OPTIMIZATION OF TECHNOLOGICAL PARAMETERS OF PREPARATION OF DOUGH FOR RUSKS OF HIGH NUTRITION VALUE

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Received March 14, 2017; Accepted in revised form May 24, 2017; Published June 29, 2017

Abstract: The work has been performed on the basis of Department of technology of baking, confectionery, macaroni and grain processing productions of Voronezh State University of Engineering Technologies. The urgent line of development of the baking industry is the development of new formulations and resource-saving technologies of dry bread products of high nutrition value and functional orientation. The application of flour made of wholemeal wheat instead of high-quality wheat flour is perspective to realize it. An important condition to obtain consistently high-quality products and increase production efficiency is the establishment of optimum technological parameters of preparation of dough. Mathematical methods of planning of experiment are applied to study the interaction of the major technological factors influencing the process of preparation and the quality of dry bread products. The following are chosen as the major factors: the dosage of flour made of wholemeal wheat and the humidity of dough. The main indicator of quality of rusks characterizing their swelling capacity in water – the swelling capacity coefficient – was the output parameter. The optimization of parameters of preparation of dough for rusks was performed using experimental and statistical methods. As a result of the performed experiment a mathematical model in the form of regression equation which adequately describes the studied process has been developed. The statistical processing of experimental data has been performed according to Student, Kokhren and Fischer criteria (with the confidential probability of 0.95). The mathematical and graphic interpretation of regression equation have allowed to determine previously the optimum area of factorial space in which the highest value of output parameter is reached. The optimization of technological parameters of preparation of dough in the value of swelling capacity coefficient of rusks was performed using the method of Lagrange multipliers. Rational values of factors have been determined: the dosage of flour made of wholemeal wheat is 99.82%, the humidity of dough is 40.86%. Their choice has been validated by a series of parallel experiments which has shown sufficient convergence of results with the average square error of no more than 0.67%. On the basis of the obtained data a formulation and a way of production of rusks of high nutrition value "Crackling delicacy" has been developed.

Keywords: Flour made of wholemeal wheat, rusks, swelling capacity coefficient, central composite rotatable uniform planning, optimization

DOI 10.21179/2308-4057-2017-1-73-80 *Foods and Raw Materials*, 2017, vol. 5, no. 1, pp. 73–80.

INTRODUCTION

The technologies of ecologically safe resource-saving production and processing of agricultural raw materials and food products play a fundamental role in the social and economic development of the state. The implementation of programs for the creation of waste-free and low-waste complex technologies is based on the modern scientific achievements and their practical realization. One of the effective measures is the introduction of innovative technology of processing of wheat grain into flour made of wholemeal wheat and its use in baking production. Such a technology will allow to increase the quality and nutrition value of production, to reduce its prime cost, to intensify the technological process, will provide an opportunity for the enterprise to react more flexibly to market conditions. Thanks to the application of disintegration-wave method of crushing, flour made of wholemeal wheat is characterized by a 100% output, high dispersion (on average, 38–40 microns) and a high nutrition value. It preserves all the components of grain having a high potential in the content of protein and irreplaceable amino acids, food fibers, vitamins and mineral substances. The expediency of application of flour made of wholemeal wheat in the production of bakery products of wide range, including that for dietetic and preventive nutrition has been established by the performed researches. The regular use of products made of this flour provides the activation of human's own microflora, the improvement of digestion processes and an increase in the accessibility of other products [1, 2].

One of the types of bakery products is rich rusks – the products with low humidity, a high nutritional value and a long period of storage allowing their use in remote regions of the country. Dry bread products are very popular with all the age groups of the population. According to Rosstat [the Federal State Statistics Service], the volume of their production in Russia steadily increases for the last 5 years, the annual gain averages 3–4%. In this regard, the development of new formulations and technologies of dry bread products of high nutrition value and functional orientation is urgent. At the same time, an important condition to obtain consistently high-quality products and increase production efficiency is the establishment of optimum technological parameters of preparation of dough.

The purpose of work was the study of interaction of the major technological factors influencing the process of preparation and the quality of dry bread products, the search of their optimum values with the use of methods of mathematical modeling.

