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OPTIMIZATION OF TECHNICAL AND TECHNOLOGICAL INDICATORS OF KEFIR ADDED WITH DEFATTED SESAME FLOUR AND RICE BRAN

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Defatted sesame cake and rice bran are all by-products of agricultural processing. The aim of the study was to optimize the recipes of kefir added with defatted sesame flour and rice bran. The previous study has yielded some results including dietary fiber content, pH values and sensory evaluation values of kefir samples added with 0, 2 %, 4 %, 6 %, 8 % DSC and 0, 0.1 %, 0.3 %, 0.5 %, 0.7 % RB, but made no optimization of kefir products. Based on these data, formulation optimization was done using a mathematical model. Two central composite designs for the two-factor analysis (x1x2 and x1x3, respectively) and one three-factor design (x1x2x3) were drawn up to predict the optimal formulation and reduce the number of future experiments. After studying the results of mathematical modeling, the optimal prescription composition corresponds to the 2 % DSC or 0.1 % rice bran content or 2 % DSC and 0.4 % RB content in the recipe. Through mathematical optimization, products with high dietary fiber content, suitable acidity and excellent sensory quality can be obtained. The products meet the current social demand for healthy food and have very good research value. In practical use, three kinds of kefir can be developed:

1. DSC should be ground separately before used, 2 % DSC was introduced into cow milk (m/v), fermented at 28 °C for 22 h until pH reached 4.7, then stored at 4 °C.

2. RB should be ground before used, 0.4 % RB was introduced into cow milk (m/v), fermented at 28 °C for 22 h until pH reached 4.7, then stored at 4 °C.

3. DSC and RB should be ground before used, 2 % DSC and 0.4 % RB were introduced into cow milk (m/v), fermented at 28 °C for 22 h until pH reached 4.7, then stored at 4 °C

Keywords: kefir optimization, defatted sesame flour, rice bran, dietary fiber, pH

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1. Introduction

In modern society, more and more people are suffering from affluenza [1, 2], hyperglycemia, hypertension, hyperlipidemia and other diseases are becoming more common, which is undoubtedly related to high energy intake. Many studies are devoted to developing foods that would reduce energy intake. For example, the work [3] investigated the effect of Agaricus bisporus mushrooms alone or in combination with soybean oil or water as fat substitutes on the properties of chicken batter for developing healthy chicken products. There is an urgent need to develop kinds of food that can satisfy the stomach without causing excessive energy intake.

Dietary fiber is known as the “seventh nutrient”. In agricultural production, dietary fiber is usually discarded in the form of waste, or used as animal feed, such as defatted sesame cake, rice bran, etc. In fact, dietary fiber has good health value, can make people feel full, thus reducing the intake of energy. Dietary fiber can reduce the incidence of hyperglycemia, hypertension, hyperlipidemia and decrease the probability of colon cancer. Dietary fiber can meet the health needs of modern society, so it is necessary to develop dietary fiber related products. At the same time, the full exploitation and utilization of dietary fiber also improve the additional value of dietary fiber, which contributes to the full utilization of resources.

According to the theory of adequate nutrition, food nutrients alone are not the main indicators of food value. The true value of food lies in its ability to autolysis in the human stomach and at the same time be food for those microorganisms that inhabit the intestines and supply our body with the necessary substances. This property is inherent in dietary fiber (ballast substances) that is not part of fermented milk drinks. Since there are no enzymes in the gastrointestinal tract that break down fibers, the latter enter the large intestine unchanged. Intestinal bacteria have enzymes that can metabolize fibers. Due to fermentation, they obtain energy for reproduction and construction of new cells.

Thus, by enriching with dietary fiber in an amount consistent with the recommended daily consumption need, a fermented milk drink can be created that will be as balanced as possible in the content of all vital nutrients, including ballast substances.

Kefir is a fermented milk drink popular in Eastern European countries, which is good for health. The previous study [4] found that the consumption of kefir, which is similar to yogurt, can improve lactose digestion and tolerance in healthy adults clinically diagnosed with lactose intolerance. Kefir exerts bactericidal effects on Gram-negative and Gram-positive bacteria. Evaluation of antibiotic activity in filtrates of traditional kefir was carried out. Some animal studies have demonstrated the hypocholesterolaemic effect of kefir. Regular consumption of probiotics improves blood sugar levels. Kefir has a higher antioxidant effect than vitamin E.

Plant raw materials were introduced into milk to obtain kefir in many previous studies, but this can lead to a serious decline in the sensory quality of the product, which is an urgent problem to be solved.

