Content optimization of foxtail millet grain flour and pumpkin oil in cracker formula by targeted programming

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Abstract. The paper suggests safe regional raw materials – foxtail millet flour and pumpkin oil – for the use in the technology of healthy nutrition. Various research works have proved the prospect of their application. Foxtail millet is one of the most ancient cereal plants in East Asia. The work used the variety of foxtail millet Amber, selection of the Russian Research, Design and Technology Institute of Sorghum and Corn Federal State Government-Funded Scientific Institution and Saratov State Vavilov Agrarian University. It was sown in Povolzhye Research, Development and Production Facility of Engelsky region and the Russian Research Institute of Sorghum and Corn. The cracker recipe compounds were optimized by experimental and statistical methods. For target programming, finished products were analyzed by strength, water absorption, mass fraction of fat and fiber, organoleptic properties. The influence of factors and their interaction on the indicators was studied by multivariate analysis of variance. To construct mathematic models of response function dependence on input factors, a complete factorial experiment was used at two levels with additional experiments carried out in star points of the plan center. The target programming made it possible to establish that the optimal content of foxtail millet grain flour in the cracker formula is 20%, pumpkin oil – 24% to the flour weight.

1. Introduction
One of the priorities of scientific and technological development of Russia is effective processing of agricultural products, creation of safe and functional food products.

The problem could be solved by developing combined food technology using functional ingredients based on regional safe and high-quality raw materials. Since bakery and flour confectionery products have high consumer demand in Russia, their enrichment with functional additives will make a significant contribution to improvement of public health [1-4].

It is promising to use the grain of foxtail millet – a valuable agricultural crop – as a useful functional additive. Foxtail millet (Panicum italicum – Italian, Chinese or many-headed millet) is one of the oldest cereals known. Chemical composition and useful properties make it advisable to use foxtail millet grain processing products in healthy nutrition technology [5, 7].

The Moscow Institute of Hygiene and Nutrition proved that the concentration of linolic acid in foxtail millet oil exceeds 61.5% of the weight of all fatty acids. The combination of linolic, linolenic and
arachidonic acids, commonly known as the vitamin F, raises the indicator of the sum of these acids to 64% and already makes it possible to talk about the concentrate of this vitamine in the composition of foxtail millet grain [8].

According to Kuznetsova L.I. et al. (2019), the foxtail millet grain is environmentally friendly [6]. According to Belarusian scientists, the foxtail millet is perfectly suitable for use in ecological farming. It hardly accumulates heavy metals and poison in its composition [8].

Due to their special taste qualities and unique healing properties, pumpkin seeds are recognized in modern dietetics as one of the best products for medicinal and prophylactic food and child nutrition. Pumpkin seeds contain up to 40% of the most useful edible oil. Pumpkin seed oil contains vitamins A, В1, В2, В6, С, Е, K, Р, РР, phospholipids, carotenoids, tocopherols, flavonoids, as well as iron, magnesium, zinc, selenium, potassium, calcium and other useful elements. The main advantage of pumpkin oil is the presence of polyunsaturated fatty acids: Omega-3 and Omega-6, vitamin F. The purpose of the study is to optimize the content of foxtail millet grain and pumpkin oil in the cracker flour formula by targeted programming.

2. Methods
The work used the variety of foxtail millet Amber, selection of the Russian Research, Design and Technology Institute of Sorghum and Corn Federal State Government-Funded Scientific Institution and Saratov State Vavilov Agrarian University. It was sown in Povolzhye Research, Development and Production Facility of Engelssky region and the Russian Research Institute of Sorghum and Corn. The cracker recipe compounds were optimized by experimental and statistical methods.

The finished products were analyzed by strength, water absorption, mass fraction of fat and fiber, organoleptic properties using the Stroganov device. Water absorption was defined according to GOST 10114, mass fraction of fat – according to GOST 31902 2012, mass fraction of fiber – according to GOST 5903.

The influence of factors and their interactions on the indicators were studied by means of a multivariate analysis of variance (Table 1). Three parallel experiments were conducted on each combination of the four factor levels.

| Indicator                        | Input variable | Fisher’s variance ratio | Influence on output value |
|----------------------------------|----------------|-------------------------|---------------------------|
| Mass fraction of fiber, %        | x1 x2          | 368.0602 1.335358       | Major influence  No influence |
| Mass fraction of fat, %          | x1 x2 x4       | 0.618608 16.34753       | No influence              |
| Mass fraction of fat, %          | x1 x2 x3      | 6437.149 1.048026       | Major influence  Insignificant influence |
| Water absorption, %              | x1 x2 x3      | 1340.926 1.34753        | Major influence  Insignificant influence |
| Strength, H                      | x1 x2 x3 x4   | 706.3105 286.2468       | Major influence  Major influence |

To construct mathematic models of response function dependence on input factors, a complete factorial experiment was used at two levels with additional experiments carried out in star points of the plan center.

