# Modeling of recipes of special purpose bakery products

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**Abstract.** In this article the results of calculations of experimental-statistical methods are given, using the optimized contents of components in "Puff buns" and "Grain bars" recipes. The proposed products are balanced in the content of nutrients (proteins, fats, carbohydrates), contain a wide range of vitamins and essential amino acids, which allows expanding the consumer food market and more efficiently using vegetable resources. In order to obtain the percentage ratio of the components in the flour products composition, the complete factor experiment – a central compositional rotatable planning experiment – was applied. According to the results of mathematical modeling for "Puff buns", the optimal percentage ratio of rice bioflour and pumpkin was chosen as 20:20, for "Grain bar" the optimal dosage of mashed bananas and Jerusalem artichoke is 28:12 respectively.

## 1 Introduction

Food products design is a process of creation rational recipes that can provide a high level of adequacy of the complex of properties of food products to the consumers' requirements and to the standardized values of nutrients and energy content [1-7]. According to the modern views, the term design of products includes the development of models that describes steps of products creation using the given quality. It also represents mathematical dependence of changing one or several key parameters on which base they are being developed, including the optimization of choice and the ratio of components [8-11].

Purpose of the study – ingredients' optimization in bakery products' recipe – "Puff buns", "Grain bars" which by quantitative content and quality composition will match the formula of balanced diet, as much as possible, meet biomedical requirements and own high consumer properties.

## 2 Materials and research methods

The optimization of the prescribed composition of "Puff buns", "Cereal bars" was performed by experimental statistical methods. To construct the mathematical models of function dependency, the response of input factors, we used central compositional rotable planning of the experiment (CCRP).

The regression equation with two variables in central compositional rotable planning is presented as the second order equation:

$$Y=b_o+b_1X_1+b_2X_2+b_{12}X_1X_2+b_{11}X_1^2+b_{22}X_2^2. \quad (1)$$

The number of experiments using CCRP in the two-factor experiment ( $n=2$ ) equals N=13. To the full factor experiment $2^2$ let us add 5 experiments in centre of the plan and four "star" points with coordinates (+*a*; 0); (-*a*;0); (0; +*a*); and (0; -*a*).

Using CCRP for the regression equations` coefficients (1) and relevant marks of dispersions, we use formulas from the tutorial [12].

## 3 Results and discussion

The grafic interpritation of the regression equation is response surface. Analysis of two-dimensional sections of response surface allows preliminarily determining areas of factor space, where we achieved an optimal value of output parameters. Figures 1-16 show a graphic picture of regression models as paraboloids and a two-dimensional section of paraboloids.

The comparison of estimated values of the Student criterion with the table at a significance level of $\alpha=0{,}05$ and the number of degrees of freedom $N(n_0-1)=16$ ($t_m$= 1.7459) allows choosing significant regression coefficients.

Table values of the Fisher criterion at a significance level of $\alpha=0{,}05$ and the number of degrees of freedom of numerator $\ddot{f}_1=3$ and denominator $\ddot{f}_2=4$ equal $F_т$ = 6.59. The comparison of the Fisher criterion estimated value and table shows that regression equations are adequate to experimental data.

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 https://doi.org/10.1051/bioconf/20202700017

