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SYSTEMIC APPROACH IN THE DEVELOPMENT OF FUNCTIONAL FOODS FOR VARIOUS NONCOMMUNICABLE DISEASES

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Abstract
The article presents a hierarchy of requirements necessary for the successful design of food products with given composition and properties considering age restrictions and various diseases. The need for generalization and systematization of scientifically based principles, specific medical and biological requirements for food products, diets for the most common nutritional diseases in the knowledge base is shown. Using the k-means cluster analysis method, 1) meat raw materials were analyzed for inclusion in functional food for gerodietetic nutrition according to the most significant descriptors (protein, methionine + cystine amino acids, tryptophan), 2) spicy herbs and spices were analyzed for inclusion in the Muhammara recipe as natural antioxidant sources according to the descriptor of antioxidant properties. Using the example of the Muhammara recipe change, all stages of a systemic approach in the development of functional foods are shown. The first stage is related to obtaining information from the knowledge base about scientifically based nutritional principles and specific biomedical requirements for the given age group. At the second stage, the clustering of raw materials of animal and vegetable origin is carried out in order to reasonably include in the recipe of food product being developed. At the third stage, a system of balance linear algebraic equations for the chemical composition of the food product being developed (mass fraction of fat, protein, water, carbohydrates, vitamins, macro- and microelements, amino acids, etc.) is formed. The fourth stage is associated with the establishment of the target function (optimization criterion), and restrictions for recipe and balance. At the fifth stage, the problem is solved using a high-level language in a modern programming environment. At the final (sixth) stage, the nutritional value of the optimal balanced recipe is analyzed considering the target function and the given restrictions. As a result, we receive a modified Muhammara recipe with optimized protein: fat ratio. Mathematical simulation was carried out using the R Studio software with open-source lpSolve and lpSolveAPI libraries.

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Introduction

In recent years, a general trend has been revealed towards the development and production of meat and meat products, which, in addition to nutritional properties, contributes not only to the prevention, but also to the treatment of various pathological conditions in the population. Many different strategies have been developed to improve the functionality of meat and meat products using various functional compounds and modification of live animals [1,2].

It should be noted that the production of functional foods with preventive and biocorrective properties, including meat, should be based on scientifically valid medical and biological principles, progressive and environmentally friendly technologies that contribute to the maximum improvement of the human body, trophic systems, biological communities and the environment [1,3].

Nutrition affects the processes of energy generation in the cell, protein biosynthesis, the structure and functions of cell and intracellular membranes, the activity of enzyme systems, neurohumoral regulation, immunity, biological rhythms, etc. Biochemical indicators of metabolism, the functional activity of various organs and systems significantly depend on the quantity and quality of nutrition. Balanced nutrition is considered as active therapeutic and preventive mean, which contributes to the preservation of physical and mental health, reduces the risk of any pathology and prevents premature aging. With proper organization of nutrition, including knowledge of the effect on health, it is possible to significantly reduce the overall disease incidence, increase the resistance to adverse environmental factors and life expectancy.

The normal activity of the brain and the body as a whole, and life expectancy depend more or less on the quality of the food consumed. The restoration of the nutrition structure, improvement of its quality and safety is currently one of the most important and priority tasks of the state, which includes a package of measures to ensure that the needs of various population groups in balanced nutrition are met, considering traditions, habits and economic situation.

The modern system of healthy nutrition is formed from many components that depend on biomedical, social, economic, technological and other factors. Failure to comply with the requirements of at least one of the components will undoubtedly lead to a violation of the integrity and balance of the entire system.

Along with the established genetic and environmental risk factors for chronic noncommunicable diseases, modifiable factors associated with lifestyle and diet play an important role in the disease development and prognosis.

With noncommunicable socially significant diseases, proper nutrition is necessary, considering established scientifically based principles and biomedical requirements. In the article, we discuss the principles of nutrition for cardiovascular diseases and gerodietetic nutrition.

Peculiarities of nutrition in people with cardiovascular diseases

Currently, cardiovascular diseases (CVD) are the leading cause of death and account for about a third of all deaths worldwide. In the last decade, CVD mortality in the world has increased by 12.5%. One of the significant risk factors that contribute to their growth is a violation of the nutrition structure in the population. In this regard, encouraging adherence to a healthy diet is important to reduce morbidity and mortality from CVD [4].

Russia is one of the world leaders in terms of morbidity and mortality from this pathology. According to the World Health Organization (WHO), since 2009 the number of deaths from cardiovascular diseases has increased by more than 2 million and reached almost 9 million in 2019. Heart diseases today account for 16% of all deaths in the world. At the same time, a relative reduction in mortality from heart diseases by 15% was noted in the European Region [5].

On the territory of the Russian Federation, this figure is 57.1%, of which CAD accounts for more than half of all cases (28.9%), which in absolute terms is 385.6 per 100,000 people per year. For comparison, the death rate from the same cause in the European Union is 95.9 per 100,000 people per year, which is 4 times less than in our country. The frequency of coronary artery disease (CAD) increases sharply with age: in women from 0.1–1% at the age of 45–54 years to 10–15% at the age of 65–74 years, and in men from 2–5% at the age of 45–54 years to 10–20% at the age of 65–74 [6].

Table 1 presents statistics from 2014 to 2020 in terms of mortality due to coronary artery disease.

Table 1. Statistics of mortality from coronary artery disease [6]

Cause of death	2016	2017	2018	2019	2020
Coronary artery disease	481,780	461,786	453,306	442,328	508,657

According to Heidenreich P. et al. [7, 8], in 2030 the prevalence of CAD will increase by 9.3%. Studies by Scarborough P. et al. [9] show that in 2035, it is possible to expect an increase in the number of myocardial infarctions in English men, while in women an increase in the number of cases is unlikely.

According to modern concepts, the pathogenesis of CAD is based on progressive atherosclerotic occlusion of the coronary arteries, among the main causes of which dyslipidemia, oxidative stress, chronic inflammation, obesity, etc. are considered [4].