2. Literature review and problem statement

Kefir is a traditional fermented beverage made by inoculating raw milk with kefir grains. It originated in the Caucasus mountains and spread through the Balkans and Eastern Europe for centuries. Kefir grains are small, gelatinous, yellowish, irregularly shaped masses with large amounts of lactic acid bacteria, acetic acid bacteria, and yeast polysaccharides [5].

Kefir can be combined with a variety of plant materials. So many scientists devoted themselves to producing healthier kefir products by adding plant materials to milk. Studies showed that the introduction of plant materials resulted in a decrease in kefir viscosity, whey separation and sensory degradation. These negative factors in turn lead to the introduction of flavors and stabilizers, which can cause a decrease in the population of probiotics, thereby reducing the biological value of kefir [6, 7]. Therefore, it is imperative to introduce plant raw materials that do not negatively affect the stability of kefir.

The introduction of dietary fiber into kefir has been a significant trend in recent years. Dietary fiber is beneficial to health and plays a role in preventing colon cancer, constipation, diabetes and losing weight [8, 9]. Studies have shown that the introduction of dietary fiber has beneficial effects on kefir, including increasing the number of probiotics, improving rheology, etc. [10]. It was also found that the introduction of dietary fiber can reduce the acidity of fermented milk drinks, thus enhancing their acceptability [11, 12].

There were a few studies on the introduction of rice bran and defatted sesame cake into kefir, which is a very meaningful topic. In [13], defatted sesame cake was introduced into kefir. Defatted sesame cake is rich in dietary fiber, and it was found to significantly improve the viscosity, number of probiotics and antioxidant activity of kefir, which are excellent qualities of kefir products. The paper [14] presented the influence of introducing fiber-rich bran on the quality of kefir. The results showed that adding RB to kefir can significantly increase pH and decrease acidity. More RB led to higher apparent viscosity. The introduction of RB can significantly improve the population of lactobacilli. However, optimization analyses of product recipes were not carried out in both papers. A way to overcome these difficulties is to optimize the product formulation by mathematical methods. Thus, three new kefir products with high viscosity, a large population of probiotics, strong antioxidant activity and a large amount of dietary fiber can be obtained. These three products would meet the public's demand for healthy products and be beneficial to human health. All this allows us to assert that it is expedient to conduct a study on the optimization of product formulation by mathematical methods.

3. The aim and objectives of the study

The aim of the study was to optimize the formula of samples to develop three kinds of kefir, which would be rich in dietary fiber, beneficial to human health and popular with consumers. An orthogonal central composite design was used to conduct statistical analysis.

To achieve the aim, the following objectives were set:

– to carry out a two-factor analysis to predict the optimal formulation of kefir samples added with RB and kefir samples added with DSC separately;

– to carry out a three-factor analysis to predict the optimal formulation of kefir samples added with RB and DSC.

4. Materials and methods

The objects of the study were three kinds of kefir: kefir added with RB, kefir added with DSC and kefir added with both RB and DSC. The main hypothesis of the study was to obtain three kinds of optimized kefir by means of central composite design. These three kinds of kefir were rich in dietary fiber and have better health value. Assumptions made in the work: dietary fiber content was chosen to be one of the most important parameters to conduct optimization for its health value, sensory evaluation is also one of the most important parameters, because it presented the acceptance of products by consumers, pH value is one of the most important parameters of kefir. So dietary fiber, sensory evaluation and pH value were chosen as indicators to conduct optimization. The nonlinear model was used for fitting, and the curve was obtained according to the horizontal response values of each factor, then the three-dimensional effect diagram was drawn by means of Statistics 12.5 software and the optimal formula was derived.

Based on the obtained data, including dietary fiber content, pH values and sensory evaluation values of kefir samples added with 0, 2 %, 4 %, 6 %, 8 % DSC and samples added with 0, 0.1 %, 0.3 %, 0.5 %, 0.7 % RB, formulation optimization was done using a mathematical model. Two central composite designs for the two-factor analysis (x_1x_2 and x_1x_3, respectively) and one three-factor design ($x_1x_2x_3$) were drawn up to predict the optimal formulation and reduce the number of future experiments. For the two-factor analysis of the recipe, 9 experiments were carried out, and for the three-factor – 15. A 3D model was built using the Statistica software package for statistical analysis.