**Table 1.** Planning matrix and results of the experiment «Grain bars».

| № of experiment | Coded values of factors | | Natural values of factors | | Response function | | | |
|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_1$, Jerusalem artichoke content, % | $X_2$, Banana content, % | $Y_1$, mass fraction of protein, % | $Y_2$, mass fraction of cellulose, % | $Y_3$, antioxidant activity, mg/100 g | $Y_4$, complex point mark |
| 1 | -1 | -1 | 5 | 20 | 6,0 | 4,9 | 29 | 69 |
| 2 | +1 | -1 | 16 | 20 | 6,8 | 5,95 | 31 | 70 |
| 3 | -1 | +1 | 5 | 32 | 7,2 | 5,3 | 31,4 | 78 |
| 4 | +1 | +1 | 16 | 32 | 7,5 | 6.16 | 32,5 | 74 |
| 5 | 0 | -1,414 | 10,5 | 17,516 | 6,0 | 4,8 | 28,1 | 80 |
| 6 | -1,414 | 0 | 2,723 | 26 | 6,8 | 5,1 | 31,0 | 62 |
| 7 | 0 | +1,414 | 10,5 | 34,484 | 7,2 | 6.29 | 32,5 | 78 |
| 8 | +1,414 | 0 | 18,277 | 26 | 7,0 | 6.0 | 30,5 | 71 |
| 9 | 0 | 0 | 10,5 | 26 | 6,0 | 6,1 | 28.7 | 95 |
| 10 | 0 | 0 | 10,5 | 26 | 6,0 | 6,1 | 28.7 | 95 |
| 11 | 0 | 0 | 10,5 | 26 | 6,0 | 6,1 | 28.7 | 95 |
| 12 | 0 | 0 | 10,5 | 26 | 6,0 | 6,1 | 28.7 | 95 |
| 13 | 0 | 0 | 10,5 | 26 | 6,0 | 6,1 | 28.7 | 95 |

**Table 2.** Dependences of response function of input factors «Grain bars».

| Response function | Regression equation |
|---|---|
| $Y_1$,- mass fraction of protein, % | $Y_1 = 6{,}00 + 0{,}45X_2 + 0{,}39X_1^2 + 0{,}24X_2^2$ |
| $Y_2$, mass fraction of cellulose, % | $Y_2 = 6{,}03 + 0{,}4X_1 + 0{,}34X_2 - 0{,}28X_1^2 - 0{,}29X_2^2$ |
| $Y_3$, antioxidant activity, mg/100 g | $Y_3 = 28{,}18 + 0{,}9X_1 + 0{,}52X_1^2 + 1{,}479X_2^2$ |
| $Y_4$, complex point mark | $Y_4 = 94{,}35 - 3{,}55X_1 + 0{,}39X_1X_2 - 12{,}342X_1^2 - 10{,}63$ |