The regression equation in such planning is presented in a quadratic form:

\[ Y = b_0 + b_1X_1 + b_2X_2 + b_3X_1X_2 + b_4X_1^2 + b_5X_2^2 \] (1)
The number of experiments within a two-factor experiment \((n = 2)\) equals \(N=13\). To the complete factorial experiment of \(2^2\) type, 5 experiments are added in the plan center and four “star” points with coordinates \((+a; 0); (-a;0); (0; +a);\) and \((0; -a)\). Here, \(a\) is the “star shoulder” equal to \(2^{\frac{n}{2}}\) (Figure 1).

![Figure 1. Area of experiment](image)

To calculate the coefficients of the regression equation (1) and the corresponding variance estimates the following constants (2)-(4) are found [1].

\[
A = \frac{1}{2B(n+2)B-n};
\]

\[
B = \frac{nN}{(n+2)(N-n_0)};
\]

\[
C = \frac{N}{N-n_0};
\]

Based on the results of the experiment, the following sums are found:

\[
S_0 = \sum_{j=1}^{N} y_j; \quad S_{jk} = \sum_{j=1}^{N} X_{ji}X_{jk} y_j; \quad S_i = \sum_{j=1}^{N} X_{ji} y_j; \quad S_{ii} = \sum_{j=1}^{N} X_{ji}^2 y_j
\]

The formulas for calculating the coefficients of the regression equation are as follows:

\[
b_0 = \frac{2AB}{N} \left[ S_0 B(n+2) - C \sum_{i=1}^{n} S_{ii} \right];
\]

\[
b_i = \frac{CS_i}{N};
\]

\[
b_{ik} = \frac{C^2 S_{ik}}{BN};
\]

\[
b_{ii} = \frac{AC}{N} \left[ S_{ii} C[B(n+2) - n] + C(1-B) \sum_{i=1}^{n} S_{ii} - 2BS_0 \right].
\]

The variance estimates in defining the coefficients of the regression equation are found by the formulas (10)-(13)

\[
\sigma_{b0}^2 = \frac{2AB(n+2)}{N} S_y^2
\]
\[ s_{b_{ij}}^2 = \frac{S_y^2}{N - n_0} \]  \hspace{2cm} (11)

\[ S_{b_{ik}}^2 = \frac{C^2 S_y^2}{N} \]  \hspace{2cm} (12)

\[ S_{b_{ii}}^2 = \frac{AC^2 S_y^2}{N} \left[ B(n+1) - (n-1) \right] \]  \hspace{2cm} (13)

The variance estimates of reproducibility, which is related to experimental results in the center of the plan, is calculated by the formula:

\[ S_y^2 = \frac{\sum_{u=1}^{n_0} (y_u - \bar{y}^0)^2}{n_0 - 1} \]  \hspace{2cm} (14)

The significance of each coefficient of the regression equation is determined through the Student criterion by calculating its value

\[ t_b = \frac{|p|}{\sqrt{\frac{S_y^2}{S_{b'}^2}}} \]

The adequacy of the obtained model is determined by the Fisher’s criterion by the formula (15):

\[ F_p = \frac{\max \left\{ S_{ab}^2, S_{b}^2 \right\}}{\min \left\{ S_{ab}^2, S_{b}^2 \right\}} \]  \hspace{2cm} (15)

where \( S_{ab}^2 \) – adequacy variance estimate (16):

\[ S_{ab}^2 = \frac{\sum_{j=1}^{N} (y_j^2 - \bar{y}^0)^2 \frac{n_0 - 1}{n - (n+2)(n-1)/2}}{N - (n+2)(n-1)/2 - (n_0 - 1)} \]  \hspace{2cm} (16)

