Optimization of the composition of minced meat semi-finished products

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Abstract. To achieve a balanced composition of the product in terms of nutritive value, many researchers recommend combining meat raw materials with vegetable components. The paper presents a technique to optimize the formulation of minced meat semi-finished products developed by mathematical modeling. The main components of semi-finished products are broiler chicken meat, egg melange, and onion, protein-fat emulsion made of chickpea flour, sunflower oil and water. Optimization was aimed at obtaining the ratio of the components to meet the requirements established for nutritive values. At the same time, the recommended amount of vitamin and mineral for adults and the requirements of normative documentation for the quality of semi-finished meat products were taken into account. The target function was the protein content to obtain its maximum value. The optimized formulation obtained was used to make samples of meat semi-finished products, and sensory indicators were evaluated. The results showed that addition of chickpea flour affected the product color. Thus, we can conclude that mathematical modeling is an efficient tool to fabricate a product with desired properties. A combination of raw materials of vegetable and animal origin allows development of nutritionally balanced formulation.

1. Introduction
Vegetable additives are widely used in the meat industry for various functional purposes [1–3]. Recently, there has been a clear tendency to combine vegetable additives with various types of meat raw materials [4, 5]. Vegetable additives are a source of vitamins, minerals, dietary fiber and other biologically active substances [6–8]. Due to these compounds, vegetable components improve digestion, cardiovascular activity and emotional state. In addition, they impart a specific vegetable flavor and odor, and attractive appearance to meat products [9]. A combination of raw materials of vegetable and animal origin in the product provides a balanced nutritional content [10–14].

Consumers are becoming increasingly concerned about their health, and there is a tendency to consume foods, including meat products, with low content of fat, salt, and cholesterol, with dietary fiber, and of lower energy value [15–18]. In addition, due to concerns about obesity and other illnesses caused
by fatty foods, many consumers prefer low-fat foods. Within the segment of meat products, poultry meat products, including those with addition of vegetable components, are of high relevance.

Chickpea products are a source of vegetable protein, dietary fiber, vitamins, and minerals [19, 20]. Studies show that chickpea flour is a potential source of high protein content to be used in meat products [21].

The study aims to optimize the composition of minced meat semi-finished products with addition of vegetable additives in terms of nutritive value.

2. Materials and methods

Meat semi-finished products include the following components: broiler chicken meat, onions, mélange, salt, ground black pepper, protein-fat emulsion (PFE), which includes water, vegetable oil, sunflower and chickpea flour.

The basic raw material used was broiler chicken meat (Healthy Farm Group, Chelyabinsk). The components of the protein-fat emulsion were flour, vegetable oil and water. The components used to produce an experimental semi-finished product included Garnets chickpea flour (Garnets LLC, Vladimir), which meets the requirements of TU 9293-009-89751414-10, refined deodorized sunflower oil of Sloboda brand, and purified drinking water.

The ratio of the components in the protein-fat emulsion was taken with regard to the studies conducted by other authors. The PFE components with addition of chickpea flour were taken in the flour : vegetable oil : water ratio of 1 : 2.2 : 2.8 [22].

For ease of calculation, the following designations were introduced: j for the index of various component names (j=1, 2, ..., n); i for the nutritive value index (i=1, 2, ..., m); x_j for the desired value of the j-th component in the composition of the product unit; b_i for the required amount of the i-th nutrient in the formulation; a_{ij} for the content of the i-th nutrient in the unit of the j-th component type.