STUDY OBJECTS AND METHODS

The objects of the study were dry bread products. Children's rusks developed in accordance with GOST 8494-96 have been taken as a basis. The dough for test specimens was prepared in the accelerated way, at the same time they replaced high-grade wheat flour by flour made of wholemeal wheat, butter – by mustard, the mass of sugar was reduced by 1/3, the mass of yeast was increased by 0.6 kg, they also added whey in the amount of 15 kg per 100 kg of flour according to the formulation. The duration of dough fermentation was 90 min. to the acidity of 4.0–4.5 degrees. The fermented dough was subjected to cutting and proving for 50 min. and baking for 15 min. at a temperature of 210–220°C. The baked dry bread plates were held at a temperature of 18–20°C for 10 h, further on their cutting in chunks and the drying of rusks for 15 min. at 180^{o} were performed.

Methods of mathematical planning of experiment – central composite rotatabel uniform planning – have been used in the work. The processing of experimental data consisted in the check of reproducibility of experiments (Kokhren Criterion), the calculation of coefficients of regression equation and the check of their statistical importance (Student Criterion), the establishment of adequacy of the obtained regression equation (Fischer Criterion) [3, 4].

The following are chosen as the major factors: x_1 is the dosage of flour made of wholemeal wheat (wheat germ oil), % to the total mass of flour; x_2 is the humidity of dough, % (Table 1). The main indicator of quality of rusks characterizing their swelling capacity in water – the swelling capacity coefficient – was used as the output parameter y. The swelling capacity of specimens was determined according to the technique provided in GOST 8494-96, the swelling capacity coefficient was calculated proceeding from an increase in the mass of each specimen after its swelling.

Table 1. Planning characteristics

Planning conditions	Values of factors	
	Dosage of wheat germ oil x_1, %	The humidity of dough x_2, %
Basic level (0)	75.00	41.0
Variability range	17.73	1.0
Upper level (+1)	92.73	42.0
Lower level (–1)	57.27	40.0
High "star" point (+1.41)	100.0	42.4
Low "star" point (–1.41)	50.00	39.6

The choice of intervals of change of factors was caused by the technical characteristics and quality of the finished products. The addition of wheat germ oil in the amount of less than 50% is inefficient as it does not has a considerable impact on the nutrition value of products. The increase in dough humidity by more than 42.0% provides a decrease in its viscosity and dilution. The semi-finished product with the dough humidity of less than 39.0% has a high viscosity and "abrupt" consistence which complicates its formation and affects the formation of properties of semi-finished products in the course of fermentation, proving and baking.

The optimization of technological parameters of preparation of dough for rusks of high nutrition value was performed using the methods of mathematical statistics and differential calculus.

RESULTS AND DISCUSSION

The first stage of work consisted in the identification of parameters of the mathematical model which adequately describes the dependence of output parameter on the studied factors. For these purposes the complete factorial experiment of type 2^2 according to the planning matrix given in Table 2 has experimentally been made (Experiments 1–4). Each experiment was implemented with two-time replication. Taking into account a possible future transition to second order planning, 5 parallel experiments have been implemented at the center point of the design (Experiments 9–13). To exclude the influence of uncontrollable parameters on the results of experiment the randomization of experiments with the application of the table of random numbers was used. Table 2 provides the arithmetic averages of response function according to the results of two parallel experiments.

Table 2. Planning matrix and results of the experiment

Experiment No.	Code values of factors		Natural values of factors		Response function
	X_1	X_2	x_1, %	x_2, %	y, c.u.
1	+1	+1	92.73	42.0	5.1
2	+1	–1	92.73	40.0	5.5
3	–1	+1	57.27	42.0	4.1
4	–1	–1	57.27	40.0	5.0
5	+1.41	0	100.0	41.0	5.8
6	0	+1.41	75.0	42.4	4.0
7	–1.41	0	50.0	41.0	4.7
8	0	–1.41	75.0	39.6	5.0
9	0	0	75.0	41.0	4.6
10	0	0	75.0	41.0	5.0
11	0	0	75.0	41.0	4.7
12	0	0	75.0	41.0	4.8
13	0	0	75.0	41.0	4.9