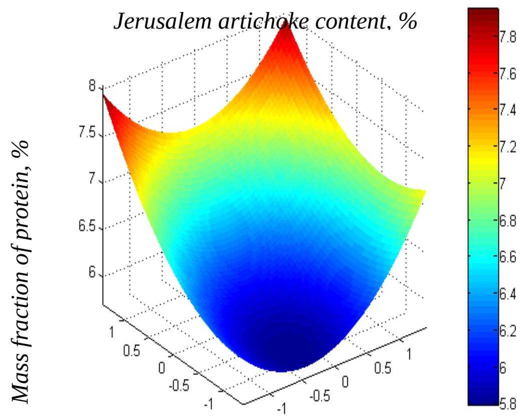


**Fig. 1.** General form of response surface $Y_1$

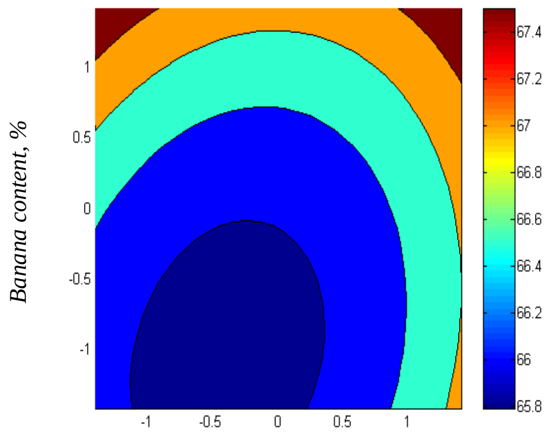


**Fig. 2.** Two-dimensional section of response $Y_1$.

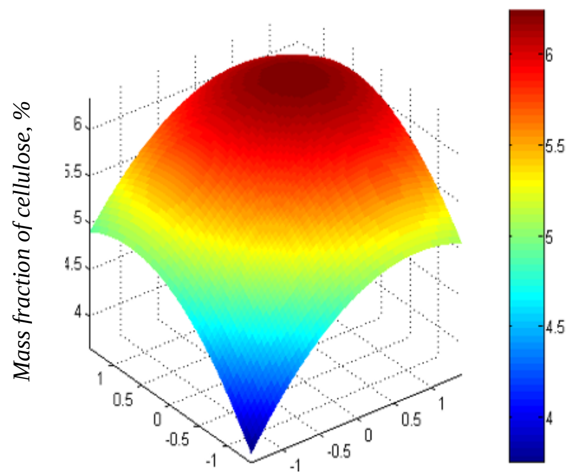


**Fig. 3.** General form of response surface $Y_2$.

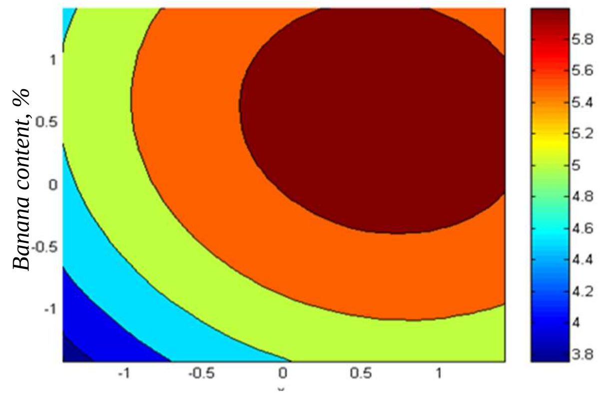


**Fig. 4.** Two-dimensional section of response surface $Y_2$.

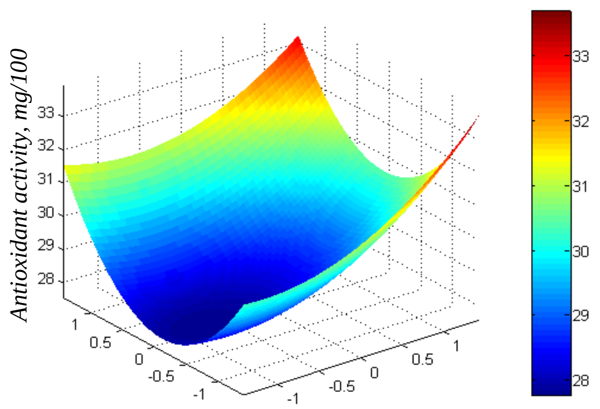


**Fig. 5.** General form of response surface $Y_3$.

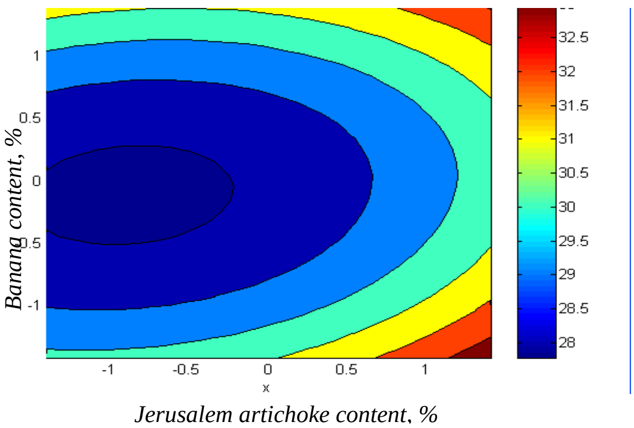


**Fig. 6.** Two-dimensional section of response surface $Y_3$.

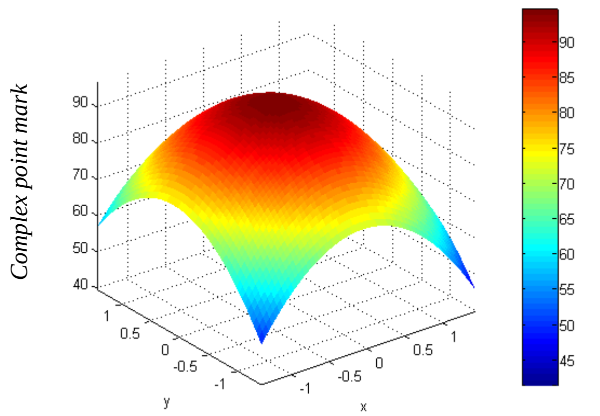


**Fig. 7.** General form of response surface $Y_4$.

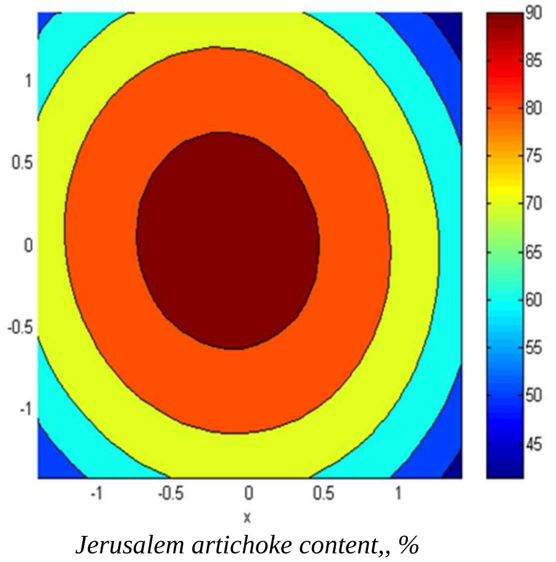


**Fig. 8.** Two-dimensional section of response surface $Y_4$.

**Table 3.** Planning matrix and results of the experiment «Puff buns».

| № of experiment | Coded values of factors | | Natural values of factors | | Response function | | | |
|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $x_1$, Rice flout content, % | $x_2$, Pumpkin puree content, % | $Y_1$, mass fraction of cellulose, % | $Y_2$, β-carotene content, mkg/cm$^3$ | $Y_3$, antioxidant activity, mg/100g | $Y_4$, complex point mark |
| 1 | -1 | -1 | 10,0 | 10,0 | 2,06 | 2,8 | 84 | 69 |
| 2 | +1 | -1 | 20,0 | 10,0 | 2,27 | 2,8 | 84 | 70 |
| 3 | -1 | +1 | 10,0 | 20,0 | 2,30 | 3,3 | 92 | 78 |
| 4 | +1 | +1 | 20,0 | 20,0 | 2,39 | 3,31 | 93 | 100 |
| 5 | 0 | -1,414 | 15 | 7,93 | 2,12 | 2,6 | 81 | 80 |
