Optimization of the mineral composition of combined formed fish products

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Abstract. The purpose of the study is to develop formulations of combined molded products from fish raw materials enriched with calcium, magnesium and phosphorus, using the method of formalizing the criterion for optimizing the mineral composition. The authors propose using an optimization criterion that includes information on the content of minerals in the ingredients of a food product and the ratio of these minerals in the diet of a certain group of consumers. We viewed an algorithm for solving the optimization problem on the example of combined molded products from fish raw materials. We determined the content of calcium, magnesium and phosphorus in the muscle tissue of fish raw materials (pink salmon, pollock, pike) and in a mineral supplement (MS) obtained from fish bones. As enrichment agents of the mineral composition of fish products, we used MS, skimmed milk powder (SMP), vegetables and cereals. The calculation of the optimization criterion and its graphical interpretation for two- and three-component mixtures showed the possibility of obtaining products with a balanced mineral composition, if one of the components is SMP or MS in the amount of 23% and 25%, respectively. We developed unified formulations of molded products, including minced fish, MS and a vegetable-fat composition (or SMP and oat). Products are characterized by a balanced mineral composition (Ca: P: Mg = 1: 1.1: 0.3-0.4); the calcium content in 100 g of the product is 17-21% of the daily requirement.

1. Introduction
A complete diet of a modern person should include a balanced composition of minerals. The role of them in the body of man is multifunctional. So calcium takes part in the regulation of the activity of the neuromuscular system, the formation of integumentary and bone tissues, is part of tooth enamel, etc.

Phosphorus is also necessary for the formation of bone tissue, is involved in the processes of muscle contraction and carbohydrate metabolism. Phosphates play an important role in regulating blood pH. Phosphoproteins of the brain provide the speed of biochemical reactions in the central nervous system cells. Magnesium has a high chemical affinity for oxygen, so it is actively involved in the metabolism and is a universal regulator of biochemical and physiological processes, it is necessary for the functioning of the nervous system [1, 2]. In accordance with the balanced nutrition formula, the ratio of Ca: P: Mg in the diet for adults should be 1: 0.8: 0.4; for children of different age groups - on average 1:1:0.25 [3].
Sour milk products are the optimal dietary sources of calcium [4]: an acidic medium promotes the dissolution of calcium salts, and lactose provides a more complete absorption of calcium in the gastrointestinal tract [5].

Monitoring of the nutritional status of children in the Russian Federation, conducted by scientists of the Federal State Budgetary Institution of Science “Federal Research Center for Nutrition, Biotechnology and Food Safety” revealed a deficiency of calcium intake in more than 80% of children. The main reason for this became the low consumption of milk and dairy products. With age, the role of milk decreases due to the increasing role of other food sources of calcium, including fortified foods [6]. At the same time, the bioavailability of calcium when entering through the gastrointestinal tract does not exceed 20–40% and depends on many nutritional factors. It is known that the processes of calcium of adsorption in the intestine are affected by the presence of protein, vitamin D, phosphorus, magnesium, dietary fiber, excess of saturated fatty acids, as well as phytic and oxalic acids [2, 7]. Dairy products also contain nutrients that reduce the bioavailability of calcium, such as casein, lipids [8].

The numerous studies have confirmed that fish is a natural food source of protein, phosphorus, polyunsaturated fatty acids and vitamin D. The content of the latest in fish of fatty varieties is from 12 to 30 μg per 100 g of product, which exceeds the daily requirement of 10 μg [9]. The addition of components of plant origin stabilizes the rheological, organoleptic characteristics; harmonizes the nutrients composition of minced fish products. Literature analysis [10, 11, 12, 13] shows that as components for enrichment mineral composition of food we widely used milk processing products; food waste of fish (heads, tails, fins, bones); eggshells, plant materials (cereals, flour, vegetables), etc. Thus, the creation of combined food products based on fish raw materials, including all the nutritional factors necessary for the assimilation of mineral substances in the right ratio, is a vital task.

2. The purpose of the study
The purpose of the work is to develop formulations of combined molded products from fish raw materials with a given mineral composition. Tasks are the study of the nutritional value of fish raw materials and mineral supplements from fish bones; formalization of the mineral composition optimization criterion; development of unified recipes for chopped fish products, balanced in mineral composition.

3. The object of the study
The objects of the study were the most common types of fish raw materials for the marine industry – frozen pollock and pink salmon (GOST 1168–86 and GOST 20057–96) and chilled river pike (GOST 814–96). As a texture agents and sources of minerals we used following additives: skimmed milk powder (GOST 10970–87), a mineral supplement from fish bones, buckwheat flour (TU 9293–003–51560870–2001), fresh white cabbage (GOST R 51809–2001).

4. Materials and methods
There were moisture, ash, protein and fat content in fish raw materials indicated by use of the standard methods (GOST 7636). There were minerals in minced fish and bone mineral supplement determined by use of the chemical methods and plasma photometry one (GOST R 51429-99 and GOST R 7636-85). There was mineral composition of two-component mixtures optimized by using of the calculation-graphic method, threefold-component ones – by using of the method of steepest descent [14, 15].

