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Enhancing the quality of wholemeal bread with chia, sesame, and rosehip: mathematical modelling and organoleptic analysis

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ABSTRACT

In this paper, the research was conducted using mathematical modelling methods to improve the quality of the product. This study aimed to determine the optimum composite mixture for producing whole wheat flour by adding sesame seeds, chia seeds, and crushed rosehip. Following the mathematical matrix, 20 different samples have been baked. The basic criteria were porosity and specific volume. The results were entered into Exel to draw up a graph. According to the graphic analysis, the most optimal mixture in terms of the dry matter mass in the dough was as follows in %: rosehip - 1.1%, chia seeds - 1.5%, and sesame - 2.2%. The organoleptic and physicochemical properties of the resulting samples were later analysed according to the recipes based on the selected composition of seeds. By swelling the protein shells of chia and sesame in a humid environment, amino acids in the flour combine into a chain to form a skeleton. At the same time, the ascorbic acid in the rosehip binds with the carbon atoms in the chain, strengthening the framework. As a result, large amounts of gases formed in whole grain flours are trapped in these frames, increasing the porosity of bread by 21.8%, increasing the volume of production by 29.5%, absorbing proteolytic enzymes under the influence of globulins in chia grain, slowing down amino acid degradation, reducing moisture content by 3%.

Keywords: whole-wheat flour, organoleptic and physicochemical properties, chia seeds, sesame rosehip.

INTRODUCTION

The strategy of creating conditions for producing a new generation of food products with specified quality characteristics, including specialised functional and enriched foods, includes research to develop their formulations and new technological methods **[1]**.

Most customers choose products made from the best-pureed varieties, as the texture of whole-grain cereal products is unappealing. Whole-meal bran flour reduces the quality of bread. However, lately, due to the focus on healthy eating, considerable attention is given not to the organoleptic properties but to the nutritional value of the bread. The assortment of bread products with various food additives used to increase their nutritional value has been increased **[2]**, **[3]**.

Whole-grain foods are well known for their nutritional benefits **[4]**. Whole-grain flour (WGF) is the flour. That has produced no peeled grain from the outer layers of the endosperm, germ, and membrane. Without them, the grain is a varietal product with high carbohydrate content, causing difficulty in the functioning of the gastrointestinal tract, obesity, and other diseases. The choice of food additive to be added in the production of floury culinary products is related to the chemical composition of whole-meal flour and the degree of its effect on the human body **[5]**, **[6]**.

To maintain good health, people should also consume foods high in bran and fiber daily, within the limits of the daily allowance. Baking with whole-meal bread products requires continuous improvement in quality and organoleptic properties to meet customers' demands. The addition of sesame seeds, chia seeds, and crushed rosehip seeds to the dough not only improves the nutritional value of the flour **[7]**, but it also significantly raises the quality of the baked bread.

Due to wholemeal flour's high carbon dioxide content, its gas-forming capacity was considerably high. However, the dough's lifting power was low because the quantity and quality of the gluten-forming particles were low. Therefore, vitamin C (300-4000 mg/100 g) in-ground rosehips improves the gelling ability.

Furthermore, the concentrations of high molecular weight thiols in the glutenins of flours from different wheat cultivars were determined. The values ranged from 5.6 to 8.2 micromol/kg of protein and showed a correlation between flour quality and SH concentration. In addition to AA and mixing of dough, the concentrations of the protein thiols in the glutenins isolated from the dough increased to a maximum when 100 mg of AA/kg of flour was added. Higher concentrations of AA led to a decrease in the SH concentration **[8]**. The protein in chia seeds and rosehips increases gelling **[9]**, **[10]**. The combination of additive combinations enhances the rheological properties of bread.

The model recipe and the technological parameter obtained a whole-meal wheat bread recipe as a control in the research. Mathematical modelling was used for this purpose. The organoleptic properties of the control sample of bread were pleasant. Nevertheless, it did not have a specific taste and aroma. Additionally, the peculiar porosity of the product was not enough. The composition of rosehip powder, chia seeds, and sesame seeds was created for whole-meal wheat flour. This composition was rich in all the vitamins and minerals that boost immunity and had high antioxidant properties **[11]**.