| 6 | -1,414 | 0 | 7,93 | 15 | 1,98 | 3,02 | 88 | 62 |
| 7 | 0 | +1,414 | 15 | 22,07 | 2,32 | 3,4 | 90 | 78 |
| 8 | +1,414 | 0 | 22,07 | 15 | 2,44 | 3,0 | 91 | 71 |
| 9 | 0 | 0 | 15,0 | 15,0 | 2,22 | 3,11 | 89 | 90 |
| 10 | 0 | 0 | 15,0 | 15,0 | 2,22 | 3,11 | 89 | 90 |
| 11 | 0 | 0 | 15,0 | 15,0 | 2,22 | 3,11 | 89 | 90 |
| 12 | 0 | 0 | 15,0 | 15,0 | 2,22 | 3,11 | 89 | 91 |
| 13 | 0 | 0 | 15,0 | 15,0 | 2,22 | 3,11 | 89 | 90 |

**Table 4.** Results of coefficients significant check of models and the adequacy of the regression equation «Puff buns».

| Response function | Value of coefficients | | | | | | Estimated value of Student criterion | | | | | | Dispersions of adequacy Sad | The estimated value of Fisher criterion |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $b_o$ | $b_1$ | $b_2$ | $b_{12}$ | $b_{11}$ | $b_{22}$ | $t_{b_0}$ | $t_{b_1}$ | $t_{b_2}$ | $t_{b_{12}}$ | $t_{b_{11}}$ | $t_{b_{22}}$ | | |
| $Y_1$, mass fraction of cellulose, % | 2.40 | 0.12 | 0.08 | -0.03 | -0.11 | -0.10 | 22.01 | 1.82 | 1.03 | -0.30 | -1.78 | -1.82 | 0,012272 | 0,252099 |
| $Y_2$, β-carotene, mkg/cm$^3$ | 3.20 | 0.00 | 0.27 | 0.00 | -0.11 | -0.12 | 18.58 | -0.02 | 2.16 | 0.02 | -1.86 | -1.90 | 0,012835 | 0,105569 |
| $Y_3$, antioxidant activity, mg/100 g | 88.10 | 1.36 | 2.29 | 0.25 | -2.41 | 0.53 | 228.53 | 4.95 | 8.36 | 0.71 | -7.58 | 2.49 | 21,61374 | 5,84368 |
| $2Y_4$, complex point mark | 89.84 | -0.31 | 3.63 | 5.23 | -8.49 | -6.78 | 63.48 | -0.30 | 3.58 | 4.07 | -7.89 | -6.29 | 232,672 | 6,37463 |