The central composite design was used to study the interaction of process variables. There are 3 variables: the content of cow milk in the recipe (x_1), the content of DSC in the recipe (x_2) and the content of RB in the recipe (x_3). Each variable has 3 different encoded levels: from low (–1) to medium (0) and high (+1), as well as star points ($-\alpha$ and $+\alpha$). For the two-factor analysis, α=1, for the three-factor α=1.215. Two central composite designs for the two-factor analysis (x_1x_2 and x_1x_3, respectively) and one three-factor design ($x_1x_2x_3$) were drawn up to predict the optimal formulation and reduce the number of future experiments.

Mathematical modeling was used to determine the coefficients of the approximating polynomial. The two-factor analysis polynomial for the recipe added with DSC, taking into account the transformation and opening the brackets, can be brought to the usual form:

$$Y_{sesame} = b_0 + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1^2 + b_{11}x_1^2. \quad (1)$$

The two-factor analysis polynomial for the recipe added with RB is as follows:

$$Y_{rice} = b_0 + b_1x_1 + b_3x_3 + b_{13}x_1x_3 + b_{11}x_1^2 + b_{33}x_3^2. \quad (2)$$

The three-factor analysis polynomial for the recipe with the addition of DSC and RB, taking into account the transformation and opening the brackets, can be reduced to the usual form:

$$Y_{sesame+rice} = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + $$
$$+ b_{23}x_2x_3 + b_{123}x_1x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2. \quad (3)$$

In central composite designs, each factor is fixed at 5 levels, taking into account the maximum and minimum amount of ingredients while leaving the basic product properties unchanged, which is given in Tables 1–3 for three central composite designs under the objectives of mathematical modeling.

Table 1

Prescription components and factor levels for the two-factor analysis of the recipe with DSC

Optimization factors		Factor levels and natural values, g				
		α (–1)	–1	0	1	α(1)
x_1	Cow milk	98	98	98.5	99	99
x_2	DSC	2	2	5	8	8

In Table 1, α(–1) was the minimum value of the content of cow milk (x_1) and DSC (x_2), namely 98 g and 2 g, respectively; α(1) was the maximum value of the content of cow milk (x_1) and DSC (x_2), namely 99 g and 8 g, respectively.

Table 2

Prescription components and factor levels for the two-factor analysis of the recipe with RB

Optimization factors		Factor levels and natural values, g				
		α(–1)	–1	0	1	α(1)
x_1	Cow milk	99.9	99.9	99.94	99.98	99.98
x_3	RB	0.1	0.1	0.4	0.7	0.7

In Table 2, α(–1) was the minimum value of the content of cow milk (x_1) and RB (x_3), namely 99.9 g and 0.1 g, respectively; α(1) was the maximum value of the content of cow milk (x_1) and RB (x_3), namely 99.98 g and 0.7 g, respectively.

In Table 3, α(–1.215) was the minimum value of the content of cow milk (x_1), DSC (x_2) and RB (x_3), namely 97.9 g, 2.0 g and 0.1 g, respectively; α(1.215) was the maximum value of the content of cow milk (x_1), DSC (x_2) and RB (x_3), namely 98.1 g, 8.0 g and 0.7 g, respectively.

Table 3

Prescription components and factor levels for the three-factor analysis of the formulation with DSC and RB

Optimization factors		Factor levels and natural values, g				
		α (–1.215)	–1	0	1	α (1.215)
x_1	Cow milk	97.9	97.918	98.0	98.082	98.1
x_2	DSC	2.0	2.531	5.0	7.469	8.0
x_3	RB	0.1	0.153	0.4	0.647	0.7

For the two-factor analysis of the recipe, 9 experiments were carried out, and for the three-factor – 15. In central composite designs, there is a constant value of *d*, depending on the number of factors, for the two-factor analysis d=0.667, for the three-factor d=0.73. Experimental results for the most significant reviews of kefir added with DSC and RB are presented by physicochemical and organoleptic analysis, including fiber content (y_1), pH (y_2) and organoleptic characteristics (y_3). Fiber contents are given in Tables 4–7.

Organoleptic indices are given in Fig. 1, 2.

All of the above, including fiber content, pH and sensory properties, were the basic data used for the mathematical analysis.