Plants play an essential role in human health maintenance. Sesame seeds are reservoirs of many nutritional components; the major bioactive components include minerals, vitamins, polyunsaturated fatty acids (PUFA), and unique natural antioxidants such as lignans (sesamin and sesamolin). Moreover, the seeds are an excellent source of the sulfur-containing amino acid methionine, which is rare in other plant proteins **[12]**.

Sesame has high health benefits but should not be consumed in large quantities. The problem is its high-calorie content potential for allergies and its ability to affect the human body. It is, therefore, best not to use sesame if you have poor blood clotting and kidney stones. The optimal amount of sesame per day is 1 or 2 tablespoons **[13]**, **[14]**.

Chia contains an appreciable amount of proteins and phytochemicals. The nutritional value of chia was the reason why it was used in prophylaxis of several non-infectious diseases such as obesity, hypertension, cardiovascular diseases (CVDs), cancer, and diabetes **[15]**, **[16]**. In the meantime, the consumption of chia seeds reduces weight and improves metabolism. However, the optimal daily intake is 25 g. Stabilisation of bread quality, the expansion of the range, and other factors lead to the correction and optimisation of the ratio of the recipe components. In addition, evaluation of the effectiveness of the baking enhancers used to influence the dough preparation process under the conditions of different properties of the main and supplementary raw materials.

Scientific hypothesis

The increased nutritional value of bread will depend on the beneficial properties of grain mixtures.

MATERIAL AND METHODOLOGY

Samples

The whole-wheat flour from winter wheat crops "Daulet" ("Research Institute of Agriculture and Crop Production" Almaty region, Republic of Kazakhstan) was used as a raw material. Additionally, sesame, chia seeds, and rosehip seeds were used as plant raw materials. Based on the calculation of daily consumption of sesame and chia seeds, they were used in an amount of 7% per 100 g of flour and, based on organoleptic characteristics of rosehip fruit, rosehip 3% per 100 g of flour, based on their optimal effect on the organism **[17]**, **[18]**, **[19]**. Various types of experimental bread were considered experiments, considering the use of these raw materials. Samples of whole-meal wheat flour bread were taken as a control.

Chemicals

All reagents were of analytical grade and were purchased from Laborfarm (Kazakhstan) and Sigma Aldrich (USA).

Animals, Plants and Biological Materials

The study used beef, horse meat, and pork for analysis.

Instruments

We used Drying cabinet SESH-3M (V-KIP, RF), Zhuravlev device (RosPromMash, RF), Bread volume meter series BVM-L370LC (TexVol, Sweden).

Laboratory Methods

The built-in surface diagram made it possible to select the best combination of a mixture of constituent components, which were difficult to find by other means except for known data.

The following indicators of whole grain bread were analysed: porosity according to GOST 5669-96 **[20]**, humidity according to GOST 21094-2022 **[21]**, acidity according to GOST 5670-96 **[22]**, volume and organoleptic indicators according to GOST 5667-65 **[23]**.

The standard method (electric dry cabinet) and the accelerated method were used to determine humidity. All laboratory studies used standard methods.

The acidity of bread was measured in degrees of acidity. The degree of acidity is the amount of 0.1 N sodium hydroxide or caustic soda solution (ml) required to neutralise the acids in 100 g of breadcrumbs.

Bread porosity is the ratio of the pore volume of the bread to the total volume of breadcrumbs. The porosity of bread was determined by the Zavyanov method using a Zhuravlev device.

Other bread's physical properties as volume, specific volume, height, width, length, density, weight, maximum diameter) were determined with a BVM-L370LC (TexVol Sweden), measured with a fully digital laser sensor and a "Bread Volume Meter" device.