**Table 5.** Dependences of the response function of input factors «Puff buns».

| Response function | Regression equation in coded variable |
|---|---|
| $Y_1$, mass fraction of cellulose, % | $Y_1 = 2{,}40 + 0{,}12X_1 - 0{,}11X_1^2 - 0{,}10X_2^2$ |
| $Y_2$, β-carotene, mkg/cm$^3$ | $Y_2 = 3{,}20 + 0{,}27X_2 - 0{,}11X_1^2 - 0{,}12X_2^2$ |
| $Y_3$, antioxidant activity, mg/100 g | $Y_3 = 88{,}10 + 1{,}36X_1 + 2{,}29X_2 - 2{,}41X_1^2 + 0{,}55X_2^2$ |
| $Y_4$, complex point mark | $Y_4 = 89{,}84_1 + 3{,}63X_2 + 5{,}23X_1X_2 - 8{,}49X_1^2 - 6{,}79X_2^2$ |

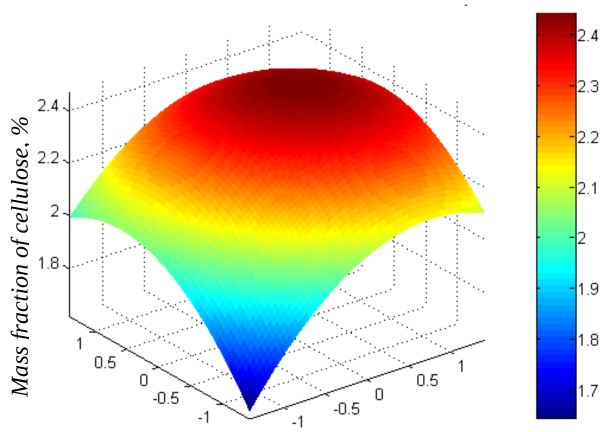


**Fig. 9.** General form of response surface $Y_1$.

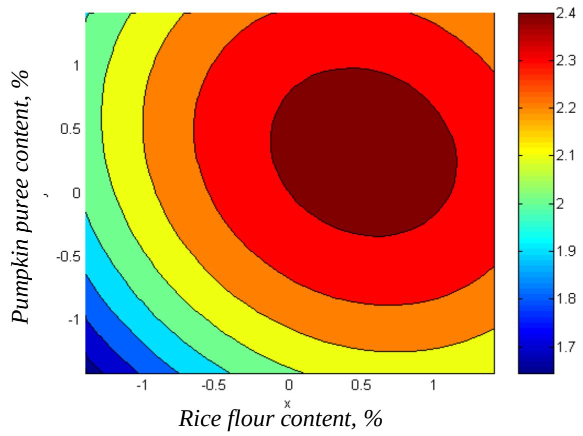