Table 4

Fiber content in different kefirs added with DSC (n=3, ±SD)

Introduction ratio	0	2 %	4 %	6 %	8 %
content ((g/100 g))	0.02±0.00	0.68±0.11	1.14±0.00	2.12±0.48	4.52±0.44

Note: Values expressed as mean ± standard deviation of duplicate samples

Table 5

Fiber content in different kefirs added with RB (n=3, ±SD)

Introduction ratio	0	0.1 %	0.3 %	0.5 %	0.7 %
content ((g/100 g))	0.000±0.000	0.029±0.002	0.086±0.02	0.127±0.02	0.100±0.02

Note: Values expressed as mean ± standard deviation of duplicate samples

Table 6

pH of kefir added with DSC (n=3, ±SD)

Introduction ratio (%)	0	2	4	6	8
pH	$5.01±0.02^{a, X}$	$4.38±0.03^{b, X}$	$4.25±0.04^{c, X}$	$4.11±0.03^{d, X}$	$4.14±0.05^{d, X}$

Table 7

pH of kefir samples added with RB

Introduction ratio (%)	0	0.1	0.3	0.5	0.7
pH	$5.06±0.02^{a, A}$	$4.92±0.00^{b, A}$	$4.74±0.01^{c, A}$	$4.71±0.00^{d, A}$	$4.57±0.00^{e, A}$

Note: $^{a, b, c, d, e}$ – values in the same column with different superscripts significantly differ (P<0.05); $^{A, B, C, D, E}$ – values in the same row with different superscripts among fermented milk drink samples significantly differ (P<0.05); SD – standard deviation

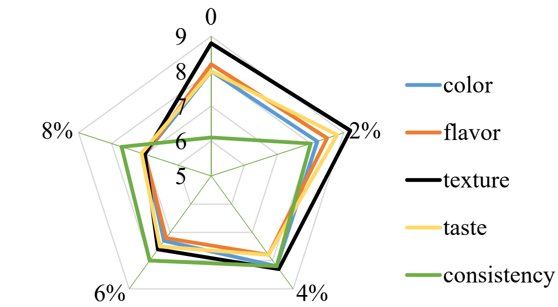

Fig. 1. Sensory characteristics of kefir added with defatted sesame cake

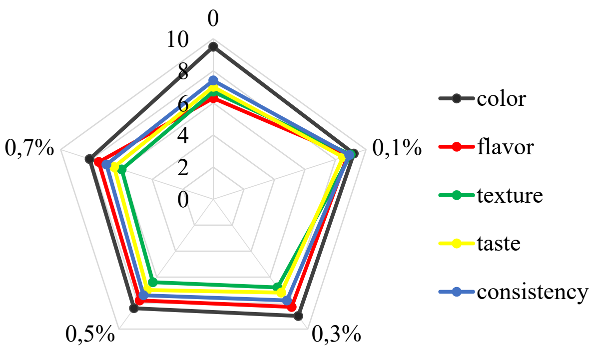

Fig. 2. Sensory characteristics of kefir added with rice bran

5. Results of formulation optimization using two-factor analysis and three-factor analysis

5. 1. Results of the two-factor analysis of defatted sesame cake and rice bran

5. 1 .1. Results of the two-factor analysis of defatted sesame cake

The experimental design and measurement results for the two-factor analysis of the recipe added with DSC are given in Tables 8, 9, respectively.

Table 8

Experimental design matrix for the two-factor analysis of the recipe added with DSC

No.	x_0	x_1	x_2	$x_1^2-0.667$	$x_2^2-0.667$	x_1x_2
1	1	1	1	0.33	0.33	1
2	1	–1	1	0.33	0.33	–1
3	1	1	–1	0.33	0.33	–1
4	1	–1	–1	0.33	0.33	1
5	1	–1	0	0.33	–0.67	0
6	1	1	0	0.33	–0.67	0
7	1	0	–1	–0.67	0.33	0
8	1	0	1	–0.67	0.33	0
9	1	0	0	–0.67	–0.67	0

By the results of the research, the coefficients of the regression equation (b_i) were obtained, and a statistical analysis of the model and its coefficients was carried out, given in Table 10.

Table 9

Measurement results for the two-factor analysis of the recipe added with DSC

No.	and_1	and_2	and_3	$\bar{y}_i$	s_j^2	$\hat{y}$	$\bar{y}$	Sad²
1	4.52	4.14	7.2	5.3	2.73	5.28	5.03	0.064
2	5.20	4.2	7.1	5.5	2.17	5.50	5.40	0.011
3	1.92	4.05	8.2	4.7	10.20	4.72	4.70	0.000
4	0.68	4.38	8.5	4.5	15.20	4.51	4.64	0.016
5	3.05	4.2	7.8	5.0	6.14	5.02	4.99	0.001
6	2.25	4.15	7.3	4.6	6.51	4.57	4.83	0.071
7	1.14	4.25	8.1	4.5	12.25	4.51	4.39	0.013
8	2.12	4.11	7.5	4.6	7.47	4.59	4.93	0.121
9	2.38	4.18	8.0	4.9	8.24	4.85	4.63	0.049