Description of the Experiment

Sample preparation: Dissolve pressed baking sourdough in warm water at 40 °C. Separately sift whole grain flour, previously finely ground with a dispersion of 140 microns, and composite flour from rosehip, chia and sesame seeds in small portions. Pour half of the whole grain flour and composite flour into a bowl and mix. The kneaded batter is placed in a proofer at 33-35 °C. The autolysis (autolysis) begins; that is, gluten develops. This stage can last 45-60 minutes. After this, the second part of whole grain flour and salt are added to the dough. Kneads the dough on a dough mixer. It should turn out soft and not too clogged with flour. The total number of test samples is 20 pieces, according to Table 2, and for comparison, a control sample was baked (the recipe is listed in Table 3). Also, place it in the proofer for 20 minutes. During this time, gluten is activated. Afterwards, the dough will be completely ready for further work. Form the dough into round balls and shape it into bread. Rolling a dense ball with good surface tension is necessary without squeezing the air when moulding. Send the dough to the proofer for 2 hours, after which we bake in a preheated baking oven at a temperature of 180 degrees for 15-20 minutes, or you can start baking at a temperature of 240-260 degrees (10 minutes), then set it to 220 degrees (20 minutes) , and finally - bake for 30-50 minutes at 150 degrees.

Number of samples analyzed: we analysed twenty-one samples.

Number of repeated analyses: All measurements of instrument readings were performed two times.

Number of experiment replications: The number of repetitions of each experiment to determine one value was two times.

Design of the experiment: Optimal amounts of recipe components, including the different volumes of sesame, chia, and rosehip, were prepared by single-phase baking, including yeast-free baking.

A predictive analysis of the quality of whole-meal wheat flour bakery products based on raw vegetable materials was conducted. A mathematical analysis determined their compatible optimum.

Using a central composite rotatable uniform planning (CCRUP), rational dosages of the components of a biologically active composition were calculated in the preparation of dough, and the effect of these dosages on the quality indicators of the finished bread was studied.

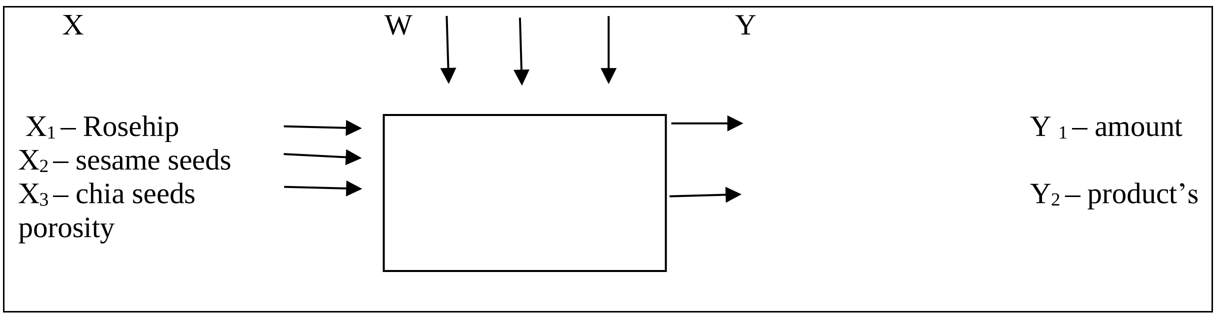


Figure 1 The model for determining the effect of the number of additives on bread quality.

The operating mechanism is complex and unknown, and a "black box" phrase has been used to illustrate the process in question (Figure 1). W - "Input" is entering information about the recipe size of the functional bread in the accidental exposure process. "Output" controls the results described by the optimisation criterion.

The output's Y functionally depends on the state X:Y = f (X) state. However, the dependence of the input data is unknown **[24]**.

The main factors were X1—rosehip powder %, X2—sesame seeds %, and X3—chia seeds. The amount of functional raw materials was chosen as the criteria for assessing the influence: product volume—Y1%, product porosity—Y2%. The regression equation was obtained from the results of mathematical processing with CCRUP.

Methods of search optimisation, planning of multifactorial experiments and statistical processing of experimental data were used to solve the tasks. For this purpose, optimisation parameters and factors that affect the technical indicators of the quality and safety of bread (the most important ones) were selected. The experimental research plan was determined, and a mathematical model was developed based on the obtained experimental data. The influence of controlled factors on the parameters of the process "output" in the stationary zone of the factor space was researched **[24]**, **[25]**.

Table 1 gives the influence parameters of the new functional bread additives on the finished bread's technological parameters and selected conversion levels.

Table 1 Research on the parameters for the effect of recipe doses on bread quality parameters and their degree of variability in the laboratory.