**Fig. 10.** Two-dimensional section of response surface $Y_1$.

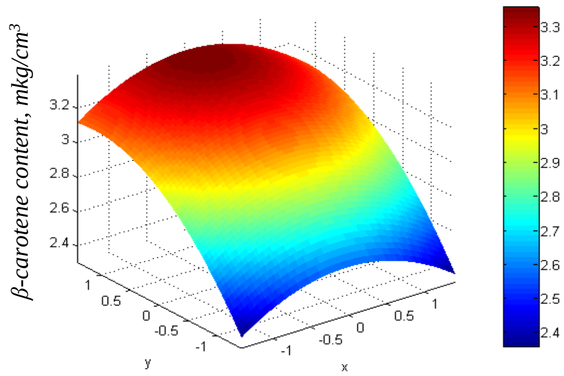


**Fig. 11.** General form of response surface $Y_2$.

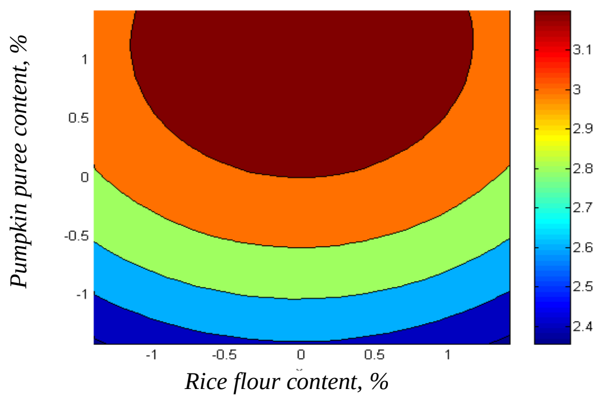


**Fig. 12.** Two-dimensional section of response surface $Y_2$.

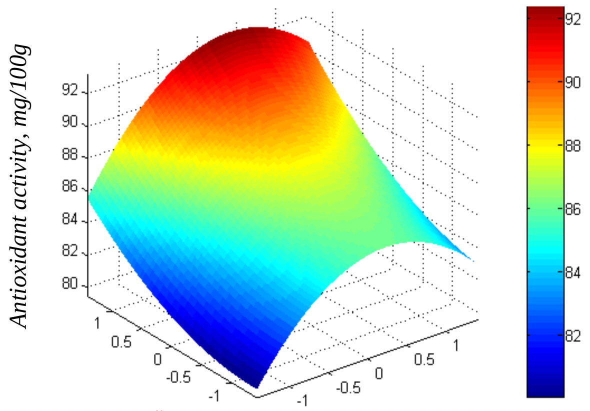


**Fig. 13.** General form of response surface Y3.

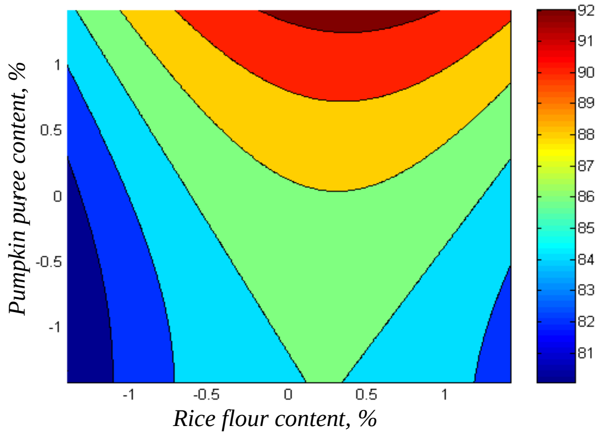


**Fig. 14.** Two-dimensional section of response surface.

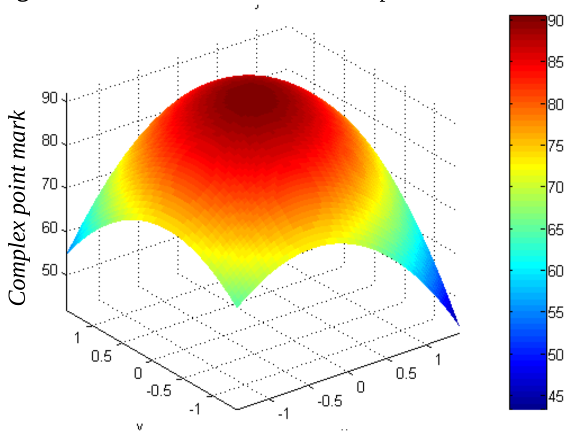


**Fig. 15.** General form of response surface Y4.

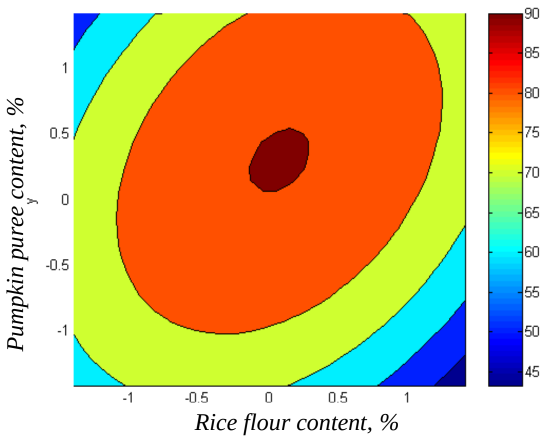


**Fig. 16.** Two-dimensional section of response surface Y4.

Built regression models may be used for recipe optimization of «Cereal bars», «Puff buns».