3. Results and discussion
The planning matrix and results of the experiment are shown in Table 2. The test of significance of the model coefficients and the adequacy of the regression equation are shown in Table 3.
Table 2. Planning matrix and results of experiment (Ogonyok cracker)

| No. experiment | Coded factor value | Natural factor value | Response function |
|----------------|--------------------|----------------------|-------------------|
|                | x1, foxtail millet grain | x2, pumpkin | Y2 mass fraction of | Y3, water | Y4, strength, | Y5, integrated |
|                | flour content, % | oil content, % | fat, % | absorption, % | H | score |
| 1              | -1                 | -1                 | 15.0  | 20.0  | 4.5  | 22.8      | 142  | 760 | 80   |
| 2              | +1                 | -1                 | 25.0  | 20.0  | 4.9  | 23.1      | 160  | 760 | 70   |
| 3              | -1                 | +1                 | 15.0  | 30.0  | 4.5  | 32.6      | 138  | 620 | 70   |
| 4              | +1                 | +1                 | 25.0  | 30.0  | 4.9  | 33.0      | 157  | 610 | 65   |
| 5              | 0                  | -1.41              | 20.0  | 17.9  | 4.7  | 21.7      | 149  | 760 | 90   |
| 6              | -1.41              | 0                  | 12.9  | 25.0  | 4.1  | 27.5      | 140  | 700 | 90   |
| 7              | 0                  | 1.414              | 20    | 32.1  | 4.7  | 35.1      | 136  | 590 | 70   |
| 8              | +1.414             | 0                  | 27.1  | 25.0  | 5.1  | 28.6      | 165  | 710 | 65   |
| 9              | 0                  | 0                  | 20.0  | 25.0  | 4.78 | 28.1      | 147  | 796 | 95   |
| 10             | 0                  | 0                  | 20.0  | 25.0  | 4.71 | 28.0      | 146  | 790 | 90   |
| 11             | 0                  | 0                  | 20.0  | 25.0  | 4.67 | 28.1      | 148  | 794 | 90   |
| 12             | 0                  | 0                  | 20.0  | 25.0  | 4.7  | 28.5      | 146.5| 791  | 95  |
| 13             | 0                  | 0                  | 20.0  | 25.0  | 4.75 | 28.2      | 146.9| 798  | 94  |

Table 3. Results of the test of significance of the model coefficients and the adequacy of the regression equation (Ogonyok cracker)

| Response function | Coefficient value | Calculated Student criterion | Adequacy dispersion, Sad | Calculated Fisher’s variance ratio |
|-------------------|-------------------|-------------------------------|--------------------------|----------------------------------|
| $b_0$             | $b_1$             | $b_2$ $b_3$ $b_4$ $b_5$ $b_6$ | $t_{b_0}$ $t_{b_1}$ $t_{b_2}$ $t_{b_3}$ $t_{b_4}$ $t_{b_5}$ $t_{b_6}$ | $b_0$ $b_1$ $b_2$ $b_3$ $b_4$ $b_5$ $b_6$ |
| $Y_1$, mass fraction of fiber, % | 4.6984            | -0.00063                      | 0.00762                 | -0.17714                        | 0.08199 |
| $Y_2$, mass fraction of fat, %     | 27.88231          | 1.10923                      | 1.38958                 | 0.02492                         | -0.15879 |
| $Y_3$, water absorption, %         | 145.33850         | 3.03491                      | 4.23767                 | 0.26262                         | -1.34700 |
| $Y_4$, strength, H                  | 765 3904          | -11.8185                     | -14.9817                | -2.48231                        | -3.59966 |
| $Y_5$, integrated score             | 918.1629          | -1.36926                     | -1.25026                | -0.82015                        | -1.43570 |

Note: $F_{crit} = 2.7185$
Table 4. Response function dependencies on input factors (*Ogonyok* cracker)

| Response function | Regression equation in coded variables                                      |
|-------------------|--------------------------------------------------------------------------------|
| $Y_1$, mass fraction of fiber, % | $Y_1 = 4.69584 - 0.17714X_1^2$                                           |
| $Y_2$, mass fraction of fat, %    | $Y_2 = 27.88231 + 1.10923X_1 + 1.30958X_2 - 1.95879X_1^2 + 1.59729X_2^2$  |
| $Y_3$, water absorption, %       | $Y_3 = 145.328 + 3.02491X_1 + 4.23767X_2 - 1.3477X_1^2 + 1.59526X_2^2$  |
| $Y_4$, strength, Н               | $Y_4 = 785.389 - 11.8185X_1 - 14.9937X_2 - 35.1966X_1^2 - 74.436X_2^2$ |
| $Y_5$, integrated score          | $Y_5 = 91.8163 - 1.86923X_1 - 2.75026X_2 - 3.5978X_1^2 - 1464663X_2^2$ |

The comparison of each of the calculated values of the Student criterion with tabulated values at the level of significance $\alpha = 0.05$ and the number of degrees of freedom $N(n_0 - 1) = 16 \ (t_m = 1.7459)$ allows selecting significant regression coefficients.

The tabulated value of the Fisher criterion at the level of significance $\alpha = 0.05$ and the number of values of freedom of the numerator $f_1 = 3$ and denominator $f_2 = 4$ equals $F_t = 6.59$. The comparison of the calculated Fisher criterion and the tabulated one shows that the regression equations are adequate to the experimental data.