Nutrition has always been part of the CVD prevention strategy. It is known that eating disorder may contribute to the development of atherosclerosis and atherothrombosis, both directly and indirectly, by increasing the body mass index, blood pressure, cholesterol and glucose levels in the serum. In 2019, the European Society of Cardiology released a new, third reissue of the guidelines on cardiovascular medicine [10], one of the sections of which is devoted to the contribution of optimal nutrition to the prevention of CVD.

Cardiovascular diseases are characterized by inadequate fat and carbohydrate metabolism, sodium metabolism and enzyme balance, vitamin and mineral deficiency [11,12].

Indisputable importance in the treatment and prevention of these diseases and the main risk factors for their occurrence is given to specialized foods, which include meats, meat and vegetable products (canned products, semi-finished products, ready meals, pates, sausages) intended for nutrition in order to prevent coronary artery disease, atherosclerosis of coronary, cerebral, peripheral vessels, hypertension.

The development of foods for the prevention of cardiovascular diseases is based on the following general scientifically based principles:

- the food product should contribute to improving metabolic processes, restoring the metabolism of the vascular wall and heart muscle, reducing blood coagulation, and have an anti-sclerotic therapeutic effect, which is ensured by a combination of animal and vegetable protein, its balance in amino acid composition, limited energy, salt, cholesterol, along with sufficient protein and optimal fat composition [13,14,15,16];
- the food product should be enriched with vitamins, macro- and microelements at their optimal ratio, polyunsaturated fatty acids, dietary fiber and other specific ingredients that help to prevent the risk of developing cardiovascular diseases [17,18,19,20];

- ingredients containing phospholipids with lipotropic action should be included in the food product to stabilize the solution of cholesterol in the bile and reduce the absorption of cholesterol in the intestine.

When developing the food product recipe, the following specific biomedical requirements must be considered:

- the protein component of the specialized products should combine protein of animal and vegetable origin, since this achieves a more pronounced hypocholesterolemic effect [21];
- the amount of animal and vegetable protein should be approximately equal;
- the content of saturated fats should not exceed 10%, while the ratio of unsaturated to saturated fatty acids should not exceed 1.0;
- the optimal ratio of SFA/MUFA/PUFA should be 1:1:1.

The source of animal protein included in the food product may be beef and pork used in semi-finished products, chicken and turkey meat. As a vegetable protein, it is recommended to use processed soybeans (concentrates and isolates) with a high content of isoflavones, which cause hypolipidemic, antioxidant, hypotensive and thrombolytic effects, as well as chickpeas, cereals.

The fat component is formed by the fat of meat raw materials and vegetable oils as a source of PUFAs: sunflower, corn, cotton oils containing mainly fatty acids of ω-6 class; linseed, soy, rapeseed oils and others rich in α-linolenic acid. PUFAs of ω-3 class especially significantly reduce the hypertriglyceridemia [22,23,24,25].

Among carbohydrates, preference should be given to plant ingredients, i. e. cereals, vegetables, which contain a sufficient amount of dietary fiber (DF). The main representatives of DF are cellulose and pectin. The addition of 15 g of soluble DF (pectin, guar gum) to the daily diet reduces the level of blood cholesterol by 15–21% [26,27,28].

As spices it is recommended to use: parsley and dill greens and roots, celery roots and seeds, marjoram, capsicum, onion.

Nutrition of the elderly and older people

According to the classification of the World Health Organization, the older people range 60 to 75 years old, the category of the elderly is in the range of 75 to 90 years old, and people over 90 years old are considered long-livers [29].

In 2019, people aged 60 and over exceeded one billion, representing 13.2% of the world's total population (7.7 billion). This is 2.5 times more than in 1980 (382 million). Therefore, it is possible to predict the number of older people in the world by 2050. Their number will reach 2.1 billion people. Indeed, in 2020, for the first time in history, the global number of older people surpassed the number of children under 5 years old.

The basis for the development of food products for older people is based on the following general scientifically based principles[1] [30,31,32]:

- energy balance of nutrition, taking into account the actual energy consumption of the body [30,32];
- preventive nature of nutrition, not only in relation to atherosclerosis, but also to other widespread pathologies of old age (obesity, diabetes mellitus, hypertension, cancer, osteoporosis, etc.) [33,34];
- compliance of food chemical composition with age-related changes in metabolism and functions [35];
- diet balance for all essential nutritional factors [36,37,38];
- alkaline nature of nutrition to correct the age-related acidotic features of homeostasis (acidification of the internal environment of the body) [39];
- enrichment of diets with foods that normalize the intestinal microflora of an aging organism [40];
- enrichment of food with substances that have geroprotective properties [41];
- the use of foods that are quite easily subjected to the action of digestive enzymes and assimilation processes [31].

The development of multi-component gerodietetic food products with desired properties is a complicated process, since it is necessary to ensure the entire complex of the above requirements. When developing the composition of a meat-based gerodietetic product, the following specific biomedical requirements must be taken into account:

- the amino acid composition of the product should correspond to the FAO/WHO ideal protein concept [42,43];
- the mass fraction of such amino acid as tryptophan should be at least 1 g per 100 g of protein [42];
- the ratio of lysine mass fraction in relation to the mass fraction of methionine + cystine should tend to be 1:1 [42];
- the ratio of the mass fractions of saturated, monounsaturated and polyunsaturated fatty acids should correspond to 3:6:1, while polyunsaturated fatty acids should include acids belonging to the ω3 group (linoleic, linolenic, arachidonic), which are very important components in treatment and prevention of cardiovascular diseases, as they are able to prevent the formation of cholesterol and triglycerides in the blood; in combination with amino acids such as arginine and glutamine they increase the body's resistance to infectious diseases; improve kidney function; reduce inflammation in the intestines and joints [44,45,46,47,48];
- the ratio of protein mass fraction of to the mass fraction of lipids should be 1:0.8 [42,43];
- the energy value of the finished product should be in the range of 600 to 650 kJ/100 g [30,32];

[1] Guidelines for catering for the elderly and older people (1975). Moscow: Research Institute of Nutrition. Retrieved from https://files.stroyinf.ru/Data2/1/4293855/4293855243.pdf Accessed June 24, 2022. (In Russian)

- the product must contain vitamins E, C, PP and group B vitamins, the presence of which in the product helps to slow down the aging process; minerals, i. e. potassium, calcium, magnesium, phosphorus, iron, selenium, zinc; as well as components that inhibit the processes of lipid membrane oxidation in the body, stimulate peristalsis and contribute to the regulation of cholesterol metabolism [49,50,51,52].

