Parameters modelling of amaranth grain processing technology

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Abstract. The article presents a technique that allows calculating the structure of a multicomponent bakery mixture for the production of enriched products, taking into account the instability of nutrient content, and ensuring the fulfilment of technological requirements and, at the same time considering consumer preferences. The results of modelling and analysis of optimal solutions are given by the example of calculating the structure of a three-component mixture of wheat and rye flour with an enriching component, that is, whole-hulled amaranth flour applied to the technology of bread from a mixture of rye and wheat flour on a liquid leaven.

1. Introduction

Discussing the issues of rational use of natural resources, it is worth mentioning the priority of tasks in the field of ensuring the food security of the Russian Federation, guaranteeing the physical and economic availability for each citizen of the country of food products that meet the requirements of the Russian Federation legislation on technical regulation, in quantities not less than rational norms for the consumption of food products, necessary for an active and healthy lifestyle. One of the factors ensuring the country's food security is the necessary production of grain resources. At the same time, traditional technologies of grain processing, as a rule, use the central layers of corn seed grain, excluding from consumption a significant share of protein, vitamins, minerals and dietary fibres [1]. More effective approaches to the integrated use of grain resources are faced with problems of deteriorating consumer properties of finished products [2]. In this connection, it is advisable to model the technologies (technology stages) taking into account the predicted consumer properties, including the content of enriching nutrients and sensory characteristics of finished products. At the same time, the methodology should contain not only mathematical models for calculation of component parts, but also models for analysing the solutions obtained.

The purpose of the analysis is to determine the sensitivity of the solutions obtained to the instability of the physicochemical properties and composition of the components, which is especially characteristic of enriching additives. The method involves solving the problem of choosing the characteristics of bakery products, adequately reflecting the preferences of consumers who, on the one hand, are loyal to enriching additives, on the other - psychologically inclined to choose traditional taste and appearance of products.
2. Materials and methods
The standard approach is the solution of the linear programming problem for composing the mixture and the subsequent so-called post-optimal analysis, which cannot be used in view of the instability of the properties and characteristics of the components and is considered only as a basis for constructing a model for calculating the structure of a baking mixture in the form of a task stochastic programming.

The mathematical model of the problem provides for the definition of:
- objective function;
- restrictions;
- boundary conditions.

The standard linear programming problem with objective function
\[ F = \sum_{j=1}^{n} c_j x_j \rightarrow \max(\min, \text{Const}) \], restrictions \[ \sum_{j=1}^{n} x_j = 1, \quad \sum_{j=1}^{n} a_{ij} x_j \leq b_i \], and boundary conditions \[ d_i \leq x_j \leq D_j, \quad i = 1, m, \quad j = 1, n \] is interpreted as follows.

The objective function characterizes the content of a certain nutrient in the mixture, and, as a rule, it is determined by the maximum of the objective function. As such substances, one can consider micro- and macronutrients, the list of which corresponds to [3]. The required values of variables \( x_j \) are the parts of the components. Consequently, coefficients \( c_j \) in the objective function are laboratory-determined nutrient contents in the components of the mixture. The first constraint is logical for the given statement of the problem: the sum of the components' fractions is equal to one. The second group of restrictions is related to the technological requirements for the baking properties of the mixture, which form the properties and characteristics of finished products and, accordingly, the preferences of consumers. Only with a certain set of baking properties, the flour composition can provide traditional or close to traditional quality of bakery products such as appearance, taste, aroma and other sensory characteristics.

If quantities \( a_{ij} \) and \( b_i \) occurring in the constraints are random, then the \( i \)-th constraints are written as:

\[ P\left[ \sum_{j=1}^{n} a_{ij} x_j \leq b_i \right] \geq \alpha_i \tag{1} \]

where \( \alpha_i \) is a given probability, with which the \( i \)-th constraint must be satisfied.

Combining the objective function, constraints, and boundary conditions, M is formulated: the problem of stochastic programming [4, 5] as the problem of composing a mixture when maximizing the average value of the objective function (2), \( n \) is the number of components of the mixture; \( m \) is the number of constraints:

\[
\begin{align*}
M[F] \rightarrow \max, \\
\sum_{j=1}^{n} x_j &= 1, \\
P\left[ \sum_{j=1}^{n} a_{ij} x_j \leq b_i \right] &\geq \alpha_i, \\
d_i \leq x_j &\leq D_j, \quad i = 1, m, \quad j = 1, n
\end{align*}
\tag{2}
\]

In solving problem (2), the deterministic equivalent is used:
Here $\alpha_i$ is given probability levels, $t(\alpha_i)$ is the inverse of the standard normal distribution, the value of $W_i$ characterizes the variation of values $a_{ij}$ and $b_i$ (\(\sigma^2\) - variances $a_{ij}$ and $b_i$ respectively). In the case of deterministic initial data, $W_i = 0$.