The application of complete factorial experiment provides the opportunity to calculate the estimates of regression coefficients and to develop a first order equation. It is known [3] that the intercept b_0 of regression equation is the estimate of process output at the center point of experiment which is mixed with the total estimate of quadratic effects of all factors. If the quadratic terms are significant, the predicted results of experiments at the center point of the design of experiment will considerably differ from their experimental values, as well. The parallel experiments at the center point of the design of experiment allow, without even starting the calculation of all (except b_0) estimates of coefficients of the equation, to judge about the possibility of description of the studied dependence using a first order equation without the inclusion of quadratic terms in it.

In this regard, values of the intercept b_0, arithmetic mean values of response function $\bar{y}_0$ at the center point of experiment, the estimation of difference dispersion $S^2(\bar{y}_0 - b_0)$ and the confidential error of difference ε (Table 3) have been calculated.

Table 3. Results of calculation of confidence error

Parameter	Value
Intercept b_0	4.93
Arithmetic average value of response function at the center point of the experiment $\bar{y}_0$	4.8
Difference-based variance estimate $S^2(\bar{y}_0 - b_0)$	$1.3 \cdot 10^{-3}$
Difference $\lvert\bar{y}_0 - b_0\rvert$	0.13
Confidence error of difference ε	0.078

The confidence error of difference ε has been estimated according to the formula

$$\varepsilon = t_{кр} \cdot \sqrt{S^2(\bar{y}_0 - b_0)}, \qquad (1)$$

where t_{kp} is the critical value of Student criterion (t_{kp} = 2.16) with the accepted confidential probability of 0.95 and the number of degrees of freedom of 13.

The fulfillment of the condition $\varepsilon < \lvert\bar{y}_0 - b_0\rvert$ follows from the results of Table 3. It allows to recognize with the accepted confidential probability of 0.95 the distinction between $\bar{y}_0$ and b_0 essential, and to consider the linear regression equation obtained using the results of complete factorial experiment an unsatisfactory mathematical description. In this regard, a decision on the transition to second order planning allowing to obtain the adequate mathematical description due to the inclusion of estimates of quadratic effects of factors in it has been made.

For this purpose, the experiments at the "star" points (Table 2, Experiments 5–8) were added to the planning matrix. The choice of value of "star" leverage ± of 1.41 is caused by the need of obtaining a uniform rotatabel design providing the obtaining of the same value of dispersion and the prediction for any point within the studied area. The experiments at the "star" points were realized with two-time replication, as well. Table 2 provides the arithmetic averages of response function according to the results of two parallel experiments.

The statistical processing of results of uniform rotatabel planning consisted in the calculation of estimates of coefficients of regression equation, the check of their importance, the estimation of reproducibility of experiments and the establishment of adequacy of the obtained regression equation [3, 5]. Statistical Student, Kokhren and Fischer criteria (with the confidential probability of 0.95) have been used for this purpose.

As a result of statistical processing of results of planning of experiment (Table 2) a regression equation which adequately describes the dependence of swelling capacity coefficient of rusks y on the studied factors has been obtained:

$$y = 4.8 + 0.39X_1 - 0.35X_2 + 0.15X_1X_2 + \\ +0.23X_1^2 - 0.14X_2^2, \quad (2)$$

where X_i is the code values of the factors related to the natural values x_i with the ratios:

$$X_1 = \frac{x_1 - 75}{17.73}; \quad X_2 = \frac{x_2 - 41}{1}. \quad (3)$$

The second stage consisted in the interpretation of the regression equation (2). The mathematical description obtained using the results of rotatabel planning provides the information on the response surface, however, the interpretation of equation in the form of (2) is complicated. In this regard, to establish the type of surface and reduce the equation to the accepted form we will use the means of analytical geometry [6].

For this purpose we will present the regression equation (2) in the form of the general second order surface equation:

$$a_{11}x^2 + a_{22}y^2 + a_{33}z^2 + 2a_{12}xy + 2a_{13}xz + \\ + 2a_{23}yz + 2a_1x + 2a_2y + 2a_3z + a_0 = 0, \quad (4)$$

where a_0 and a_{ii} are the coefficients of the equation of surface of the second order; x, y and z are the variables which correspond to the factors X_1 and X_2 and the response function y.