When developing a meat-based gerodietetic product, it is extremely important to choose the type of product from the assortment of meat products. The difficult process of digestion and assimilation of food by the gastrointestinal tract of older people predetermines the fact that this product must be finely dispersed and tender. Based on this fact, pate is the most suitable type of meat products.

The article considers a systemic approach to the development of food products that may be recommended as a nutritional support, by the example of a product for the prevention of cardiovascular diseases and gerodietetic nutrition.

A systemic approach to the development of food products for prevention and nutritional support for various noncommunicable diseases includes the following steps:

Stage 1 — obtaining information from the knowledge base on scientifically based nutritional principles and specific biomedical requirements for a given age group;

Stage 2 — clustering raw materials of animal and vegetable origin in order to reasonably include into food product being developed;

Stage 3 — generating a system of balance linear algebraic equations for the chemical composition of the food product being developed (mass fractions of fat, protein, water, carbohydrates, vitamins, macro- and microelements, amino acids, etc.);

Stage 4 — setting the target function (optimization criterion), restrictions for recipe and balance;

Stage 5 — solving the problem using a high-level language in a modern programming environment;

Stage 6 — analyzing the nutritional value of the optimal balanced recipe considering the target function and the given restrictions.

Objects and methods

The material of the study was modern data on the contribution of optimal (healthy) nutrition to gerodietetics and the prevention of cardiovascular diseases.

For the analysis of meat raw materials, the Food Products database was used [53]. The analysis was carried out using the k-means method for various indicators (protein content, methionine + cystine, tryptophan, the ratio between protein and fat, etc.). The k-means clustering algorithm involves partitioning objects into classes, which minimizes the differences (“distances”) between objects of the same class and maximizes the distances between objects of different classes. The number of clusters is 3. The center of the cluster is the average value of the coordinates of all points included in the cluster (products for this indicator) [54].

Mathematical simulation was carried out using the R Studio software with open-source lpSolve and lpSolveAPI libraries [55,56].

Muhammara was chosen as the object of the study. This is a Syrian pasta with beneficial properties and amazing flavor. Muhammara is usually made with fresh or dried peppers, walnuts, bread, olive oil, onions, garlic, salt, lemon juice, pomegranate syrup, and cumin. Nutritional and energy value of Muhammara: protein — 6.9 g, fat — 27.8 g, carbohydrates — 20.3 g, calorie content — 351.6 kcal.

Results and discussion

Nutrition for cardiovascular diseases

The V. M. Gorbatov Federal Research Center for Food Systems develops functional foods. For example, sterilized canned minced meat “Healthy Heart” for functional nutrition from porcine hearts and aortas — for the prevention of cardiovascular diseases [57].

Sensory and physicochemical parameters of the canned meat “Healthy Heart” must meet the following requirements (Table 2).

Table 2. Physicochemical and sensory characteristics[2]

Parameter	Characteristics and value
Sectional view	Light brown to brown minced meat, without gray spots, voids, without visible inclusions of connective tissue. A small amount of broth is allowed.
Odor and taste	Pleasant, with a pronounced meat flavor, lightly salted, without off-odor and off-flavor.
Texture	Juicy, noncrumbly, dense
Impurities	Not allowed
Protein mass fraction, %	16.5 to 18.0
Fat mass fraction, %	3.5 to 4.0
Salt mass fraction, %	0.3 to 0.5 inclusive
Acid number, mg KOH/g, not more	1.5 to 3.0 inclusive
Calorie content, kcal	97.5 to 108

Porcine aorta and heart are used as the main raw materials as they contain 1) tissue-specific peptides with molecular weights of 809.4 ± 1.0; 776.5 ± 1.0; 765.6 ± 1.0; 739.2 ± 1.0; 710.8 ± 1.0; 229.2 ± 1.0; 162.1 ± 1.0; 156.0 ± 1.0; 148.1 ± 1.0; 140.2 ± 1.0 and 133.1 ± 1.0 kDa; 2) Apo 1 (contributes to the formation of high-density lipoproteins) or 3) pre-Apo A-1 (participates in the inhibition of oxidative stress) [58–60].

Using the example of Muhammara recipe changing, we will consider all the stages of a systemic approach. Enrichment of Muhammara was carried out in order to balance the recipe for the main food nutrients, reduce calorie content, and include ingredients with antioxidant properties to inhibit oxidative processes.

[2] Proprietary standard 00419779–003–2015 “Sterilized canned minced meat “Healthy Heart” for functional nutrition from porcine hearts and aortas”. Specifications. — Moscow: VNIIMP. 55 p.

At the first stage, data on nutrition in cardiovascular diseases were obtained from the knowledge base (see Introduction).

At the second stage, the clustering of herbs, spices and vegetables according to the descriptor "Antioxidant activity" was carried out for their reasonable inclusion in the Muhammara recipe. The dendrogram (Figure 1) shows that three clusters were formed. Table 3 shows detailed information about each cluster. The first cluster includes only 2 products (red color on the dendrogram). This cluster contains products with the highest ORAC index — ground cinnamon (ORAC — 314446), ground cloves (ORAC — 267536). Moderate ORAC values are contained in the second cluster (blue color on the dendrogram) ranging from 119929 to 200129 with the average value of 151497. The lowest ORAC values are in the third cluster (32 products) ranging from 821 to 76800 with the average value of 24500.