Table 10

Results of statistical analysis of the experiment for the two-factor analysis of the recipe added with DSC

–	x_0	x_1	x_2	$x_1^2-0.667$	$x_2^2-0.667$	$x_1 x_2$
Σxi^*avg	43.5	–0.5	1.6	0.6	0.1	–0.4
Σxi^2	9	6.0	6.0	2.0	2,0	4
b_i	4.84	–0.08	0.27	0.28	0.03	–0.11
Statistical analysis						
S_{and}^2	7.88	G	0.21	Sad^2	0.0576	
A	0.05	m–1	2.00	F	0.007316	
f_1	8.00	N	9.00	$k1$	2	
t_T	2.31	G_{table}	0.47	$k2$	6.00	
		$G-G_{table}$	–0.26	Fkp (table)	5.14	
$G<G_{table}$	F–Fkp				–5.132683638	
Homogeneity of variance	$F<Fkp$ the statistical model is significant, the regression equation is reliable					

After mathematical modeling, calculations and determination of the regression equation as reliable, the coefficients in (4) are replaced with those defined in the studies, which makes it possible to determine the relationship of prescription components and their impact on optimization indicators. As a result, the obtained regression model in encoded units has the following form:

$$Y_{sesame}=4.84-0.08x_1+0.27x_2-$$
$$-0.11b_{12}x_1x_2+0.28x_1^2+0.03x_2^2. \quad (4)$$

To determine the optimal prescription composition in accordance with the specified parameters, a 3D model was built using the Statistica software package for statistical analysis (Fig. 3).

On 3D models, we can see the number of the point with the best composition. This is the conclusion that this particular composition is the best. After studying all the results of mathematical modeling in Fig. 3, samples No. 4 were defined as the optimal prescription compoe sition, corresponding to the 2 % DSC content in the recipe.

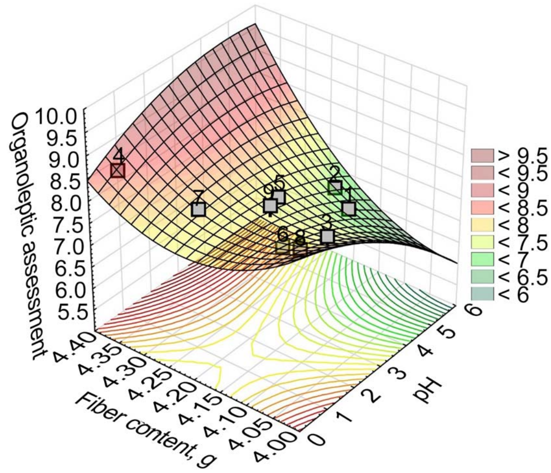

Fig. 3. 3D optimization model for the two-factor analysis of the recipe with defatted sesame cake

5. 2 .1. Results of the two-factor analysis of RB

The experimental design and measurement results for the two-factor analysis of the recipe added with RB are given in Tables 11, 12, respectively.

Table 11

Experimental design matrix for the two-factor analysis of the formulation with RB

No.	x_0	x_1	x_3	$x_1^2-0.667$	$x_3^2-0.667$	x_1x_3
1	1	1	1	0.33	0.33	1
2	1	–1	–1	0.33	0.33	1
3	1	1	–1	0.33	0.33	–1
4	1	–1	1	0.33	0.33	–1
5	1	–1	0	0.33	–0.67	0
6	1	1	0	0.33	–0.67	0
7	1	0	–1	–0.67	0.33	0
8	1	0	1	–0.67	0.33	0
9	1	0	0	–0.67	–0.67	0

Table 12

Measurement results for the two-factor analysis of the formulation with RB

No.	and_1	and_2	and_3	$\bar{y}_j$	s_j^2	$\hat{y}$	$\bar{y}$	Sad^2
1	0.100	4.57	7.0	3.9	12.25	3.89	3.90	0.000
2	0.029	4.92	8.9	4.6	19.74	4.62	4.54	0.005
3	0.110	4.72	8.3	4.4	16.86	4.38	4.35	0.001
4	0.025	4.95	8.0	4.3	16.19	4.33	4.29	0.001
5	0.095	4.65	8.1	4.3	16.12	4.28	4.38	0.010
6	0.127	4.71	7.4	4.1	13.52	4.08	4.09	0.000
7	0.086	4.74	7.8	4.2	15.09	4.21	4.30	0.009
8	0.210	4.30	7.3	3.9	12.67	3.94	3.95	0.000
9	0.075	4.70	7.8	4.2	15.11	4.19	4.09	0.010

By the results of the research, the coefficients of the regression equation (b_i) were obtained, and a statistical analysis of the model and its coefficients was carried out, given in Table 13.