Comparing the regression equation (2) with the general surface equation (4), we determine the coefficients a_0 and a_{ii} (Table 4). Orthogonal invariants of the quadratic function (4) provide the information on the configuration of surface of the second order which is described by the equation (2):

– the determinant δ of a matrix of quadratic form

$$\delta = \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{12} & a_{22} & a_{23} \\ a_{13} & a_{23} & a_{33} \end{vmatrix} = \begin{vmatrix} 0.23 & 0.075 & 0 \\ 0.075 & -0.14 & 0 \\ 0 & 0 & 0 \end{vmatrix} = 0,$$

– the determinant Δ of a matrix of quadratic function

$$\Delta = \begin{vmatrix} a_{11} & a_{12} & a_{13} & a_1 \\ a_{12} & a_{22} & a_{23} & a_2 \\ a_{13} & a_{23} & a_{33} & a_3 \\ a_1 & a_2 & a_3 & a_0 \end{vmatrix} = \begin{vmatrix} 0.23 & 0.075 & 0 & 0.195 \\ 0.075 & -0.14 & 0 & -0.175 \\ 0 & 0 & 0 & -0,5 \\ 0.195 & -0.175 & -0.5 & 4.8 \end{vmatrix} = 0.00946,$$

– the trace τ_1 of the matrix (the sum of diagonal elements of the matrix A)

$$\tau_1 = a_{11} + a_{22} + a_{33} = 0.23 + (-0.14) + 0 = 0.09,$$

– the sum τ_2 of the main minors of the second order of the matrix

$$\tau_2 = \begin{vmatrix} a_{11} & a_{12} \\ a_{12} & a_{22} \end{vmatrix} + \begin{vmatrix} a_{11} & a_{13} \\ a_{13} & a_{33} \end{vmatrix} + \begin{vmatrix} a_{22} & a_{23} \\ a_{23} & a_{33} \end{vmatrix} = \\ = \begin{vmatrix} 0.23 & 0.075 \\ 0.075 & -0.14 \end{vmatrix} + \begin{vmatrix} 0.23 & 0 \\ 0 & 0 \end{vmatrix} + \begin{vmatrix} -0.14 & 0 \\ 0 & 0 \end{vmatrix} = -0.03783.$$

As $\delta = 0$ and $\Delta > 0$ are the determinants, the response surface described by the equation (2) has the form of a hyperbolic paraboloid.

The reduction of a square regression equation of the type (2) to the accepted form consists in the transition from the initial coordinate axes X_1 and X_2 to the new axes Z_1 and Z_2. At the same time the beginning of coordinates should be transferred to a new point of factorial space, and the new coordinate axes Z_1 and Z_2 should be turned by a certain angle of φ of the initial axes X_1 and X_2.

Proceeding from the necessary condition of existence of the function extremum y

$$\begin{cases} \dfrac{\partial y}{\partial X_1} = 0.39 + 0.15X_2 + 0.46X_1 = 0, \\ \dfrac{\partial y}{\partial X_2} = -0.35 + 0.15X_1 - 0.28X_2 = 0, \end{cases}$$

we define the coordinates $X_{1s} = -0.37$ and $X_{2s} = -1.45$ of the stationary point (the center of response surface) which contains the extremum of function (2). The insertion of coordinates of the stationary point in the equation (2) provides the value of response function at the center point of the surface $y_s = 4.98$.

Solving the second order characteristic equation

$$\begin{vmatrix} (b_{11} - B) & \frac{1}{2}b_{12} \\ \frac{1}{2}b_{21} & (b_{22} - B) \end{vmatrix} = \\ = B^2 - (b_{11} + b_{22})B + (b_{11}b_{22} - 0,25b_{12}^2) = 0,$$

we define the coefficients of the accepted form $B_{11} = 0.25$ and $B_{22} = -0.15$.