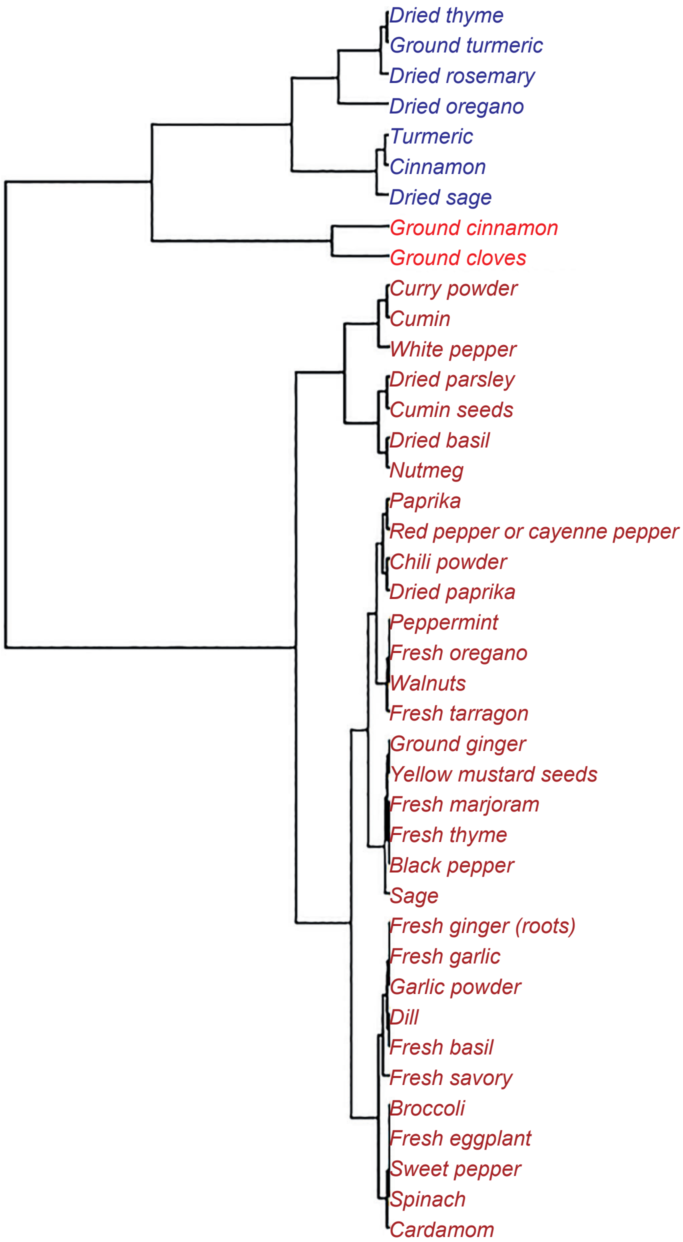

Figure 1. Dendrogram of herbs, spices and vegetables by the descriptor "Antioxidant activity", ORAC (Oxygen Radical Absorbance Capacity)

Table 3. The result of clustering by the descriptor "Antioxidant activity"

Cluster	Number of products in cluster	Mean, %	Min. value for the field «Antioxidant activity»	Max. value for the field «Antioxidant activity»
1	2	290991	267536	314446
2	7	151497	119929	200129
3	32	24500	821	76800

Natural sources of antioxidants were introduced into the recipe: paprika (ORAC — 21932), walnuts (ORAC — 13541), fresh garlic (ORAC — 5770), basil (greens) (ORAC — 4805), as ingredients with antioxidant properties.

As a result, Muhammara recipe was changed. Its dendrogram is shown in Figure 2.

Figure 2. Dendrogram of the Muhammara recipe

Task complexity for a multicomponent recipe is in the fact that it includes many ingredients (more than 5). In our version there are 15 of them. In this case, the calculation of the recipe without the use of modern digital technologies is extremely laborious (with possible human errors). These shortcomings of the traditional method may be successfully solved using modern digital technologies, i. e. computer environments and application packages such as MathCAD, R Studio, MS Excel, Maple, etc. This software saves time for calculations and eliminates the human factor. It also allows the development of functional multicomponent food products with predetermined composition and properties. The basic principle of recipe calculation is the mass conservation law. Its implementation is carried out by solving a system of linear equations by the balance method.

The mathematical technique for solving the classical recipe problem is the simplex method developed by the Nobel laureate, mathematician L. V. Kantorovich [61, 62], and the American scientist, G. Danzig [63, 64].

The third stage is associated with the generation of a system of balance linear algebraic equations for the chemical composition of the food product being developed (mass fractions of fat, protein, water, carbohydrates, vitamins, macro- and microelements, amino acids, etc.).

Table 4 provides information on the chemical composition (water, protein, fat, essential amino acids and the amount of SFA, MUFA and PUFA) of the ingredients used in the Muhammara recipe.

To perform mathematical calculations, mathematical dependencies were compiled for the protein and fat contents:

$$P=(20.85\cdot x_1+6.5\cdot x_2+13.9\cdot x_3+1.3\cdot x_4+14.14\cdot x_5+ \\ +1.2\cdot x_6+0.6\cdot x_7+16.2\cdot x_8+18.08\cdot x_{10}+ \\ +3.7\cdot x_{12}+3.15\cdot x_{13})\cdot 0.99 \quad (1)$$

$$F=(9.25\cdot x_1+0.5\cdot x_2+14.4\cdot x_3+0.44\cdot x_4+12.89\cdot x_5+ \\ +0.1\cdot x_6+0.3\cdot x_7+60.8\cdot x_8+50.87\cdot x_{10}+99.8\cdot x_{11}+ \\ +0.4\cdot x_{12}+0.64\cdot x_{13})\cdot 0.99 \quad (2)$$

where x_1, x_2, x_3, …. , x_{15} are the mass fractions of the components in the recipe, i. e. chicken breast, garlic, ground coffee, hot pepper (capsicum), paprika, eggplant, vegetable marrow, walnut, pomegranate sauce, sesame paste, olive oil, parsley (greens), basil (greens), water and salt respectively; 0.99 is the preservation of the corresponding food component during heat treatment.

Along with this, an additional ratio between protein and fat is included

$$P:F=1:1 \quad (3)$$

Fourth stage: setting the target function (optimization criterion).