Controllable parameters: coded (natural)	**Coded levels**			**Variation interval**
	-1	**0**	**1**	
X_1 – rosehip, g	2	3	4	1
X_2 – sesame, g	6	7	8	1
X_3 – chia seeds, g	6	7	8	1

Table 2 Statistical description of the effect on the quality of the bread. According to the quantity of the recipe of raw materials in its composition.

Experiment №	**Coding factor indicators**			**Natural factor indicators**			**Evaluation criteria indicators**	
	X_1	**X_2**	**X_3**	**X_1, %**	**X_2, %**	**X_3, %**	**Y_1, cm^3/100g**	**Y_2, cm^3/100 g**
1	1	1	1	4	8	8	247	54.7
2	1	1	-1	4	8	6	247	55.1
3	1	-1	1	4	6	8	234	56.2
4	1	-1	-1	4	6	6	239	53.6
5	-1	1	1	2	8	8	230	52.8
6	-1	1	-1	2	8	6	232	52.2
7	-1	-1	1	2	6	8	227	51.1
8	-1	-1	-1	2	6	6	225	51.2
9	-1.68	0	0	1.32	7	7	227	54.8
10	1.68	0	0	4.68	7	7	244	61.5
11	0	-1.68	0	3	5.32	7	229	51.2
12	0	1.68	0	3	8.68	7	243	51.3
13	0	0	-1.68	3	7	5.32	238	52.2
14	0	0	1.68	3	7	8.68	240	67.1
15	0	0	0	3	7	7	250	67.3
16	0	0	0	3	7	7	250	67.3
17	0	0	0	3	7	7	250	67.3
18	0	0	0	3	7	7	250	67.3
19	0	0	0	3	7	7	250	67.3
20	0	0	0	3	7	7	250	67.3

A mathematical model of the process was created. That allowed us to calculate the parameters of the internally selected interval transition. Table 2 shows the dependence of the "Output" parameter on the "Input" parameters.

The method had required to draw of two-dimensional sections $Y=f(X_1, X_2)$, $Y=f(X_1, X_3)$ and $Y=f(X_2, X_3)$ at $X_3=0$, $X_2=0$ and $X_1=0$, accordingly.

Searching for multivariate dependencies was conducted under a priori uncertainty about the limited experimental data and type of regression functions for bread quality indicators.

Statistical Analysis

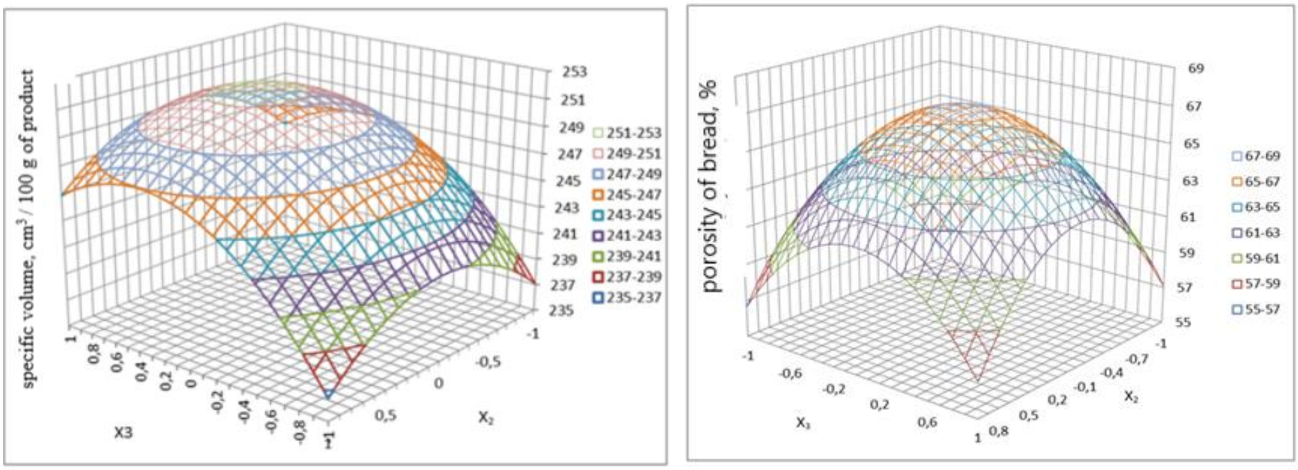
The data obtained during the experiments were processed using the mathematical method of variation statistics using the Statistika 10.0 developer StatSoft, USA. The data were also analysed using MS Excel for Windows 10 Pro, 2010. The data collected during the study were subjected to independent testing, and questionnaires were conducted to assess the organoleptic characteristics of control and test samples. The analysis used absolute and relative statistical indicators and tabular and graphical methods to present the results. Values were estimated using mean and standard deviations. The experiment was conducted with three repetitions. Considering the presence of significant coefficients of pair interaction (i.e., the nonlinearity of the objective function and quality assessment criteria) in numerous equations, the search for optimal processing modes was performed using nonlinear programming methods. This Newton method is part of the ‘Find a solution’ procedure in the MS Office Excel package.