Table 13

Results of statistical analysis of the experiment for the two-factor analysis of the recipe added with RB

–	x_0	x_1	x_3	$x_1^2-0.667$	$x_3^2-0.667$	$x_1\,x_3$
∑xi*avg	37.9	–0.9	–1.1	0.3	0.1	–0.2
∑xi^2	9	6.0	6.0	2.0	2.0	4
b_i	4.21	–0.15	–0.18	0.14	0.04	–0.05
Statistical analysis						
S^2_{and}	15.28	G	0.14		Sad^2	0.0061
A	0.05	$m-1$	2.00		F	0.000398
f_1	8.00	N	9.00		k1	2
t_T	2.31	G_{table}	0.47		k2	6.00
		$G-G_{table}$	–0.33		Fkp (table)	5.14
$G<G_{table}$ Homogeneity of variance		F–Fkp				–5.139601864
		F<Fkp the statistical model is significant, the regression equation is reliable				

After mathematical modeling, calculations and determining the regression equation as reliable, the coefficients in (5) are replaced with those defined in the studies, which makes it possible to determine the relationship of prescription components and their impact on optimization indicators. As a result, the obtained regression model in encoded units has the following form:

$$Y_{rice}=4.21-0.15x_1-0.18x_3-$$
$$-0.05x_1x_3+0.14x_1^2+0.04x_3^2. \quad (5)$$

To determine the optimal prescription composition in accordance with the specified parameters, a 3D model was built using the Statistica software package for statistical analysis (Fig. 4).

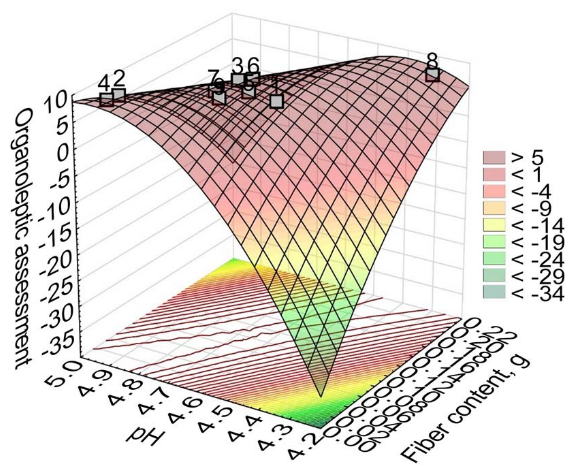

Fig. 4. 3D optimization model for the two-factor analysis of the formulation with rice bran

On 3D models, we can see the number of the point with the best composition. This is the conclusion that this particular composition is the best. After studying all the results of mathematical modeling in Fig. 4, samples No. 2 were defined as the optimal prescription composition, corresponding to the 0.1 % rice bran content in the recipe.

5. 2. Results of the three-factor analysis

The experimental design and measurement results for the three-factor analysis of the recipe added with DSC and RB are given in Tables 14, 15, respectively.

By the results of the research, the coefficients of the regression equation (b_i) were obtained, and a statistical analysis of the model and its coefficients was carried out, given in Table 16.

Table 14

Experimental design matrix for the three-factor analysis of the recipe added with DSC and RB

No.	x_0	x_1	x_2	x_3	$x_1^2-0.73$	$x_2^2-0.73$	$x_3^2-0.73$	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$
1	1	1	1	1	0.27	0.27	0.27	1	1	1	1
2	1	–1	1	1	0.27	0.27	0.27	–1	–1	1	–1
3	1	1	–1	1	0.27	0.27	0.27	–1	1	–1	–1
4	1	–1	–1	1	0.27	0.27	0.27	1	–1	–1	1
5	1	1	1	–1	0.27	0.27	0.27	1	–1	–1	–1
6	1	–1	1	–1	0.27	0.27	0.27	–1	1	–1	1
7	1	1	–1	–1	0.27	0.27	0.27	–1	–1	1	1
8	1	–1	–1	–1	0.27	0.27	0.27	1	1	1	–1
9	1	–1.215	0	0	–0.73	–0.73	–0.73	0	0	0	0
10	1	1.215	0	0	–0.73	–0.73	–0.73	0	0	0	0
11	1	0	–1.215	0	–0.73	0.75	0.75	0	0	0	0
12	1	0	1.215	0	–0.73	0.75	0.75	0	0	0	0
13	1	0	0	–1.215	0.75	–0.73	–0.73	0	0	0	0
14	1	0	0	1.215	0.75	–0.73	–0.73	0	0	0	0
15	1	0	0	0	–0.73	–0.73	–0.73	0	0	0	0