The energy value was chosen as an optimization criterion. Because to reduce the risk of cardiovascular diseases developing and for their dietary therapy, meat-based foods should improve metabolic processes, restore the metabolism of the vascular wall and heart muscle, and have an anti-sclerotic therapeutic effect. This may be achieved by limiting the energy value, salt and fat contents [65].

Fifth stage: solving the problem using a high-level language in a modern programming environment.

The simulation was carried out in the R Studio software using the R programming language. The open-source lpSolve and lpSolveAPI libraries were used.

As a result, the following data were obtained (Table 5).

Nutritional value analysis of the optimal balanced recipe considering the target function and the given restrictions is carried out at *the sixth stage*.

Table 4. Chemical composition of the ingredients used in the Muhammara recipe

	Water, %	Protein, %	Amino acids, g/100 g of protein									Fat, %	Total fatty acids		
			Val	Ile	Leu	Lys	Met + Cys	Thr	Trp	Phe + Tyr	His		SFA	MUFA	PUFA
Chicken breast	69.46	20.85	5.59	5.29	8.93	10.37	3.94	4.84	1.36	8.24	4.02	9.25	3.26	6.48	3.34
Garlic	60.00	6.50	4.48	3.34	4.74	4.20	2.17	2.42	1.02	4.06	1.74	0.50	0.089	0.011	0.249
Ground coffee	7.00	13.90										14.40			
Hot pepper (capsicum)	88.00	1.30	6.15	5.38	8.46	6.92	4.62	5.38	2.31	10.77	3.08	0.44	0.02	0.11	0.11
Paprika	11.24	14.14	5.30	4.03	6.51	4.88	3.04	3.47	0.50	7.00	1.77	12.89	2.14	1.7	7.77
Eggplant	91.00	1.20	5.92	5.08	4.17	4.67	1.67	3.92	1.00	9.17	2.25	0.10	0.03		0.08
Vegetable marrow	93.00	0.60	9.00	7.33	11.83	11.17	5.00	4.83	1.67	12.50	4.33	0.30	0.10		0.10
Walnut	3.80	16.20	7.35	4.75	7.59	2.72	2.65	3.64	1.11	8.33	2.53	60.80	6.20	14.70	40.40
Pomegranate sauce	83.00	0.00										0.00			
Sesame paste	1.60	18.08	5.59	4.30	7.66	3.21	5.32	4.15	2.19	9.49	2.94	50.87	7.12	19.21	22.30
Olive oil	0.20	0.00										99.80	15.75	66.90	13.20
Parsley greens	85.00	3.70	4.65	3.19	5.51	4.89	1.51	3.30	1.22	6.14	1.65	0.40	0.10		0.12
Basil greens	92.06	3.15	4.03	3.30	6.06	3.49	2.03	3.30	1.24	6.57	1.62	0.64	0.04	0.09	0.39
Water	100	0.00										0.00			
Salt	0.20	0.00										0.00			

Table 5. Results of the Muhammara recipe simulation

	Water, %	Protein, %	Amino acids, g/100 g of protein									Fat, %	Total fatty acids		
			Val	Ile	Leu	Lys	Met + Cys	Thr	Trp	Phe + Tyr	His		SFA	MUFA	PUFA
Muhammara	64.27	13.29	5.54	5.05	8.48	9.23	3.76	4.57	1.30	8.02	3.71	13.75	7.72	26.50	15.85
Protein: fat ratio		1:1.03		**SFA: MUFA: PUFA ratio**			1:3.43:2.05			**Energy value, kcal**					215

The chosen ingredient ratios as a result of the execution of the program code in the R language made it possible to obtain the protein: fat ratio of 1:1.03 (recommended ratio 1:1), SFA: MUFA: PUFA ratio — 1:3.43:2.05 (recommended ratio 1:1:1). The energy value of the product is 215 kcal.

The chemical composition of the traditional Muhammara recipe: protein 6.9 g, fat 27.8 g, carbohydrates 20.3 g, protein: fat ratio 1:4.02. Energy value is 351.6 kcal.

The modified and optimized Muhammar recipe is balanced in such a way that, in addition to lowering cholesterol levels, they have a reduced calorie content compared to the traditional recipe.

Gerodietetic nutrition

Another example of systemic approach is the development of products for gerodietetic nutrition.

During the study, meat raw materials, offals and poultry meat were clustered according to important descriptors in the selection of meat ingredients for the recipe of a gerodietetic product being developed: protein content (Figure 3), methionine + cystine content (Figure 4), tryptophan content (Figure 5).

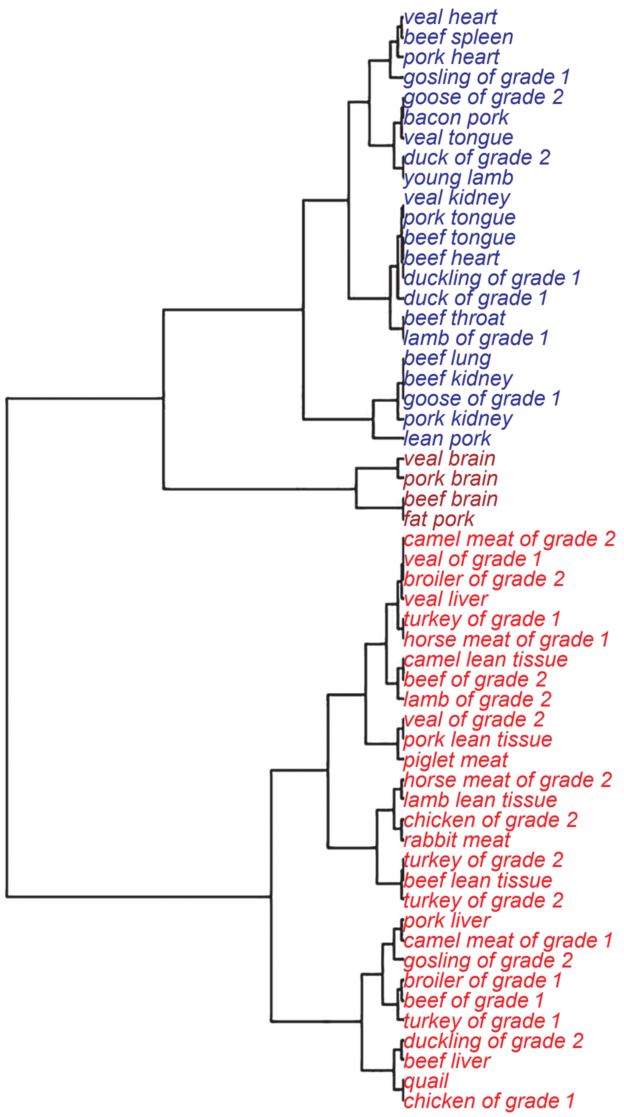

Figure 3. Dendrogram for meat raw materials and poultry meat by the descriptor «Protein content,%»