RESULTS AND DISCUSSION

Consumers in many developed countries have recently started to choose bakery products made without preservatives, sprouted grains, and whole-wheat flour **[26]**. This shows that the focus is not on the bread's physical and organoleptic qualities but on its nutritional value. Bread products made from whole wheat flour have low organoleptic values **[27]**. They contain bran and germ in addition to endosperm **[28]**. Whole grain products contain more fiber, so you feel full faster **[29]**. The fiber content of whole grain spelt flour is slightly lower than wheat flour, but they have similar amounts of soluble fiber **[30]**. Whole grain spelt flour has a moderate effect on blood sugar levels when ranked by glycemic index **[31]**

Whole-wheat flour is chemically rich in minerals and vitamins, but the gluten's low amino-acid content deteriorates the bread's rheological properties **[32]**. Research was carried out to prevent such deficiencies with raw vegetable materials and determine the necessary raw materials per 100 g of flour.

Figure 2 shows a graph of the porosity and volume of 20 bakery samples based on the matrix sample obtained from the research.



a) b)

Figure 2 Graph of whole-meal wheat bread with vegetable raw materials.
Note: a) Effect of the ratio of sesame, chia and rosehip on the specific volume of the bread; b) Effect of the ratio of sesame, chia and rosehip on the porosity of the bread.

Graphical analysis and mathematical calculations showed that the optimal wheat flour in the dough in terms of % weight is rosehip powder - 2.86 %, sesame - 6.9 %, chia - 7.13 %.

Conducted studies have shown the effectiveness of using rosehip, sesame, chia and sesame raw materials as an additive to whole grain flour in the preparation of bread **[33]**. Today, calcium deficiency causes many negative consequences for patients **[34]**. Rose hips, sesame and chia seeds were selected as additives for the production of bread products enriched with calcium and highly digestible by the body in order to solve such urgent problems **[35]**. Sesame and chia seeds are one of the highest among food production raw materials in terms of calcium content **[36]**. In addition to calcium, the selected grains contain a large amount of minerals and vitamins, which play an important role in the body.

The dough was prepared according to a new recipe based on the positive effect (organic and physicochemical properties) of chia and sesame seeds on whole-meal bread (Table 3).

Table 3 Recipe for wholemeal bread dough.

Name of the raw material	Dry matter content, %	Count of 100 g raw materials added to the flour, %
Whole-meal grain	83.2	100
Salt	96.5	1.5
Pressed baking yeast	25.00	2.5
Rosehip	-	2.86
Chia seeds	-	7.13
Sesame	-	6.9
Water	49% calculated based on humidity	
Total	-	104

The organoleptic properties of wholemeal wheat bread with the addition of rosehip, chia, and sesame were studied according to a recipe based on graphic analysis. The research data are shown below in Figure 3.