Table 4. Values of coefficients of the general equation of surface of the second order (5)

Coefficient	a_{11}	a_{22}	a_{33}	a_{12}	a_{13}	a_{23}	a_1	a_2	a_3	a_0
Value	0.23	–0.14	0	0.075	0	0	0.195	–0.175	–0.5	4.8

Thus, the regression equation (2) after canonical transformations has the form

$$y = 4.98 + 0.25Z_1^2 - 0.15Z_2^2 . \qquad (5)$$

The angle of rotation of the new coordinate axes Z_1 and Z_2 of the initial axes X_1 and X_2 is

$$\varphi = \frac{1}{2}\mathrm{arctg}\frac{b_{12}}{b_{11} - b_{22}} = 10.9\,°.$$

Taking into account the parameters of the canonical transformation the relation between the coordinates X_i and the new Z_i has the form:

$$X_1 = (Z_1 + X_{1s})\cos\phi - (Z_2 + X_{2s})\sin\phi = 0.982Z_1 - 0.19Z_2 - 0.087,$$
$$X_2 = (Z_1 + X_{1s})\sin\phi + (Z_2 + X_{2s})\cos\phi = 0.19Z_1 + 0.982Z_2 - 1.494.$$

Fig. 1 provides the graphic interpretation of the regression equation (2) in the form of response surface. It is visible that the surface described by the equation (2) the accepted form of which is presented in the form of (5) has the form of a hyperbolic paraboloid with a special central point (the minimax point). In the line of one of the accepted axes there is the minimum and in the line of other axis there is the maximum.

More detailed information on the configuration of response surface is provided by its two-dimensional sections. Fig. 2 provides flat sections of response surface. It is visible that the sections of hyperbolic paraboloid made by the coordinate planes $y = h$ (where h is an arbitrary constant) have the form of hyperboles. With $h < 4.98$ the half-hyperboles are extended along the accepted axis Z_2, and with $h > 4.98$ the half-hyperboles are extended along the accepted axis Z_1.

Fig. 2 also presents a two-dimensional section of the area of experiment in the form of a circle with a radius of $R = 1.41$ the center of which coincides with the center point of the experiment.

The analysis of two-dimensional sections of response surface allows to determine previously the optimum area of factorial space in which the highest value of output parameter y is reached. Such a mode (see Fig. 2) obviously corresponds to the vicinities of the right "star" point (according to Table 1 for dosages of wheat germ oil x_1 = 100% and the humidity of dough x_2 = 41%).

These results are determined by the influence of flour made of wholemeal wheat and the humidity of dough on the formation of properties of semi-finished products and indicators of quality of finished products. It has been revealed that with an increase in the dosage of flour made of wholemeal wheat and a decrease in the humidity of dough the swelling capacity coefficient of rusks increases. Its highest value has been noted when adding the maximum amount of wheat germ oil and humidity of dough at the center point of the design (Fig. 2). The existence of considerable amounts of peripheral parts of grain (food fibers) with a high water absorbing ability in such flour is determinative. The mass of water retained by 1 g of flour made of wholemeal wheat is 1.27 g compared to 0.85 g for high-grade wheat flour.

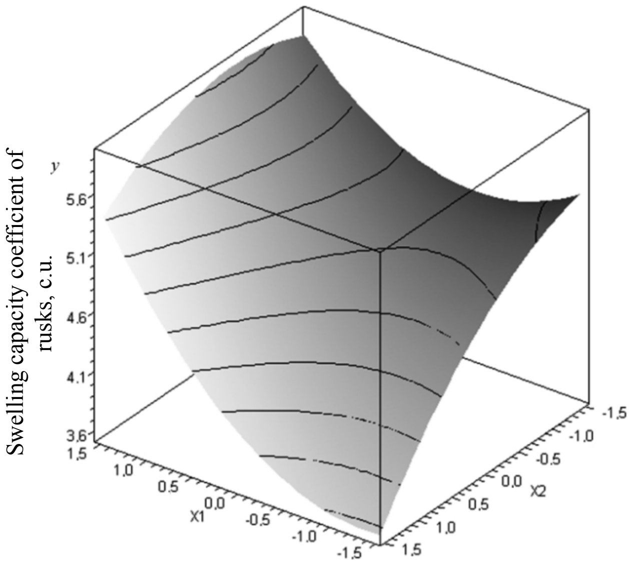

Fig. 1. General view of the response surface y.