**Figure 2.** General view of response surface $Y_1$

**Figure 3.** Two-dimensional sections of response surface $Y_1$ opening surface (numbers on curves – values of fiber mass fraction, %)
Figure 4. General view of response surface $Y_2$

Figure 5. Two-dimensional sections of response surface $Y_2$ (numbers on curves – values of fat mass fraction, %)

Figure 6. General view of response surface $Y_3$

Figure 7. Two-dimensional sections of response surface $Y_3$ (numbers on curves – values of water absorption, %)

Figure 8. General view of response surface $Y_4$

Figure 9. Two-dimensional sections of response surface $Y_4$ (numbers on curves – values of strength, %)
The designed regression models can be used to optimize the cracker formulation. To determine the ratio of components, let us build a mathematical model of optimization according to five criteria:

\[
\begin{align*}
4.69584 - 0.17714X_1^2 & \rightarrow \text{max} ; \\
27.88231 + 1.10923X_1 + 1.30958X_2 - 1.95879X_1^2 + 1.59729X_2^2 & \rightarrow \text{min} ; \\
145.328 + 3.02491X_1 + 4.23767X_2 - 1.3477X_1^2 + 1.59526X_2^2 & \rightarrow \text{max} ; \\
785.389 - 11.8185X_1 - 14.9937X_2 - 35.1966X_1^2 - 74.4361X_2^2 & \rightarrow \text{max} \\
91.8163 - 1.86923X_1 - 2.75026X_2 - 3.5978X_1^2 - 1464663X_2^2 & \rightarrow \text{max}
\end{align*}
\]

under constraints \(X_1^2 + X_2^2 \leq 2\);

Here \(X_1, X_2\) – coded values of factors associated with the natural values of \(x_i\) ratios:

\[
X_1 = \frac{x_1 - 20}{5} ; \\
X_2 = \frac{x_2 - 25}{5}.
\]

The multi-objective optimization problem by target programming is converted into a single-objective problem of minimizing the sum of deviations with some indicator \(p\):

\[
G = \left( \sum_{k=1}^{K} w_k \left| f_k(x, y, z) - \tilde{f}_k \right|^{\frac{1}{p}} \right)^{\frac{1}{p}} \rightarrow \text{min} ,
\]

where \(w_k\) – some weighting factors characterizing the importance of a particular criterion, \(\tilde{f}_1, \tilde{f}_2, ..., \tilde{f}_k\) – values of target functions on the optimal plan for each criterion, \(p\) – parameter, \(k\) – number of target functions.
At \( p=2 \) and \( w_k = 1 \) we get the following minimization problem with criteria and constraints:

\[
G = \left( \sum_{k=1}^{5} w_k \left( \frac{f_k(x, y, z) - \bar{f}_k}{\bar{f}_k} \right)^2 \right)^{\frac{1}{2}} \rightarrow \min ; \quad x_1^2 + x_2^2 \leq 2;
\]

where \( \bar{f}_1 \) – maximum of the first criterion, \( \bar{f}_2 \) – minimum of the second criterion, \( \bar{f}_3 \) – maximum of the third criterion, where \( \bar{f}_4 \) – maximum of the fourth criterion, \( \bar{f}_5 \) – maximum of the fifth criterion.

The optimization problem for each criterion is solved in MS Excel using the Find Solution procedure. Table 5 shows the solution results.

**Table 5. Results of optimization problems**

| Optimal design criterion | Coded factor value | Natural factor value |
|--------------------------|-------------------|---------------------|
|                          | \( x_1 \) | \( x_2 \) | \( x_1 \), foxtail millet grain flour content, % | \( x_2 \), pumpkin oil content, % |
| \( \bar{f}_1 = 5.1 \)    | +1.414 | 0 | 24 | 25.0 |
| \( \bar{f}_2 = 23.0 \)   | -1.2 | -0.748331477 | 14 | 21,25834 |
| \( \bar{f}_3 = 158 \)    | 1 | 1 | 25 | 30 |
| \( \bar{f}_4 = 780 \)    | 0 | 0 | 20 | 25 |
| \( \bar{f}_5 = 95 \)     | 0 | -0.2 | 20 | 24 |
| \( G = 0.19312 \)       | 0 | -0.2 | 20 | 24 |

4. Conclusion
The optimal solution to the single-objective problem is the point \( x_1 = 20, x_2 = 24 \). The optimal content of foxtail millet grain flour and pumpkin oil in the cracker formula is 20% and 24%, respectively.

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