of Enterprise Technologies, 1 (11 (109)), 51–60. doi: https://doi.org/10.15587/1729-4061.2021.225001

2. Bayisbayeva, M. P., Izembayeva, A. K., Dautkanova, D. R., Baibatyrov, T. A. (2014). Ways and processing method of baking the Kazakh national flaky flatbread. Advances in Environmental Biology, 8 (16), 248–251.
3. Baiysbayeva, M. P., Zhiyenbayeva, S. T., Rustemova, A. Zh., Batyrbayeva, N. B., Izembayeva, A. K., Irmatova, Z. K. (2019). The effect of formulating supplements on the quality, nutritional value, safety and microbiological parameters of butter cookies. Eurasian Journal of Biosciences, 13 (2), 2015–2021. Available at: http://www.ejobios.org/download/the-effect-of-formulating-supplements-on-the-quality-nutritional-value-safety-and-microbiological-7368.pdf
4. Karavay, L. V., Levochkina, L. V. (2008). Gidrolizovannaya risovaya sheluha dlya proizvodstva muchnyh izdeliy. Pischevaya promyshlennost', 11, 53. Available at: https://cyberleninka.ru/article/n/gidrolizovannaya-risovaya-sheluha-dlya-proizvodstva-muchnyh-izdeliy
5. Vurasko, A. V., Driker, B. N., Zemnuhova, L. A., Galimova, A. R. (2007). Resursosberegayuschaya tehnologiya polucheniya cellyulozy pri kompleksnoy pererabotke solomy risa. Himiya rastitel'nogo syr'ya, 2, 21–25. Available at: https://cyberleninka.ru/article/n/resursosberegayuschaya-tehnologiya-polucheniya-tsellyulozy-pri-kompleksnoy-pererabotke-solomy-risa
6. Kalinina, I. V., Fatkullin, R. I., Naumenko, N. V. (2014). On the use of flax meal in bread and pastry production. Bulletin of the South Ural State University. Series "Food and Biotechnology", 2 (4), 50–56. Available at: https://vestnik.susu.ru/food/article/view/3038/2850
7. Arjmandi, R., Hassan, A., Majeed, K., Zakaria, Z. (2015). Rice Husk Filled Polymer Composites. International Journal of Polymer Science, 2015, 1–32. doi: https://doi.org/10.1155/2015/501471
8. Lim, S. L., Wu, T. Y., Sim, E. Y. S., Lim, P. N., Clarke, C. (2012). Biotransformation of rice husk into organic fertilizer through vermicomposting. Ecological Engineering, 41, 60–64. doi: https://doi.org/10.1016/j.ecoleng.2012.01.011
9. Bisht, N., Gope, P. C., Rani, N. (2020). Rice husk as a fibre in composites: A review. Journal of the Mechanical Behavior of Materials, 29 (1), 147–162. doi: https://doi.org/10.1515/jmbm-2020-0015
10. Liu, T., Duan, H., Mao, X., Yu, X. (2020). Influence of flaxseed flour as a partial replacement for wheat flour on the characteristics of Chinese steamed bread. RSC Advances, 10 (47), 28114–28120. doi: https://doi.org/10.1039/d0ra05742h
11. Koca, A. F., Anil, M. (2007). Effect of flaxseed and wheat flour blends on dough rheology and bread quality. Journal of the Science of Food and Agriculture, 87 (6), 1172–1175. doi: https://doi.org/10.1002/jsfa.2739
12. Martin, K. R. (2007). The chemistry of silica and its potential health benefits. The journal of nutrition, health & aging, 11 (2), 94–97.
13. Silicon dioxide. National Center for Biotechnology Information. Available at: https://pubchem.ncbi.nlm.nih.gov/compound/Silicon-dioxide#section=Information-Sources
14. Glushankova, I., Ketov, A., Krasnovskikh, M., Rudakova, L., Vaisman, I. (2018). Rice Hulls as a Renewable Complex Material Resource. Resources, 7 (2), 31. doi: https://doi.org/10.3390/resources7020031
15. Podolske, J., Cho, S. S., Gonzalez, R., Lee, A. W., Peterson, C. (2013). Rice Hull Fiber: Food Applications, Physiological Benefits, and Safety. Cereal Foods World, 58 (3), 127–131. doi: https://doi.org/10.1094/cfw-58-3-0127
16. Phonphuak, N., Chindaprasirt, P. (2015). Types of waste, properties, and durability of pore-forming waste-based fired masonry bricks. Eco-Efficient Masonry Bricks and Blocks, 103–127. doi: https://doi.org/10.1016/b978-1-78242-305-8.00006-1
17. St RK 1466–2005. Wheat flour and rye flour. General guidance for the design of baking tests. Available at: https://online.zakon.kz/Document/?doc_id=30192078#pos=1;-16
18. GOST 31807-2018. Bakery products from rye baking flour and rye-and-wheat baking flour. General specifications. Available at: https://allgosts.ru/67/060/gost_31807-2018.pdf
19. Pallarés, M. G., Léon, A. E., Rosell, C. M. (2007). Capítulo 1: Trigo. De tales harinas, tales panes. Granos, harinas y productos de panificación en Iberoamérica. Córdoba: Hugo Báez, 17–71. Available at: https://digital.csic.es/bitstream/10261/17118/1/libro%20panificacion-2007.pdf