Table 15

Measurement results for the three-factor analysis of the recipe added with DSC and RB

No.	and_1	and_2	and_3	$\bar{y}_j$	s_j^2	$\hat{y}$	$\bar{y}$	Sad^2
1	4.62	4.36	7.40	5.5	2.85	5.46	5.38	0.006
2	5.23	4.56	7.20	5.7	1.88	5.66	5.43	0.056
3	2.03	4.39	8.40	4.9	10.37	4.94	5.02	0.007
4	0.71	4.67	8.60	4.7	15.58	4.66	4.58	0.006
5	2.33	4.21	7.40	4.6	6.57	4.65	4.71	0.004
6	4.81	4.45	7.80	5.7	3.38	5.69	5.59	0.009
7	0.61	4.54	8.40	4.5	15.17	4.52	4.74	0.051
8	0.65	4.6	8.10	4.5	13.89	4.45	4.52	0.005
9	0.65	4.43	7.80	4.3	12.79	4.29	4.57	0.076
10	2.38	4.43	7.40	4.7	6.38	4.74	4.49	0.061
11	0.71	4.65	9.00	4.8	17.20	4.79	5.28	0.241
12	1.23	4.50	8.20	4.6	12.18	4.64	4.60	0.002
13	2.20	4.50	8.00	4.9	8.53	4.90	4.68	0.047
14	2.45	4.21	7.40	4.7	6.30	4.69	4.94	0.065
15	2.46	4.44	8.10	5.0	8.20	5.00	4.53	0.221

Table 16

Results of statistical analysis of the experiment for the three-factor analysis of the recipe added with DSC and RB

–	x_0	x_1	x_2	x_3	$x_1^2-0.73$	$x_2^2-0.73$	$x_3^2-0.73$	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$
∑*xi*avg*	73.1	–0.4	3.1	1.2	0.8	0.6	0.6	–1.6	1.1	0.2	0.6
∑*xi^2*	15	11.0	11.0	11.0	4.4	4.4	4.4	8	8	8	8
b_i	4.87	–0.03	0.28	0.11	0.19	0.14	0.14	–0.20	0.13	0.02	0.08

Statistical analysis					
S_{and}^2	9.42	G	0.12	Sad^2	0.0779
A	0.05	$m-1$	2.00	F	0.008276
f_1	14.00	N	15.00	$k1$	3
t_T	2.14	G_{table}	0.33	$k2$	11.00
		$G-G_{table}$	–0.21	Fkp (table)	3.59
$G<G_{table}$ Homogeneity of variance		$F-Fkp$			–3.581724219
		$F<Fkp$ the statistical model is significant, the regression equation is reliable			

After mathematical modeling, calculations and determining the regression equation as reliable, the coefficients in (6) are replaced with those defined in the studies, which makes it possible to determine the relationship of prescription components and their impact on optimization indicators. As a result, the obtained regression model in encoded units has the following form:

$$Y_{sesame+rice} = 4.87 - 0.03x_1 + 0.28x_2 + +0.11x_3 - 0.20x_1x_2 + 0.13x_1x_3 + 0.02x_2x_3 + +0.08x_1x_2x_3 + 0.19x_1^2 + 0.14x_2^2 + 0.14x_3^2. \quad (6)$$

To determine the optimal prescription composition in accordance with the specified parameters, a 3D model was built using the Statistica software package for statistical analysis (Fig. 5).