For the ratio of components determination in the «Cereal bars» recipe, let`s build a mathematical model of optimization by four criteria:

$$6{,}00+0{,}45X_2+0{,}39X_1^2+0{,}24X_2^2 \to miax;$$

$$6{,}03+0{,}4X_1+0{,}34X_2-0{,}28X_1^2-0{,}29X_2^2 \to \max;$$

$$28{,}18+0{,}9X_1+0{,}52X_1^2+1{,}479X_2^2 \to \max x;$$

$$94{,}35-3{,}55X_1+0{,}39X_1X_2-12{,}342X_1^2-10{,}63X_2^2 \to \max$$

while limiting $X_1^2+X_2^2 \le 2;$

here $X_1$, $X_2$ – coded values of factors, related with natural values *xi* by ratios:

$$X_1=\frac{x_1-10{,}5}{5{,}5}; \quad X_2=\frac{x_2-26}{6}.$$

For determination of the components ratio in the recipe of «Puff buns» let`s build a mathematical model of optimization by four criteria:

$$2{,}40+0{,}12X_1-0{,}11X_1^2-0{,}10X_2^2 \to \max;$$

$$3{,}20+0{,}27X_2-0{,}11X_1^2-0{,}12X_2^2 \to \max;$$

$$88{,}10+1{,}36X_1+2{,}29X_2-2{,}41X_1^2+0{,}55X_2^2 \to \max x;$$

$$89{,}84_1+3{,}63X_2+5{,}23X_1X_2-8{,}49X_1^2-6{,}79X_2^2 \to \max$$

while limiting $X_1^2+X_2^2 \le 2;$

here $X_1$, $X_2$ – coded values of factors, related with natural values *xi* by ratios: $X_1=\frac{x_1-15}{5}$; $X_2=\frac{x_2-15}{5}$.

The task of multi-criteria optimization by the target programming method transformation into a mono-criteria task of minimization of the number of deviations with some indicator $p$:

$$G=\left(\sum_{k=1}^{K} w_k\left|\frac{f_k(x,y,z)-\bar{f}_k}{\bar{f}_k}\right|^p\right)^{\frac{1}{p}} \to \min, \qquad (2)$$

where $w_k$ – some weight coefficients that characterize the importance of one or other criterion, $\bar{f}_1, \bar{f}_2,..., \bar{f}_K$ – values of target functions on the optimal plan for each criteria, $p$ – parameter, $k$ – number of target functions.

At $p$=2 and $w_k=1$ we get the following task of minimization of the amount and limitations:

$$G=\left(\sum_{k=1}^{4} w_k\left|\frac{f_k(x,y,z)-\bar{f}_k}{\bar{f}_k}\right|^2\right)^{\frac{1}{2}} \to \min \; X_1^2+X_2^2 \le 2;$$

where $\bar{f}_1$ – maximum of the first criterion, $\bar{f}_2$ – maximum of the second criterion. $\bar{f}_3$ – maximum of the third criterion, $\bar{f}_4$ – maximum of the fourth criterion.

According to the results of the calculations, experimental and statistical methods optimized the contents of the components in the formulation of the developed products, which are confirmed by the results of trial laboratory baking.

The optimal solution of the single criterion task is point $x_1 = 12$, $x_2 = 28$.

The optimal dose of banana and Jerusalem artichoke puree is 28% and 12% respectively.

The optimal solution of the single criterion task is point $x_1 = 20$, $x_2 = 20$.

The optimal dose of rice flour and pumpkin puree is 20% and 20% respectively.

## 4 Conclusion

Thus, the presented results of mathematical modeling of recipes "Grain bars" and "Puff buns", based on the use of raw materials with different chemical composition and functional and technological properties, make it possible to obtain the ratio of recipe components, providing high organoleptic and physicochemical indicators of specialized products.

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