The accepted designations were used to develop a mathematical model of optimization of the desired formulation. The amount of each nutrient in the formulation of minced semi-finished products was calculated using equation (1)

\[ b = \sum_{j=1}^{n} x_j a_{ij} \]  

if the following conditions are met:

1) the presence of the required ingredients in the formulation:
   a) maximum constraint:
   \[ \sum_{j=1}^{n} x_j a_{ij} \leq b_i \]
   b) minimum constraint:
   \[ \sum_{j=1}^{n} x_j a_{ij} \geq b_i \]

2) formation of a unit mixture:
   \[ \sum_{j=1}^{n} x_j = 1 \]

3) non-negativity of variables:
   \[ x_j \geq 0, j = 1, 2, ..., n. \]

For optimization, data on the content of nutrients, vitamins and minerals in raw materials used were summarized in tables 1, 2 and 3, respectively.
Table 1. Nutrient content of components.

| Component            | Mass fraction, % | protein | fat  | moisture |
|----------------------|------------------|---------|------|----------|
| broiler chicken meat | 20.3             | 11.1    | 69.0 |
| onion                | 1.4              | 0.2     | 86.0 |
| egg melange          | 12.7             | 11.5    | 74.0 |
| ground black pepper  | 10.4             | 3.3     | 12.0 |
| chickpea flour       | 10.9             | 2.9     | 10.3 |
| water                | –                | –       | 100.0|
| sunflower oil        | –                | 99.8    | –    |

Table 2. Vitamin content of components.

| Component            | Vitamin content, mg | B<sub>1</sub> | B<sub>2</sub> | choline | B<sub>6</sub> | E | PP |
|----------------------|---------------------|---------------|--------------|---------|--------------|---|----|
| broiler chicken meat | 0.059               | 0.086         | –            | 0.480   | 0.27         | 8.908|     |
| onion                | 0.050               | 0.020         | 6.1          | 0.120   | 0.20         | 0.500|     |
| egg melange          | 0.070               | 0.440         | 251.0        | 0.140   | 0.60         | 3.600|     |
| ground black pepper  | 0.108               | 0.180         | 11.3         | 0.291   | 1.04         | 1.143|     |
| chickpea flour       | 0.490               | 0.110         | –            | 0.490   | 41.10        | –   |     |
| sunflower oil        | –                   | –             | 0.2          | –       | 41.10        | –   |     |

Table 3. Mineral content of components.

| Component            | Mineral content, mg | Ca | K | Si | Mg | Fe | Mn | Zn |
|----------------------|---------------------|----|---|----|----|----|----|----|
| broiler chicken meat | 11                  | 204| – | 23 | 0.79 | 0.018 | 0.93|
| onion                | 31                  | 175| 5 | 14 | 0.80 | 0.230 | 0.85|
| egg melange          | 55                  | 140| – | 12 | 2.50 | 0.029 | 1.11|
| salt                 | 368                 | 9  | – | 22 | 2.90 | 0.250 | 0.60|
| ground black pepper  | 443                 | 1329| – | 171| 9.71 | 12.75 | 1.19|
| chickpea flour       | 45                  | 846| – | 166| 4.86 | 1.600 | 2.81|
| water                | 4.5                 | –  | – | 1  | –   | 0.002 | –   |

During optimization, the content of protein, fat, vitamins and minerals was taken into account. The content of vitamins and minerals was determined with regard to the daily intake recommended for adults (table 4).

Table 4. Daily intake of vitamins and minerals.

| Vitamins | Daily intake, mg/day | Minerals | Daily intake, mg/day |
|----------|----------------------|----------|----------------------|
| B<sub>1</sub> | 1.5                  | K        | 2500                 |
| B<sub>2</sub> | 1.8                  | Si       | 30                   |
| B<sub>6</sub> | 2                    | Mg       | 400                  |
| E        | 15                   | Fe       | 18                   |
| PP       | 20                   | Mn       | 2                    |
|          |                      | Zn       | 12                   |
The designations used were \( x_1 \) for the amount of broiler chicken meat in the formulation, \( x_2 \) for the amount of onion, \( x_3 \) for the amount of melange, \( x_4 \) for the amount of black pepper, \( x_5 \) for the amount of flour, \( x_6 \) for the amount of oil, \( x_7 \) for the amount of salt, and \( x_8 \) for the amount of water; \( x_1-8 \) for the desired specific gravity of inclusion of each component in the product.