It is suggested to distinguish the following classes of restrictions:

1. Technological limitations, for example, restrictions on the content of gluten in the mixture, on the limiting autolytic activity of the flour mixture (assuming that the values of the parameters in the mixture are linearly dependent on their values in the components).

2. Restrictions related to the preferences of consumers, for example, restrictions on the cost, energy value, colour of the crumb of the finished product, etc. Here, additional research is needed to relate the physic-chemical characteristics of the mixture to the characteristics of finished products, which are evaluated by consumers and influence their choice.

3. Additionally, limitations on the compatibility of individual components can be introduced into the model.

The problem formulated is the determining one in the proposed procedure for calculating the structure of a multicomponent baking mixture for the production of enriched products, taking into account the instability of the nutrient content. The solution of the problem makes it possible to determine the structure of the mixture that provides the given properties of the finished product. According to the results of the task, additional studies can be performed:

- determination of the dependence of the optimal value of the objective function on the characteristics variation of the mixture components;
- determination of the dependence of the optimal value of the objective function on $\alpha_i$
- probability with which the $i$-th restriction must be satisfied;
- determination of the relationship between the values of technological characteristics and the content of a particular nutrient content;
- determination of the relationship between the values of consumer characteristics and the content of a particular nutrient content.

3. Results

The proposed technique was used to calculate a three-component mixture of the first grade wheat flour, rye bread baking stripping flour and whole-wheat flour from Valentina variety amaranth. It should be noted that Valentina amaranth refers to varieties that have a dark colour of shell particles, which generally limits its use in the baking industry. At the same time, it has high agro technical characteristics and can be used in bread technology from a mixture of rye and wheat flour.
The results of studies for the task of composing a mixture with the maximum nutrient content of "Dietary Fibres" at given levels of gluten (technological parameter) and ash content are below. Since ash determines the colour of the crumb of the finished product, it was chosen as a restriction associated with the preferences of consumers. The dimensionality of the model (3) is: \( n = 3, m = 2 \).

The following designations are introduced: \( x_1 - \) wheat flour fraction, \( x_2 - \) rye flour fraction, \( x_3 - \) amaranth flour fraction. The mathematical expectations of the values of the objective function coefficients and constraints for model (3) are presented in Table 1.

### Table 1. Values and mathematical expectations of the values of the coefficients of the objective function and constraints

| The name of the coefficient | Notation | Coefficient value |
|----------------------------|----------|-------------------|
| The mathematical expectation of the content of dietary fibre in wheat, rye and amaranth flour, respectively, g / 100 g | \( M[c_1] \) | 0.56 |
| | \( M[c_2] \) | 0.85 |
| | \( M[c_3] \) | 2.8 |
| The mathematical expectation of gluten content in wheat, rye and amaranth flour, respectively, % | \( M[a_{11}] \) | 30 |
| | \( M[a_{12}] \) | 0 |
| | \( M[a_{13}] \) | 0 |
| The mathematical expectation of ash content in wheat, rye and amaranth flour, respectively, % | \( M[a_{21}] \) | 0.45 |
| | \( M[a_{22}] \) | 1.45 |
| | \( M[a_{23}] \) | 3.1 |
| The lower limit of the content of wheat, rye and amaranth flour in the mixture, the share | \( d_1 \) | 0.4 |
| | \( d_2 \) | 0 |
| | \( d_3 \) | 0 |
| The upper limit of the content of wheat, rye and amaranth flour in the mixture, the share | \( D_1 \) | 0.8 |
| | \( D_2 \) | 0.4 |
| | \( D_3 \) | 0.2 |
| The maximum allowable content of gluten in the mixture, % | \( b_1 \) | Not less than a) 20 |
| | | b) 18 |
| | | Not more than 1.0 |
| | | Not more than 1.5 |

Table 2 shows the coefficients of the objective function.