As a result of clustering, a dendrogram is formed, which visualizes the results of hierarchical clustering. It allows to visually assess the degree of proximity of individual objects and clusters, and also graphically demonstrates the sequence of their combination. Colored areas (red, blue, brown) in the dendrogram visually display the division of products into clusters. Along with the dendrogram, a table is formed with details for each cluster: 1) the number of products included in this cluster; 2) the mean value for this cluster; 3) maximum content in this cluster; 4) minimum content in this cluster. The user can see more detailed information when opening each cluster, i. e. what products are included in this cluster and their value for this indicator (descriptor).

Dendrogram analysis by the descriptor "Protein content,%" (Figure 3) shows that 3 clusters were formed (Table 6) with high, moderate and low protein content. The first cluster (red color on the dendrogram) included 29 items of meat raw materials and poultry meat with a range from the minimum value (17.90%) to the maximum value (21.70%) and an average value of 19.76%. The second cluster (blue color on the dendrogram) included 22 items of meat raw materials and poultry meat with a range from the minimum value (14.3%) to the maximum value (17.2%) and an average value of 16.02%. The third cluster (brown color on the dendrogram) included 4 items of meat raw materials and poultry meat with a range from the minimum value (10.3%) to the maximum value (11.7%) and an average value of 11.05%.

Table 6. Clustering result by the descriptor «Protein content, %»

Cluster	Number of products in cluster	Mean, %	Min. value for the field «Protein», %	Max. value for the field «Protein», %
1	29	19.76	17.90	21.70
2	22	16.02	14.30	17.20
3	4	11.05	10.30	11.70

According to the requirements and restrictions that are set within the framework of his task, the researcher may choose one or more components of the future recipe from the formed samples. If this information is not enough, he can use clustering by different descriptor(s), for example, by the content of the sulfur-containing amino acids, methionine and cystine (Figure 4, Table 7).

Dendrogram and table analysis by the descriptor «Methionine + cystine amino acids content, g/100 g of protein» (Figure 4 и Table 7) shows that the formed first cluster contains 30 types of meat raw materials and poultry meat with a high content of these amino acids. The range of values in this cluster is as follows: the minimum value is 3.48 g/100 g of protein, the maximum value is 4.22 g/100 g of protein, the average value is 3.8 g/100 g of protein.

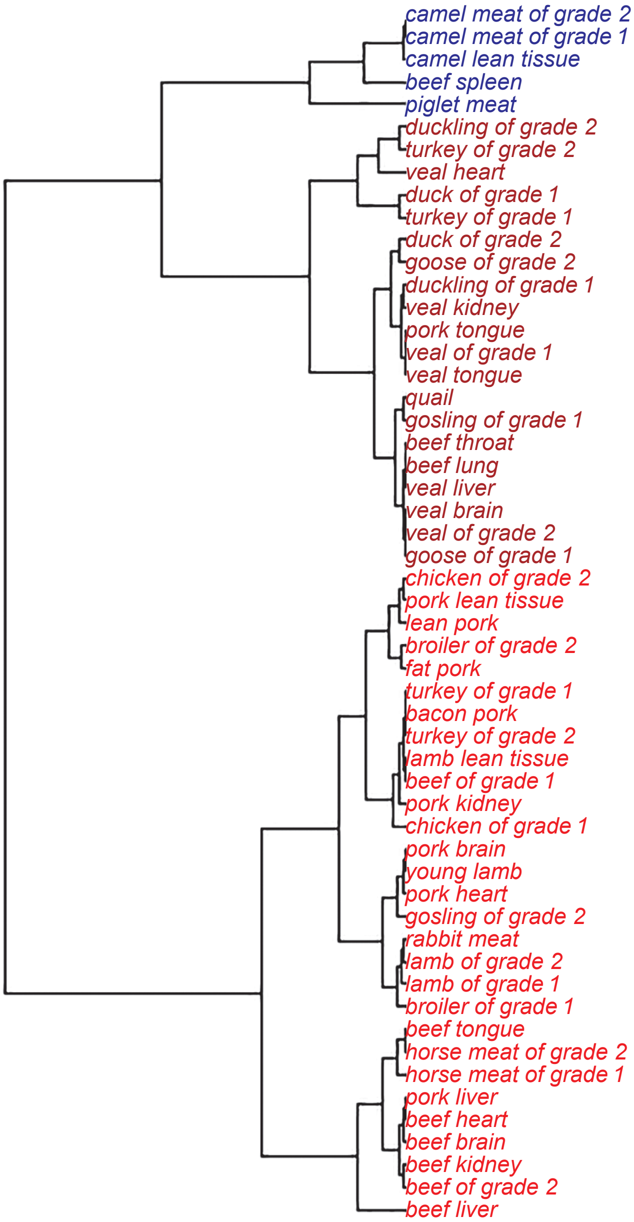

Figure 4. Dendrogram for meat raw materials and poultry meat by the descriptor «Methionine + cystine amino acids content, g/100 g of protein»