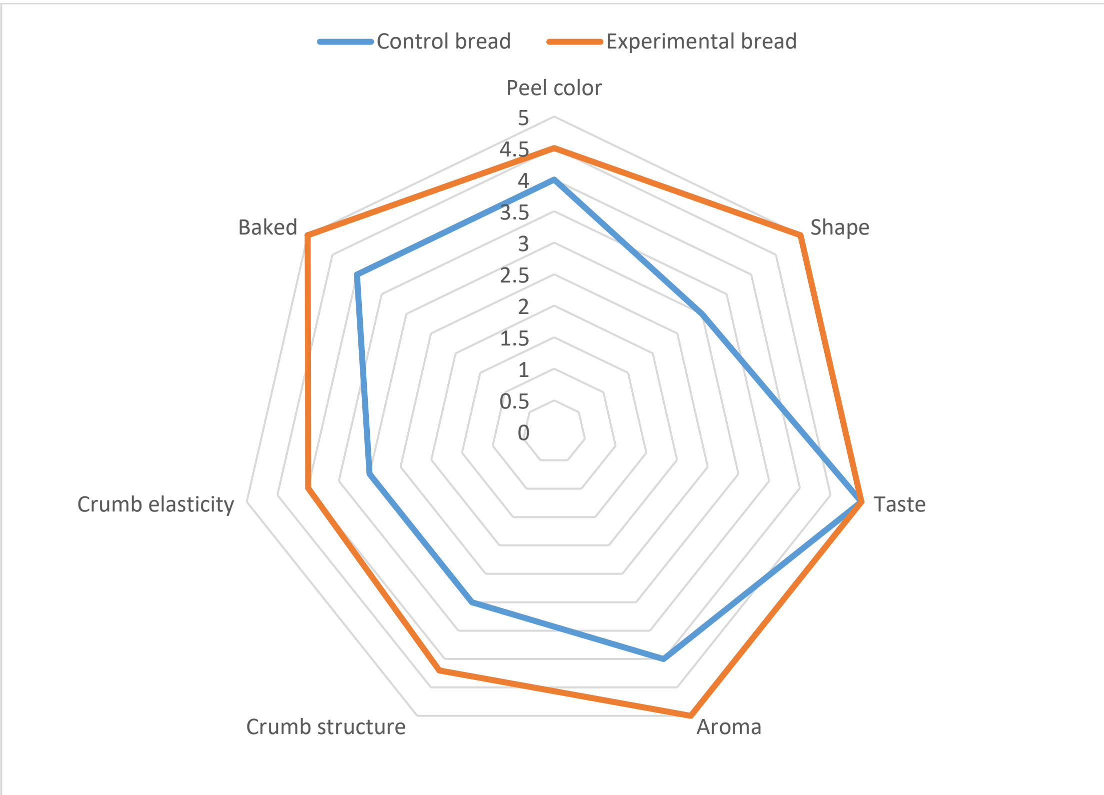


Figure 3 The effect of raw vegetable materials on wholemeal wheat bread's organoleptic characteristics.

According to organoleptic properties, the control sample of whole-meal wheat bread had an inconsistent shape, slightly convex, an outer crust, and a rough and lumpy surface, unbroken and hollow. The colour was brownish-black with light spots. Baked, slightly moist to the touch, elastic, and dense, it did not return to its former shape when lightly pressed with the finger, conformed to the product type, was sweeter, and had no extraneous smell.

The experimental bread's organoleptic properties were much better than the control sample's. The surface was rough but without cracks or concavities. The bread was fully baked, slightly moist, elastic, and recovered when lightly pressed with the finger. It was traceable with a light brown colour, pleasant to the taste, and aromatic.

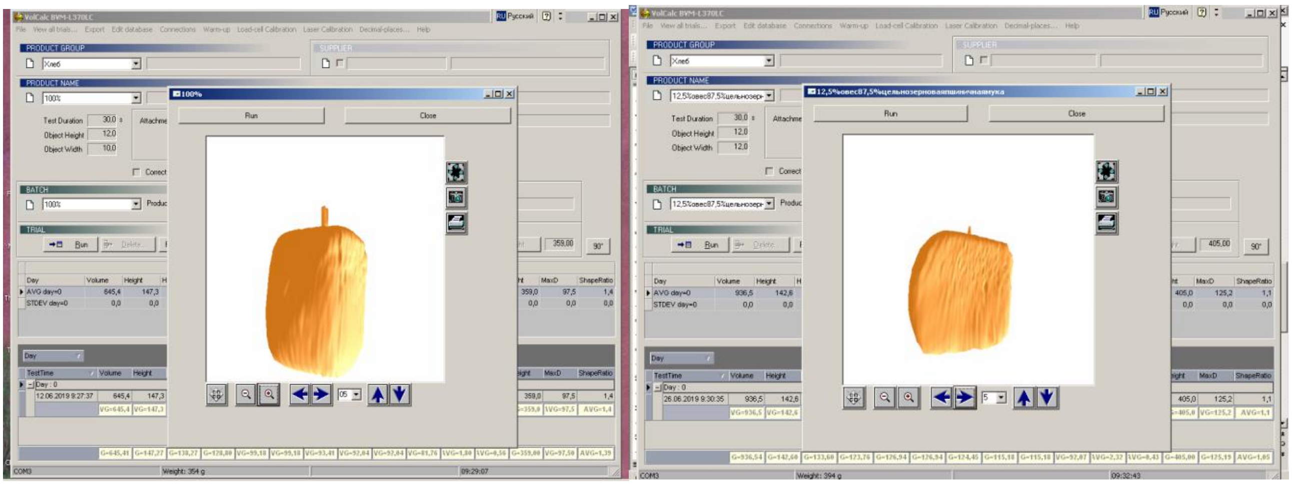
Research data for the physicochemical properties of the bread samples are presented in Table 4.