For optimization, the following balance equations were derived:

1) the content of fat in the finished product equal to not more than 50%, unit fractions:
   \[
   0.111 \cdot x_1 + 0.002 \cdot x_2 + 0.115 \cdot x_3 + 0.033 \cdot x_4 + 0.029 \cdot x_5 + 1 \cdot x_6 \leq 0.5;
   \]

2) the content of the daily intake of vitamins in the finished product, unit fractions:
   a) vitamin E
   \[
   0.27 \cdot x_1 + 0.2 \cdot x_2 + 0.6 \cdot x_3 + 1.04 \cdot x_4 + 0.83 \cdot x_5 + 41.1 \cdot x_6 \geq 15;
   \]
   b) vitamin PP
   \[
   8.908 \cdot x_1 + 0.5 \cdot x_2 + 3.6 \cdot x_3 + 1.143 \cdot x_4 + 1.76 \cdot x_5 \geq 20;
   \]

3) the content of the daily intake of minerals in the finished product, unit fractions:
   a) potassium, K
   \[
   204 \cdot x_1 + 175 \cdot x_2 + 140 \cdot x_3 + 1329 \cdot x_4 + 846 \cdot x_5 + 9 \cdot x_7 \geq 2500;
   \]
   b) magnesium, Mg
   \[
   23 \cdot x_1 + 14 \cdot x_2 + 12 \cdot x_3 + 171 \cdot x_4 + 166 \cdot x_5 + 22 \cdot x_7 + x_8 \geq 400;
   \]
   c) iron, Fe
   \[
   0.79 \cdot x_1 + 0.8 \cdot x_2 + 2.5 \cdot x_3 + 9.71 \cdot x_4 + 4.86 \cdot x_5 + 2.9 \cdot x_7 + 0.001 \cdot x_8 \geq 18;
   \]
   d) manganese, Mn
   \[
   0.018 \cdot x_1 + 0.23 \cdot x_2 + 0.029 \cdot x_3 + 12.8 \cdot x_4 + 1.6 \cdot x_5 + 0.25 \cdot x_7 + 0.0016 \cdot x_8 \geq 2;
   \]
   e) zinc, Zn
   \[
   0.93 \cdot x_1 + 0.85 \cdot x_2 + 1.11 \cdot x_3 + 1.19 \cdot x_4 + 2.81 \cdot x_5 + 0.6 \cdot x_7 \geq 12;
   \]

4) fabrication of unit of product:
   \[
   x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 = 1;
   \]

5) obtaining of non-negative variables, since this mathematical model was supplemented with the conditions for mandatory inclusion of all components in the product in the given quantity:
   \[
   x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \geq 0.
   \]

When solving this problem, we considered the ratio of the components in protein-fat emulsion – chickpea flour : vegetable oil : water (1 : 2.2 : 2.8) and the amount of the emulsion added to the formulation, which was determined experimentally and equaled 20%. During modeling, the equations were derived with regard to this ratio:

\[
\begin{align*}
  x_5 &= x_6 / 2.2; \\
  x_8 &= 2.8 \cdot x_6 / 2.2.
\end{align*}
\]

The amount of protein-fat emulsion in the formulation of semi-finished products is 20%:
\[
\begin{align*}
  x_5 + x_6 + x_8 &= 0.2.
\end{align*}
\]
The target function was the protein content to obtain its maximum value. The protein content in the product was calculated as follows:

\[ 20.3 \cdot x_1 + 1.4 \cdot x_2 + 12.7 \cdot x_3 + 10.4 \cdot x_4 + 10.9 \cdot x_5 \rightarrow \text{max.} \]

The composition of semi-finished products was optimized using the Excel Solver.

Organoleptic properties of the finished semi-finished products were determined in accordance with GOST 32951-2014 Semi-finished meat and meat-containing products. General specifications. The main organoleptic properties for minced molded semi-finished products include appearance, appearance of the cut, color, odor and flavor. The odor of semi-finished products was evaluated after thermal processing.