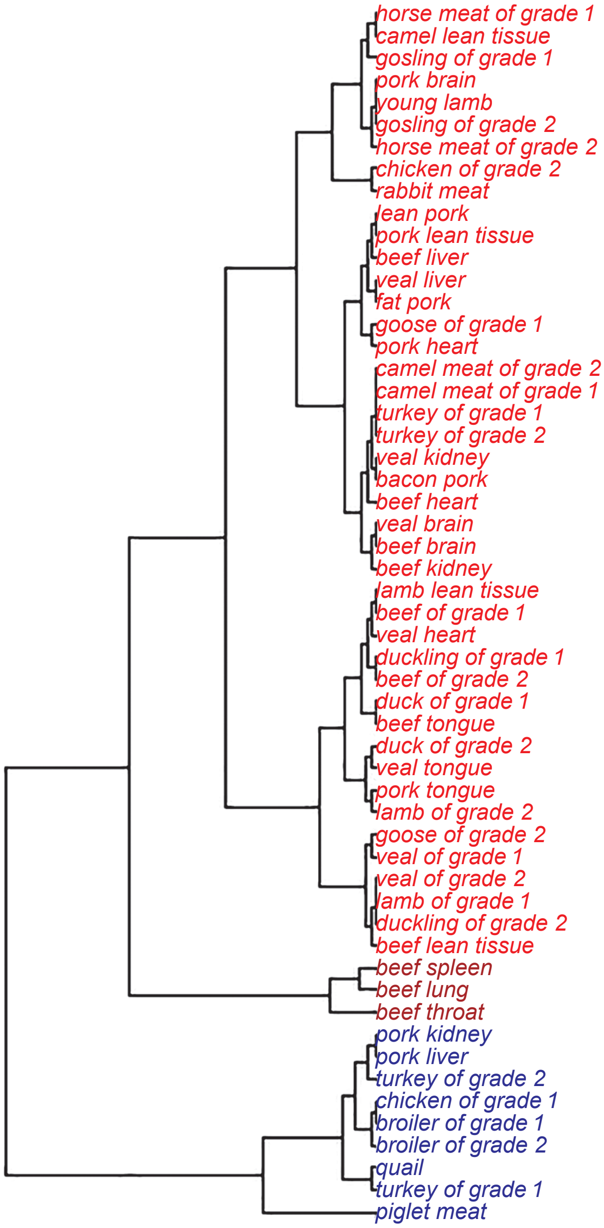

Figure 5. Dendrogram for meat raw materials and poultry meat by the descriptor «Tryptophan amino acid content, g/100 g of protein»

Table 7. Clustering result by the descriptor «Methionine + cystine amino acids content, g/100 g of protein»

Cluster	Number of products in cluster	Mean, g/100 g of protein	Min. value for the field «Met+Cys content», g/100 g of protein	Max. value for the field «Met+Cys content», g/100 g of protein
1	30	3.80	3.48	4.22
2	5	2.49	2.14	2.64
3	20	3.28	2.92	3.41

Along with this, one of the significant indicators included in the medical and biological requirements is the content of tryptophan amino acid. Its value in the product should be at least 1 g per 100 g of protein. Therefore, the clustering of meat raw materials and poultry meat was carried out according to this descriptor (Figure 5, Table 8).

Table 8. Clustering result by the descriptor «Tryptophan amino acid content, g/100 g of protein»

Cluster	Number of products in cluster	Mean, g/100 g of protein	Min. value for the field «Trp content», g/100 g of protein	Max. value for the field «Trp content», g/100 g of protein
1	43	1.32	1.10	1.56
2	9	1.68	1.60	1.94
3	3	0.89	0.81	0.95

As a result of clustering, three clusters were formed. The second cluster contains 9 types of meat raw materials and poultry meat with the content of tryptophan amino acid ranged from 1.6 to 1.94 g/100 g of protein. These are the highest figures. On the dendrogram, cluster 2 is highlighted in blue. Detailed information about the raw materials included in it may be obtained by opening this cluster (clicking on the "+" icon in the table» (Table 9).

Table 9. Clustering result (detailed information on luster 2) by the descriptor «Tryptophan amino acid content, g/100 g of protein»

Cluster	Number of products in cluster	Mean, g/100 g of protein	Min. value for the field «Trp content», g/100 g of protein	Max. value for the field «Trp content», g/100 g of protein
1	43	1.32	1.10	1.56
2	9	1.68	1.60	1.94
broiler of grade 1	1	1.61	1.61	1.61
broiler of grade 2	1	1.60	1.60	1.60
turkey of grade 1	1	1.69	1.69	1.69
turkey of grade 2	1	1.64	1.64	1.64
chicken of grade 1	1	1.61	1.61	1.61
piglet meat	1	1.94	1.94	1.94
quail	1	1.70	1.70	1.70
pork liver	1	1.66	1.66	1.66
pork kidney	1	1.66	1.66	1.66
3	3	0.89	0.81	0.95

As it can be seen from Table 9, the highest value of tryptophan amino acid is found in piglet meat (1.94 g/100 g of the product), and poultry meat (quail and turkey of grade 1: 1.7 and 1.69 g/100 g of protein, respectively).

Scientific research and publications by Yudina S. B., a specialist in the field of gerodietetic nutrition, confirm this. In the monograph on gerodietetic nutrition [66], it is noted that the mass fraction of protein in beef (18.5%), rabbit meat (21%) and poultry (chicken of grade 1) (18.2%) is high. The amino acid composition of this raw material is the most balanced in relation to the reference protein and meets the requirements for the nutrition of the elderly and older people.

Beef proteins are high in methionine + cystine (3.79 g/100 g of protein) and low in tryptophan (1.13 g/100 g of protein). Rabbit meat and poultry (chicken of grade 1) also have a high content of methionine + cystine (3.6 and 3.82 g/100 g of protein respectively), and a low content of tryptophan (1.32 and 1.51 g/100 g protein respectively).

In beef and rabbit meat, the protein: fat ratio is ≈ 1:0.8, which corresponds to the nutritional recommendations for older people.

This raw material of animal origin contains a high amount of B vitamins (the content of vitamin B6 in beef is 0.38 mg/100 g of product; in rabbit meat 0.46 mg/100 g of product; in poultry (chicken of grade 1) 0.50 mg/100 g of product), niacin (in beef, rabbit meat and poultry (chicken of grade 1) is 4.7; 6.17; 7.10 mg/100 g of product respectively), and vitamin E (0.51; 0, 50; 0.23 mg/100 g of product respectively).