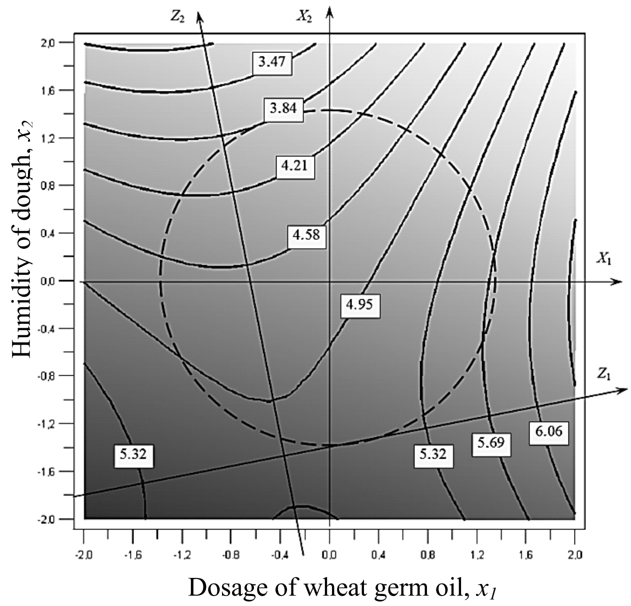

Fig. 2. Flat sections of response surface.

The third stage consisted in the optimization of dough formulation in the value of swelling capacity coefficient of rusks y.

We will formulate the problem of optimization of technological parameters of preparation of dough for rusks of high nutrition value as follows. It is necessary to determine such values of the variables X_1 and X_2 which provide the maximum value of the swelling capacity coefficient $y = y(X_1, X_2)$. At the same time the values of the variables X_1 and X_2 are also to be in the area of experiment the borders of which are determined by the values of factors at the "star" points.

We will present the specified restriction imposed on the variables X_1 and X_2 in the form of constraint equation

$$\varphi(X_1, X_2) = X_1^2 + X_2^2 = R^2, \quad (6)$$

which is a sphere in the factorial space with a radius of R the center of which is at the center point of the experiment.

Thus, we have a problem of conditional optimization:

$$\begin{cases} y(X_1, X_2) = 4.8 + 0.39X_1 - 0.35X_2 + 0.15X_1X_2 + 0.23X_1^2 - 0.14X_2^2 \to \max \\ \phi(X_1, X_2) = X_1^2 + X_2^2 = R^2. \end{cases} \quad (7)$$

We will solve the problem of conditional optimization using the method of Lagrange multipliers [7] which allows to reduce the problem of conditional extremum to an unconditional problem of search of function extremum.

For this purpose we will generate a Lagrange auxiliary function $F(X_1, X_2, \lambda)$ which is the sum of the equation $y(X_1, X_2)$ and the restriction $\varphi(X_1, X_2)$ multiplied by an uncertain Lagrange multiplier λ:

$$F(X_1, X_2, \lambda) = 4.8 + 0.39X_1 - 0.35X_2 + 0.15X_1X_2 + 0.23X_1^2 - 0.14X_2^2 + \lambda(X_1^2 + X_2^2 - R^2). \quad (8)$$

A necessary condition of unconditional extremum of Lagrange function $F(X_1, X_2, \lambda)$ is the equality of differential derivatives of function (8) to zero by all the independent variables X_1, X_2 and an uncertain multiplier λ:

$$\begin{cases} \dfrac{\partial F(X_1, X_2, \lambda)}{\partial X_1} = 0.39 + 0.15X_2 + 0.46X_1 + 2\lambda X_1 = 0 \\ \dfrac{\partial F(X_1, X_2, \lambda)}{\partial X_2} = -0.35 + 0.15X_1 - 0.28X_2 + 2\lambda X_2 = 0. \\ \dfrac{\partial F(X_1, X_2, \lambda)}{\partial \lambda} = X_1^2 + X_2^2 - R^2 = 0 \end{cases} \quad (9)$$

To solve the system of equations (9) it is necessary to assign the values of the radius R in the range from 0 to 1.41. However, as it follows from Fig. 2, the conditional extremum of coefficient of swelling of rusks $y = y(X_1, X_2)$ is reached under the condition $R = 1.41$. In this regard the problem of optimization is considered in future for the case $R = 1.41$.