5. Discussion of the results
Table 1 shows the data on the chemical composition of fish muscle tissue with skin. The tested fish species are characterized by a high content of proteins. The pink salmon is rich in fats and, accordingly, fat-soluble vitamins [8], which creates favorable conditions for the absorption of calcium. The mineral composition of the muscle tissue of fish is poorly balanced, the ratio of calcium to phosphorus is from 0.12 to 0.26.
According to the literature, a diet with a low ratio Ca / P (below 0.5) reduces calcium absorption in the intestine and leads to its excretion in urine and feces [16]. For the rational use of the nutritional potential of fish raw materials, it is necessary to adjust the mineral composition by introducing sources of calcium, and the fatty acid composition by introducing vegetable oil.

Table 1. The total chemical composition of fish raw materials (per 100 g of product)

| Indicators   | pollock       | pink salmon  | pike          |
|--------------|---------------|--------------|---------------|
| Moisture, g  | 81.3 ±1.6     | 71.3±1.4     | 79.3±2.4      |
| Proteins, g  | 16.2±0.4      | 20.8±0.6     | 18.4±0.6      |
| Lipids, g    | 0.91±0.02     | 6.71±0.02    | 1.10±0.02     |
| Ash, g, including | 1.2±0.03   | 1.23±0.02    | 1.24±0.03     |
| Sodium, mg   | 40.2±0.8      | 70.3±1.8     | 42.1±0.8      |
| Potassium, mg| 354±17        | 300±14       | 262±13        |
| Calcium, mg  | 38.5±1.2      | 25.1±1.3     | 51.5±2.5      |
| Magnesium, mg| 72.5±1.5      | 45.2±0.9     | 32.1±0.9      |
| Phosphorus, mg| 265±5      | 202±6        | 196±4         |
| Iron, mg     | 0.62±0.02     | 0.91±0.03    | 0.73±0.02     |
| Ratio Ca : P : Mg | 1 : 6.88 : 1.88 | 1 : 8.05 : 1.80 | 1 : 3.84 : 0.62 |

When preparing minced fish as the texture agents and sources of mineral substances we added the following supplements: skimmed milk powder (SMP), a mineral supplement from fish bones (MS), buckwheat flour, and fresh white cabbage. The vegetables were minced and then added in the fish mass as an emulsion composition with plant oil (VPO). To obtain the MS, the bones obtained by cutting fish were cooked for 2-2.5 hours with the addition of 50% water to the bone mass to make it completely softened and after cooling, the bone mass was crushed to a particle size of 0.5-1 mm [9]. Table 2 shows the mineral composition of the additional ingredients of the combined molded products.

Table 2. Content of minerals in additional ingredients of combined molded fish products

| Indicators  | MS            | SMP          | White cabbage | Buckwheat flour |
|-------------|---------------|--------------|---------------|-----------------|
| Mass fraction of solids, % | 23.2±0.7     | 96.0         | 10.0          | 91.0            |
| Ash, %      | 6.21±0.18     | 6.8          | 0.7           | 1.5             |
| Macronutrients, mg/100 g | 480±14       | 1224         | 185           | 130             |
| Potassium   | 1720±43       | 1155         | 48            | 42              |
| Calcium     | 490±14        | 160          | 16            | 48              |
| Magnesium   | 1160±35       | 920          | 31            | 250             |
| Phosphorus  | 0.815±0.031   | 0.5          | 0.6           | 4.0             |
| Iron        | 1 : 0.67 : 0.28 | 1 : 0.79 : 0.14 | 1 : 0.65 : 0.33 | 1 : 5.95 : 1.14 |
| Ratio Ca : P : Mg | 1 : 0.67 : 0.28 | 1 : 0.79 : 0.14 | 1 : 0.65 : 0.33 | 1 : 5.95 : 1.14 |

Analysis of the data in table 2 indicates a high content of minerals in MS and SMP. The ratio of macronutrients in all products except buckwheat flour is close to the balanced nutrition formula. This creates the prerequisites for optimizing the mineral composition of combined products.

When developing the optimization criterion we were guided by the following provision: the mineral composition of the combined product should correspond to the balanced nutrition formula for a specific group of consumers. The content of minerals (calcium, magnesium and phosphorus) in the combined product was calculated according to the following formulas:

\[ Q^{Ca} = \sum_{t=1}^{n} Q_t^{Ca} \cdot p_t \quad Q^{Mg} = \sum_{t=1}^{n} Q_t^{Mg} \cdot p_t \quad Q^P = \sum_{t=1}^{n} Q_t^P \cdot p_t \]
where $Q_{i}^{Ca}$, $Q_{i}^{Mg}$, $Q_{i}^{P}$ is the content of calcium, magnesium and phosphorus in the $i$-component of the combined product, respectively; $p_{i}$ is a proportion of the $i$-component in the combined product on condition $\sum_{i=1}^{n} p_{i} = 1$.