Table 4 Physicochemical properties of bread samples.

Name of the parameter	Control sample of bread	Experimental bread
Moisture content of crumb, %	48	46.5
Acidity, deg	6.5	6.4
Porosity, %	55	67
Size, cm	645	916.5

The physical and chemical properties of the products compared with the control sample in the experimental bread product were as follows: Moisture decreased by 3%; there was no significant change in acidity; porosity increased by 21.8%; and volume increased by 29.5%.

Research on different physical properties (volume, specific volume, height, width, length, density, mass, and the maximum diameter of the product) of whole-meal bread measured with the device "BVM—L370LC Bread volume meter." The results are shown in Figure 4.



A) B)

Figure 4 3D view of whole-meal bread created with the "BVM - L370LC Bread Volume Meter".
Note: A) Whole-meal wheat bread; B) Whole-meal wheat bread with the addition of vegetable raw materials.

The physical parameters of the prototype compared to the control were as follows: specific volume increased by 28 %, length 9.3 %, width 7.1 %, height 15 %, maximum diameter 4.6 %, and density 7.5 %.

In the production of wheat bread, the possibilities of using improvers based on the principle of different effects are based on the improvement of their functional properties, which indicates the interaction of the main components included in their composition with the structural components of the dough made from whole grain flour **[37]**. The functional properties of improvers affect the formation of bread properties, directly related to the intensity and microbiological purity of the processes occurring during dough fermentation **[38]**.

In recent years, the frequency of spoilage of wheat bread by thermophilic microorganisms is increasing, because in the current situation, according to the demand of the consumer, in the process of production of dietary and healthy products, the addition of bran and seeds as raw materials and the production of products without preservatives are increasing **[39]**. Traces of microbiological contamination are observed during the preparation of high value whole wheat bread **[40]**, because the endosperm of the grain in whole wheat flour is not separated. Therefore, there is a risk of contamination with spore-forming bacteria and microscopic fungi that produce toxic substances. It is very effective to use white cabbage containing lysozyme as an inhibitor of disease-causing pathogens in bread **[41]**.

Calculating rational dosages of the components of the composition of plant materials during the dough preparation and studying the effect of these dosages on the quality indicators of the finished bread was carried out using a central composite rotatable uniform planning **[42]**. Mathematical modelling was the convenient and accurate method for determining the rate of different vegetable raw materials according to defined criteria **[43]**.

A marked improvement in the bread products was observed during the physicochemical analysis of the recipe developed based on the graphical analysis **[44]**.

If a higher grade of flour had been used, the more the moisture content of the bread decreases, the higher the percentage of dry matter would be **[45]**. Due to the high fibre and ash content of wholemeal bread, its moisture content was high, and the moisture content of the bread product with the addition of vegetable raw materials decreased by 3 % **[46]**. Due to the colloidal structure of the dough, the moist phase was reduced because the presence of globulins in chia and sesame seeds inhibits the activity of proteolytic enzymes, which have autolytic properties **[47]**. The breakdown of amino acids limits their transfer to the wet phase **[48]**.

Due to the high content of mono- and disaccharides in the pores **[49]** and fibres of the flour, the acidity of wholemeal bread is 2.5 times higher than that of higher-grade flour because fermentation is more intense even in the first phase **[50]**.

Furthermore, no matter how intense the carbon dioxide was, carbon dioxide retention was low due to the weakness of the amino acids that made up gluten **[51]**.