Solving the system (9) referring the variables X_1, X_2 and the Lagrange multiplier λ, we obtain the values λ^* and coordinates of stationary points of factorial space X_1^* and X_2^* at which the conditional extremum of function is reached (2) (Table 5). It is not difficult to see that the coordinates of each extreme point satisfy the constraint equation (6).

The condition (9) is a necessary condition for the existence of Lagrange function extremum (8), but not a sufficient one. To check the sufficient condition for the existence of the found extrema and the establishment of their character we will use a matrix

$$H = \begin{pmatrix} 0 & \dfrac{\partial\varphi}{\partial X_1} & \dfrac{\partial\varphi}{\partial X_2} \\ \dfrac{\partial\varphi}{\partial X_1} & \dfrac{\partial^2 F}{\partial X_1^2} & \dfrac{\partial^2 F}{\partial X_1 \partial X_2} \\ \dfrac{\partial\varphi}{\partial X_2} & \dfrac{\partial^2 F}{\partial X_2 \partial X_1} & \dfrac{\partial^2 F}{\partial X_2^2} \end{pmatrix}, \quad (10)$$

which is generated using the differential derivatives $\dfrac{\partial\varphi}{\partial X_i}$ of the constraint equation (6) and the Hessian matrix $\begin{pmatrix} \dfrac{\partial^2 F}{\partial X_1^2} & \dfrac{\partial^2 F}{\partial X_1 \partial X_2} \\ \dfrac{\partial^2 F}{\partial X_2 \partial X_1} & \dfrac{\partial^2 F}{\partial X_2^2} \end{pmatrix}$.

Table 5. Results of optimization

Point No.	X_1^*	X_2^*	λ^*	det$H$	Constraint extremum functions	y, c.u.
1	–0.55	1.30	0.31	–8.57	min	3.86
2	–0.44	–1.34	–0.016	–2.12	min	4.98
3	–0.99	–1.0	–0.11	2.18	max	5.0
4	1.40	–0.14	–0.36	7.62	max	5.82

Inserting all the differential derivatives in the matrix (10), we will generate its determinant

$$\det H = \begin{vmatrix} 0 & 2X_1 & 2X_2 \\ 2X_1 & (0.46+2\lambda) & 0.15 \\ 2X_2 & 0.15 & (-0.28+2\lambda) \end{vmatrix}. \quad (11)$$

For each found stationary point with the coordinates (X_1^*, X_2^*, λ^*) we calculate the value of determinant of the matrix H (Table 5) using the formula (11). It is visible that the matrix H is negatively certain for the first two stationary points (since $\det H < 0$), therefore, for these points, the second order differential of the Lagrange function $d^2F > 0$ and, thus, these points are the points of conditional minimum. For other stationary points, the matrix H is positively certain, the second order differential of the Lagrange function $d^2F < 0$, therefore, the required stationary points are the points of conditional maximum. The values of optimization parameter y at the established stationary points of factorial space are calculated using the equation 2 and are presented in Table 5.

The results of optimization are in full accordance with the configuration of response surface. Thus, the first two stationary points with the coordinates (–0.55; 1.3) and (–0.44; –1.34) respectively are located on the descending half-hyperbole paraboloids (see Fig. 2). Therefore, the specified points are classified as the points of conditional minimum of the optimization parameter (2) (see Table. 5). Two remained points the coordinates of which are equal to (–0.99;–1.0) and (1.40;–0.14) respectively, are located on the ascending half-hyperbole paraboloids (see Fig. 2) and are classified as the points of the conditional maximum.

Thus, proceeding from the formulated condition of optimization (7), the parameters of doughing $X_1^* = 1.4$ and $X_2^* = -0.14$ those which provide the obtaining of rusks with the maximum value of swelling capacity coefficient, $y = 5.82$ c.u., should be considered as rational ones.