### Table 2. Mathematical expectations of the values of the coefficients of the objective function

| Coefficient notation | Notation | Coefficient value |
|----------------------|----------|-------------------|
| The mathematical expectation of the content of dietary fibre in wheat, rye and amaranth flour, respectively, g / 100 g | \( M[c_1] \) | 0.2 |
| | \( M[c_2] \) | 1.2 |
| | \( M[c_3] \) | 6.7 |

The result of the solution of the problem showed that the limiting limitation is the content of gluten in the mixture. At a minimum permissible level of 20% the problem does not have an acceptable solution with a variation level in characteristics of 20%. Solutions for a given probability of fulfilling the constraints \( \alpha_1 = \alpha_2 = 0.8 \) are presented in Table 3.
Table 3. Estimated values of the composition of the mixture and the content of dietary fibre (the probability of fulfilling the constraints is 0.8)

| Coefficient of variation | Share of wheat flour | Share of rye flour | Share of Amaranth flour | Dietary fibre content, g / 100 g |
|--------------------------|----------------------|-------------------|-------------------------|-------------------------------|
| The level of gluten is not lower than 18% |                      |                   |                         |                               |
| 0                        | 0.6                  | 0.2               | 0.2                     | 1.7                           |
| 0.05                     | 0.63                 | 0.17              | 0.20                    | 1.67                          |
| 0.1                      | 0.66                 | 0.14              | 0.20                    | 1.64                          |
| 0.15                     | 0.69                 | 0.11              | 0.20                    | 1.61                          |
| 0.2                      | 0.72                 | 0.08              | 0.20                    | 1.58                          |
| The level of gluten is not lower than 20% |                      |                   |                         |                               |
| 0                        | 0.67                 | 0.13              | 0.20                    | 1.63                          |
| 0.05                     | 0.70                 | 0.10              | 0.20                    | 1.60                          |
| 0.1                      | 0.73                 | 0.07              | 0.20                    | 1.57                          |
| 0.15                     | 0.76                 | 0.04              | 0.20                    | 1.54                          |
| 0.2                      | There is no optimal solution |         |                         |                               |

The dependence of gluten on the content of dietary fibre is linear (Figure 1) and depends on the given probability of restriction $\alpha_1 = 0.8$ and $\alpha_2 = 0.9$.

Figure 1. Dependence of the gluten content in the mixture on the content of dietary fibre (variability of the characteristics of the components $v = 0.1$)

The method of evaluating the potential of the enriching grain ingredient in the formation of the bakery products quality made it possible to identify two benchmarks for approbation of bread recipes from a mixture of rye, wheat and amaranth flour at a ratio of 0.2: 0.6:0.2 and 0.13-0.6: 0.2 in mass fractions.

In experimental studies, the technology of bread from a mixture of rye and wheat flour was tested with the introduction of whole-wheat flour from an amaranth of Valentine variety into a nutritious mixture at mass ratio fractions of 0.13: 0.6: 0.2.

Dynamics of the main biotechnological characteristics of the leaven (Table 4, Fig. 2) shows that the introduction of whole-hulled amaranth flour into the nutrient medium of the leaven promotes the intensification of the vital activity of lactic acid bacteria.

Table 4. Microbiological characteristics of leaven

| Sourdough sample                          | Number of cells, million / g |
|-------------------------------------------|------------------------------|
|                                           | lactic acid bacteria         | yeast                        |
| Control leaven                            | 756±22                       | 40±1.2                       |
| The leaven with the introduction into the culture medium of whole-hulled amaranth flour | 816±24                       | 32±1.2                       |
Probably, microorganisms of amaranth, primarily manganese, which prevent autolysis of cells and play an important role in the metabolism of lactic acid bacteria, exert a stimulating effect on lactic acid bacteria [6].

![Image](image_url)

**Figure 2.** The microflora of a liquid rye ferment: a - control, b - leaven with the introduction of whole-hulled flour from amaranth

4. Conclusion

The conducted studies made it possible to propose a methodology for calculating the structure of a multicomponent bakery mixture for the production of enriched products, taking into account the instability of the nutrient content, and ensuring the fulfilment of technological requirements and, at the same time, taking into account consumer preferences. The methodology involves setting the problem of calculating the components of a mixture in the form of a stochastic programming problem in the M-statement, i.e. the mathematical expectation of the value of the objective function is optimized for given values of the variation of the coefficients and the probability of the fulfillment of the constraints. The results of modelling and analysis of optimal solutions are shown by the example of calculating the structure of a three-component mixture of wheat and rye flour with an enriching component that is whole-hulled amaranth flour applied to the technology of bread from a mixture of rye and wheat flour on a liquid leaven.

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