Bread made from low-grade flour is sour and has low porosity and specific gravity. The bottom of the product was very dense. The appearance of the crust deteriorates to become brown **[52]**.

Adding vegetable raw materials did not significantly change the bread products compared to the control sample **[53]**. The bread's sourness was characterised by its defined acceptability and use of raw materials **[54]**.

The porosity of the control sample increased by 21.8%, and the sample with the addition of raw vegetable materials had a higher porosity. Bread porosity shows the percentage of the total number of pores. The porosity of the bread depends on its absorbency. The uniformly thin-walled porosity of well-loosened bread was easily rinsed out and absorbed by the digestive juices, so it was fully absorbed.

Based on scientific research, while porosity and volume were reduced, chia and sesame seeds were added to the dough unmilled. If they had been added in milled form, it would have increased acidity w. Chinese scientist Lin observed an increase in the specific gravity of bread when a protein shell was added. So, in this research, chia seeds and sesame were added as grains. Based on these data, chia seeds and sesame were added without grinding. When exposed to a moist environment, the outer protein shell moistened, forming a gelatinous layer 12 times larger than chia. The protein shell of sesame in a moist environment also binds well to flour proteins **[55]**.

The addition of rosehip, as a plant raw material, was in the form of a powder, as only a large amount of ascorbic acid included in its composition was required, and its amino acid content was low **[56]**.

The daily allowance of sesame and chia seeds should not exceed two teaspoons. The research added 3% rosehip, 7% chia, and sesame to the dough. Considering the above, only 7% of chia and sesame seeds had been added to the dough. There is a reason for adding 3% rosehip fruit: if this amount has been exceeded, the acidity of the bread will increase, and the whole-meal bread will turn brown due to its high sugar content, which affects its colour.

We believe that vegetable raw materials depend on colloidal and biochemical processes, which occur in close contact with each other inside the dough. The reason for this is the high gluten content of the vegetable raw material, i.e. the very high gel-forming protein layers in the outer layer of sesame and chia seeds, in which the amino acid chains bind with the amino acid chains of the flour, resulting in porosity. Rosehip powder rich in vitamin C was used to enhance it. Because rosehip powder contains 650 mg of vitamin C in 100 grams, it forms a strong frame, binding carbon atoms in the amino acid chain's outer and inner side layers by disulfide bonds. It was determined that the organoleptic and physicochemical properties of the product were improved.

CONCLUSION

Due to the weak bond in the proteins that make up the gluten in wholemeal flour and its high proteolytic enzyme content, the moisture content of the product increases. Generally, the bread quality is deteriorating due to the breakdown of amino acids and their transfer from the liquid phase to the solid phase. Therefore, producers of wholemeal bread need to introduce new ways of improving product quality. The vegetable raw materials were added to the whole-meal flour during this research. The porosity and volume values were considered the highest, following the two main criteria presented to the whole-wheat flour. Suppose the protein shells of chia seeds and sesame swell in a humid environment. In that case, they combine with the amino acid chains in the flour to form a framework in the rosehip fruit that binds to the carbon atoms in the side groups of the amino acid chain. The results were obtained from the graphical analysis of the raw materials and reported using specific mathematical modelling. When sesame seeds, chia seeds, and rosehip powder were added to the dough, the organoleptic and physicochemical properties of whole-meal flour were determined to be significantly enhanced.

The bread's porosity increased by 21.8%, reaching 67% in the experimental samples compared to 55% in the control sample. The bread volume increased by 29.5%, from 645 cm^3 in the control sample to 916.5 cm^3 in the experimental samples. The optimal mixture for wholemeal bread dough was 2.86% rosehip powder, 7.13% chia seeds, and 6.9% sesame seeds, which showed the best performance regarding specific volume and porosity. The moisture content of the experimental bread decreased by 3%, from 48% in the control to 46.5% in the experimental samples, improving the bread's texture and shelf life. The specific volume of the bread increased by 28%. Other physical dimensions, such as length, width, and height, improved by 9.3%, 7.1%, and 15%, respectively. These results demonstrate the positive effects of adding chia, sesame, and rosehip to wholemeal bread, significantly improving its quality, structure, and nutritional value.

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