The transition from code values of factors to natural ones taking into account the characteristics of planning (see Table 1) allows to obtain rational values of dosage of wheat germ oil x_1 = 99.82% and humidity of dough x_2 = 40.86%.

The fourth stage consisted in the estimation of reliability and degree of accuracy of the obtained value of optimization criterion.

Dispersion of prediction of the value of optimization parameter [3]

$$S^2(y) = S_{b_0}^2 + S_{b_i}^2 R^2 + S_{b_{ii}}^2 R^4 + 2\operatorname{cov}_{b_0 b_{ii}} R^2, \quad (12)$$

where $S_{b_0}^2$, $S_{b_i}^2$ and $S_{b_{ii}}^2$ are the dispersions when determining the regression coefficients b_0, b_i and b_{ii} respectively; $\operatorname{cov}_{b_0 b_{ii}}$ is covariance; R is the radius of the sphere with a point of the optimum values of factors $X_1^* = 1.4$ and $X_2^* = -0.14$ ($R = 1.41$).

Dispersions when determining regression coefficients are related to residual dispersion and constants of dispersion matrix by the known ratios. Error of prediction of value of optimization criterion

$$\delta = t_{кр}\sqrt{S^2(y)}, \quad (13)$$

where t_{kp} is the critical value of Student criterion (t_{kp} = 2.37 with the significance value p = 5% and the number of degrees of freedom f = 7).

Table 6 provides the results of calculations of dispersion of prediction $S^2(y)$ of the optimization parameter and its confidential interval $y \pm \delta$ (with the confidential probability of 0.95).

The objectivity of determination of rational values of parameters of preparation of dough is confirmed by the results of parallel experiments that show sufficient convergence of results. The average square error did not exceed 0.67%.

CONCLUSION

On the basis of the obtained data a formulation and a way of production of rusks of high nutrition value "Crackling delicacy" has been developed. As for the organoleptic and physical and chemical indicators of quality, the products do not concede the traditional ones, and as for the content of protein, food fibers, mineral substances and vitamins they considerably surpass them (Table 7). Technical documentation (TU 9110-394-02068108-2017) has been developed for the enriched product.

Table 6. Optimum modes. Results of determination of confidential interval

Parameter	Value
Optimum value of criterion of optimization, c.u.	5.82
Dispersion $S^2(\hat{y})$	0.08
Prediction error δ, c.u.	0.67
Confidential interval $y \pm \delta$, c.u.	5.82 ± 0.67

Table 7. Characteristics of nutrition value of dry bread products

Name of the indicator	Daily rate for the adult (according to TR TS 022/2011)	Children's rusks (control)		Rusks "Crackling delicacy"	
		Contents in 100 g of the product	Degree of satisfaction of daily requirement, %	Contents in 100 g of the product	Degree of satisfaction of daily requirement, %
Proteins, g	75	9.6	13	11.9	16
Fats, g	83	2.9	3	4.6	6
Carbohydrates, g	365	74.9	21	63.1	17
Food fibers, g	30	3.1	10	9.8	33
Potassium, mg	3500	108	3	307	9
Calcium, mg	1000	16	2	55	6
Phosphorus, mg	800	76	9	336	42
Magnesium, mg	400	14	4	98	25
Iron, mg	14	1.3	9	4.2	30
Vitamin B_1, mg	1.4	0.14	10	0.40	28
Vitamin B_2, mg	1.6	0.02	1	0.13	8
Vitamin PP, mg	18	1.05	6	4.80	27
Vitamin E, mg	10	0.85	9	3.88	39
Caloric value, kcal / kJ	2500/10467	364/1524	15	341/1428	14

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Please cite this article in press as: Zhuravlev A.A., Lukina S.I., Ponomareva E.I., and Roslyakova K.E. Optimization of technological parameters of preparation of dough for rusks of high nutrition value. *Foods and Raw Materials*, 2017, vol. 5, no. 1, pp. 73–80. DOI: 10.21179/2308-4057-2017-1-73-80.