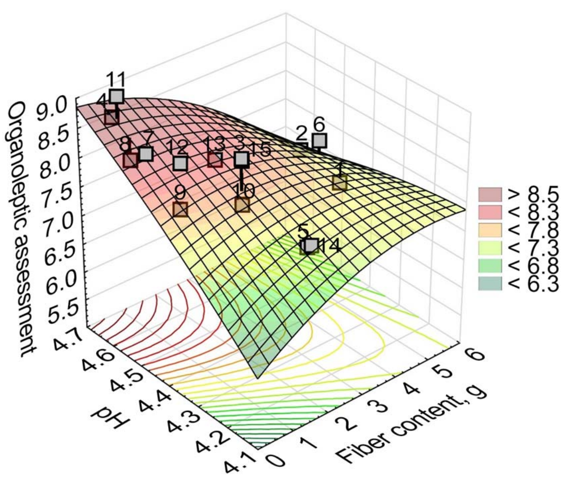

Fig. 5. 3D optimization model for the three-factor analysis of the recipe added with defatted sesame cake and rice bran

On 3D models, we can see the number of the point with the best composition. This is the conclusion that this particular composition is the best. After examining all the results of mathematical modeling in Fig. 5, samples No. 11 were det fined as the optimal prescription composition, corresponding to the 2 % DSC and 0.4 % RB content in the recipe.

6. Discussion of formulation optimization using two-factor analysis and three-factor analysis

In this study, the central composite design was chosen for formula optimization. Compared to other optimization methods, the central composite design has a high fitting degree and high accuracy. Two central composite designs for the two-factor analysis (x_1x_2 and x_1x_3, respectively) and one three-factor design ($x_1x_2x_3$) were drawn up in this study. For the two-factor analysis of the recipe, 9 experiments were carried out, as shown in Tables 8, 11 (Table 8 was the experimental design matrix for the two-factor analysis of the formulation with DSC, and Table 11 was the experimental design matrix for the two-factor analysis of the formulation with RB), and for the three-factor – 15 (Table 14, the experiment design matrix for the three-factor analysis of the recipe added with DSC and RB). Based on the obtained data, including fiber content (Tables 4, 5), pH (Tables 6, 7) and sensory properties (Fig. 1, 2), the design results are shown in Tables 9, 12, 15, respectively, and three nonlinear formulas were determined based on the results, shown as formula (4)–(6), respectively. The reliability of the three nonlinear models was analyzed, as shown in Tables 10, 13, 16, respectively. For the three curves, $F<Fkp$, the three statistical models were significant, the regression equation is reliable. Then 3D diagrams were constructed based on three nonlinear models, as shown in Fig. 3–5. 3D models were built using the Statistica software package for statistical analysis. After studying all the results of mathematical modeling, the optimal prescription composition corresponds to the 2 % DSC or 0.1 % rice bran content or 2 % DSC and 0.4 % RB content in the recipe.

The central composite design was a good method to conduct optimization analysis. By this method, the influence of the main factors on the product quality can be considered comprehensively, so as to obtain the optimal formula, the results were more scientific. In previous studies, the optimization of products mainly relied on the data of sensory evaluation [11, 15], but in this study, the dietary fiber content parameter was introduced to optimize products, highlighting the health value of the product, which is the innovation of this study.

The results are theoretical optimization results, have not been applied in large-scale experiments, and the influence of DSC and RB treated by different methods on kefir was also uncertain. So the proposed scheme needs advanced pre-testing in large-scale industrial applications.

In this study, pH, sensory characteristics and dietary fiber content were chosen to conduct a comprehensive analysis, and other important parameters, including viscosity, water holding capacity, the population of probiotics, or antioxidant ability were not taken into account. The results may not be objective enough, which is the limitation of this study. Considering more parameters in the optimization can give more objective results.

According to relevant studies [5, 6, 11, 15], dietary fiber has a great impact on the sensory properties of kefir, and pretreatment methods of DSC and RB will have a great impact on its application in kefir. Therefore, the application scope of dietary fiber in food would be greatly expanded if more economic and practical pretreatment methods of dietary fiber can be developed in the follow-up studies.

7. Conclusions

1. Two-factor analysis of the recipe. According to the experimental design and research results, the coefficients of the regression equation were obtained, and a statistical analysis of the model and its coefficients was conducted. To determine the optimal prescription composition in accordance with the specified parameters, a 3D model was built using the Statistica software package for statistical analysis. After studying all the results of mathematical modeling, the optimal prescription composition corresponds to the 2 % DSC and 0.1 % RB content in the recipe.

2. Three-factor analysis of the recipe. According to the experiment design and measurement results for the three-factor analysis of the recipe added with DSC and RB, a statistical analysis of the model and its coefficients was conducted. To determine the optimal prescription composition in accordance with the specified parameters, a 3D model was built using the Statistica software package for statistical analysis. After examining all the results of mathematical

modeling, the optimal prescription composition corresponds to the 2 % DSC and 0.4 % RB content in the recipe.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has associated data in a data repository.

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