3. Results and discussion
With regard to the conditions and data, different solutions to the problem stated were considered and the formulation was finally developed (table 5).

Table 5. Formulation of minced meat semi-finished products.

| Component                  | Amount, % |
|----------------------------|-----------|
| broiler chicken meat       | 70.1      |
| onion                     | 5.0       |
| egg melange               | 3.0       |
| salt                      | 1.8       |
| ground black pepper       | 0.1       |
| chickpea flour            | 3.3       |
| water                     | 9.3       |
| sunflower oil             | 7.4       |

The calculation results showed that according to GOST 32951-2014 Semi-finished meat and meat-containing products. General specifications, the finished minced semi-finished products belong to category B in terms of the mass fraction of muscle tissue in the formulation (from 60.0% to 80.0% inclusive).

The calculation results for nutrients, vitamins and minerals are provided in tables 6 and 7, respectively.

According to the calculation results, minced meat semi-finished products in an amount of 200 g per day cover the daily need for the considered vitamins and minerals by 10–64% of the daily intake due to enrichment of the product with chickpea flour.

Table 8 presents the results of organoleptic analysis.

Table 6. Nutrient calculation results.

| Indicator                        | GOST 32951-2014 requirements, category B | Calculation results |
|----------------------------------|-------------------------------------------|---------------------|
| Mass fraction of protein, %      | Not less than 12.0                        | 15.05               |
| Mass fraction of fat, %          | Not more than 35.0                        | 15.59               |
| Mass fraction of moisture, %     | Not standardized                          | 64.58               |

Table 7. The content of vitamins and minerals in minced meat semi-finished products.

| Nutrient | Recommended daily intake for adults, mg/day | Calculation results, mg |
|----------|---------------------------------------------|-------------------------|
| vitamins |                                             |                         |
| E        | 15                                          | 3.27                    |
Table 8. Results of sensory analysis of minced meat semi-finished products.

| Indicator                  | Description                                                                                                                                                                                                 |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Appearance                 | Homogeneous mass of minced meat free from bones, cartilage, tendons, coarse connective tissue, clots of blood and films, uniformly mixed, of different shape and mass of oval shape and mass of 100±2 g                |
| Appearance of the cut      | Minced meat is well mixed, homogeneous with inclusions of formulation ingredients with inclusions of chopped onion                                                                                           |
| Color, odor, flavor        | Characteristic of this semi-finished product, with regard to the formulation components used, off-odor and off-flavor – yellowish                                                                                   |

The experimental sample with chickpea flour meets the requirements for organoleptic properties specified in GOST 32951-2014 Semi-finished meat and meat-containing products. General specifications. The sample contained inclusions of chopped onions and exhibited insignificant discoloration. Similar results of sensory analysis were obtained by Verma et al. in the study of low-fat chicken nuggets with the addition of chickpea flour. It was found that the optimal amount of chickpea flour that does not cause significant deterioration of sensory indicators is 5% [22, 23].

Shariati-Levari et al. (2016) investigated the effect of chickpea flour on quality indicators of low-fat beef burgers. The results showed that the amount of micronized chickpea flour favorable for physical and chemical properties and acceptable to consumers attains 6% [24].

4. Conclusion
As a result of optimization, the formulation was developed for minced meat semi-finished products produced from poultry meat and protein-fat emulsion. Protein-fat emulsion included chickpea flour, water and sunflower oil that imparts dietary properties to semi-finished products. Due to addition of chickpea flour to semi-finished products, the content of vitamins and minerals ranged from 10 to 64% of the daily intake. The results of sensory analysis of the finished meat semi-finished product showed that its color changed insignificantly.

Thus, methods of mathematical modeling were proved to be useful for manufacturing products with desired properties. The combination of plant and animal raw materials allows development of nutritionally balanced formulation.

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