The content of minerals in the balanced diet was symbolized as: calcium is $Q_{R}^{Ca}$, phosphorus is $Q_{R}^{P}$, magnesium is $Q_{R}^{Mg}$, thus, their ratios can be put in the following way:

$$\frac{Q_{R}^{Ca}}{Q_{R}^{P}} \frac{Q_{R}^{Ca}}{Q_{R}^{Mg}} \frac{Q_{R}^{P}}{Q_{R}^{Mg}} .$$

Then the optimization criterion takes the following form:

$$\left| \frac{Q_{R}^{Ca}}{Q_{R}^{P}} - \frac{Q_{R}^{Ca}}{Q_{R}^{Mg}} \right| + \left| \frac{Q_{R}^{Ca}}{Q_{R}^{Mg}} - \frac{Q_{R}^{Ca}}{Q_{R}^{P}} \right| + \left| \frac{Q_{R}^{P}}{Q_{R}^{Mg}} - \frac{Q_{R}^{P}}{Q_{R}^{Mg}} \right| \rightarrow \min.$$  

For the combinations of pink salmon with various additional ingredients, we calculated values of this criterion using the data from Table 2. In this case, the following ratios of mineral substances in a balanced diet were taken: calcium to phosphorus is 1, calcium to magnesium is 4, phosphorus to magnesium is 4. It was found that adding all the ingredients to pink salmon reduces the value of the optimization criterion: in combination with buckwheat flour and cabbage, the criterion takes a minimum value with the complete exclusion of pink salmon from the mixture. Graphs of the dependence of the content of mineral substances and the optimization criterion on the ratio of components in the mixture of "Pink Salmon + MS" are presented in Figure 1 and Figure 2.

![Figure 1](image1.png)  
**Figure 1.** Graph of mineral content and optimization criterion in the mixture “SMP + Pink Salmon” from the ratio of components: (a) – the change in the content of calcium, phosphorus, magnesium; (b) – the change in the optimization criterion.

![Figure 2](image2.png)  
**Figure 2.** Graph of mineral content and optimization criterion in the mixture “MS + Pink Salmon” from the ratio of components: (a) - the change in the content of calcium, phosphorus, magnesium; (b) - the change in the optimization criterion.
As can be seen from the graphs in Fig. 1 and Fig. 2, an increase in the share of SMP and MS in the formulations leads to a significant increase in the absolute content of calcium, phosphorus, and magnesium. The optimization criterion assumes the minimum values of 1.4 and 2.3 with the addition of 23% SMP and 25% MS, respectively.

When solving the problem of optimizing a three-component mixture, the criterion graph represents a surface in three-dimensional space. The optimal ratio can be found by one of the standard optimization methods, for example, steepest descent. According to the graph shown in Fig. 3, the optimization criterion takes a minimum value of 0.05 with the following ratio of ingredients: pink salmon - 66%, SMP - 24%, MS - 10%. The mineral content in this combination of ingredients is (in 100 g of the product): calcium - 466 mg, phosphorus - 470 mg, magnesium - 117 mg.

![Figure 3. The dependence of the optimization criterion in the three-component mixture “Pink Salmon + mineral supplement from fish bones (MS)+ skimmed milk powder (SMP)” on the ratio of components](image)

The optimal ratio of ingredients is used in the development of unified formulations of molded products from fish raw materials including:

- minced fish, MS, VPO (vegetables: carrots or cabbage or beets);
- minced fish, MS, SPM, cereals (millet, oatmeal) or flour (rye, buckwheat).

| Table 3. Assessment of the balance of mineral composition and functional significance of fish combined products |
|---------------------------------------------------------------|
| **The composition of the combined fish product** | **Mineral content, mg per 100 g** | **Ratio** | **The degree of satisfaction of daily calcium requirement, %** |
|                                               | Ca | P  | Mg | Ca : P : Mg | |
| Pink Salmon and MS                              | 207| 240| 81 | 1 : 1.16 : 0.39 | 17.3 |
| Pink Salmon, MS and SPM                         | 250| 289| 86 | 1 : 1.16 : 0.34 | 20.8 |

The developed combined fish products are characterized by the balanced ratio of the mineral composition compared to fish raw materials. The calcium content in 100 g of the product exceeds 15% of the daily requirement, which allows us to classify these products as functional.
6. Conclusion
Studies have shown that the proposed optimization criterion can be used to develop combined products with a given ratio of mineral components, which corresponds to a balanced nutrition formula for a specific social group of consumers. The theoretical basis of the proposed criterion is modern ideas about the influence of nutritional factors on the bioavailability of mineral substances from food products entering the human gastrointestinal tract. The use of digital technologies at the design stage of multicomponent food products makes it possible to assess the balance of the mineral composition of the feedstock, make an informed choice of ingredients for its correction, find the optimal ratio of ingredients in the recipe, and determine the boundaries of parameters for planning a further experiment. The developed combined products have a balanced mineral composition and have functional properties.

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