To obtain products with high nutritional value, it is necessary to use a combination of raw materials of animal and vegetable origin. The use of vegetable raw materials for the production of gerontological nutrition products is predetermined by its high biological properties: an increased content of ballast substances, vitamins, and essential macro- and micronutrients.

Analysis of the data revealed that full-fat flour and chickpeas contain a large amount of protein. The following are distinguished by an increased content of methionine + cystine (g/100 g of protein): chickpeas — 2.93; rice grits — 3.28; soy flour — 6.10; wheat germ — 3.70; white cabbage — 2.34.

For the content of tryptophan, all types of vegetable raw materials meet the requirements for the nutrition of older people.

The lipids of chickpeas, rice grits, full-fat soy flour, wheat germ are rich in polyunsaturated fatty acids, especially linolenic acid.

The choice of meat and vegetable raw materials intended for the production of gerodietetic products, and determination of their chemical composition are important steps in the development of a future product recipe.

The most common diseases in older people are diabetes mellitus, obesity, cardiovascular diseases, atherosclerosis, digestive system disorders, oncological diseases, central nervous system disorders, iodine deficiency and iron deficiency. A special attention is paid to musculoskeletal system disorders. First of all, these are osteoporosis and osteoarthritis. These diseases are leading both in prevalence and in the causes of disability and mortality from complications.

One of the approaches to the prevention of the musculoskeletal system disorders is the introduction of functional foods into diet as they contain essential nutrients in quantities that largely meet the needs of older people.

Sausages are quite popular products for older people. This is due to a number of reasons and specific circumstances: tender texture; a wide range of prices and quality; no cooking is needed. However, these products are not favorable for metabolic, physiological and biochemical processes of the body due to the increased amount of salt and fat, the presence of flavorings and technological additives.

Based on the analysis of data on the physiological needs of older people for nutrients, specialists from the V. M. Gorbatov Federal Research Center for Food Systems together with specialists from the Institute of Nutrition developed scientifically based recommendations for the composition and quality of cooked sausages, which include requirements for the meat raw materials used, protein, fat, vitamin and mineral components and finished product in terms of nutritional value and safety.

When developing scientifically based requirements for functional cooked sausages, deficiencies often found in older people were taken into account, which have the greatest impact on the development of musculoskeletal system disorders (Table 10).

Table 10. Formalized requirements for the composition of gerodietetic products for the prevention of musculoskeletal system disorders

Parameters	Content per 100 g of product	% of daily requirement
Proteins, g, including	10.0 to 14.0	20 to 25
connective tissue proteins, g	4.0 to 6.0	—
Fat, not more, g, including	8.0 to 12.0	20 to 25
vegetable oils	2.0 to 4.0	20 to 25
Carbohydrates, g, including	4.0 to 8.0	5 to 7
dietary fiber, g	3.0 to 6.0	20 to 30
Cholesterol, g, not more	0.06 to 0.012	20
ω6/ω3 ratio	(1 to 7):1	—
Energy value, kcal/100 g	120 to 180	6 to 9
Salt, g, not more	2.0	60
Minerals, mg:		
Calcium	180 to 360	15 to 30
B_1, mg	0.2 to 0.45	15 to 30
B_2, mg	0.27 to 0.54	15 to 30
B_6, mg	0.3 to 0.6	15 to 30
E, mg tocopherol eq.	2.25 to 4.5	15 to 30
PP, mg	3.0 to 6.0	15 to 30
D, µg	2.25 to 4.5	15 to 30

Considering the anti-atherogenic nature of the diet for older people, when developing cooked sausages, raw materials with a low content of saturated fats and a high content of connective tissue (shank meat) were selected. The use of horse meat is due to the high content of α-linolenic acid, linoleic acid, eicosapentaenoic acid and docosahexaenoic acid.

Vegetable oils (rapeseed oil and soybean oil) are important for an aging organism due to the presence of polyunsaturated fatty acids of the ω3 class, as well as phosphatides (lecithin) and phytosterols, which have a beneficial effect on cholesterol metabolism.

To make a functional product, the composition includes dietary supplement developed on the basis of protein hydrolysate with the introduction of a number of food ingredients, including dietary fiber, biologically active substances (chondroprotectors that have a positive effect on the metabolic processes in cartilage tissue), mineral salts and vitamins (B1, B2, B6, B3, D3, E).

Based on the data on the distinctive features of meat raw materials and taking into account the formalized scientifically based requirements given in [67, 68], cooked sausage recipe compositions for gerodietetic nutrition were obtained by computer simulation (Table 11).

The results of amino acid and fatty acid balance assessment are presented in Table 12.

Analyzing the data on the amino acid balance in the resulting sausage compositions, we see the rather high values of the rationality coefficient for the amino acid composition, which is in the range of 0.89 to 0.93, and the comparable redundancy coefficient of 3.1 to 3.12, which indicates a high biological value of the developed cooked sausages. The results of fatty acid balance assessment confirmed the high nutritional value and compliance with the developed scientifically based requirements.

Table 11. Composition of sausages

Sample	Ingredients
Cooked sausage (Recipe 1)	➢ Trimmed beef of grade 1 ➢ Beef shank meat ➢ Pork shank meat ➢ Dietary supplement (inulin, egg albumen, dietary fiber, collagen hydrolysate, calcium, calcium citrate (E333), ascorbic acid, nicotinic acid (PP), tocopherol acetate (vitamin E), pyridoxine hydrochloride (B6), thiamine bromide (B1), riboflavin (B2 E101), cholecalciferol (D3)) ➢ Water ➢ Rapeseed oil ➢ Linseed oil ➢ Salt ➢ Black or white pepper ➢ Nutmeg ➢ Pimento
Cooked sausage (Recipe 2)	➢ Horse meat ➢ Poultry meat ➢ Egg albumen ➢ Rapeseed oil ➢ Linseed oil ➢ Dietary supplement (inulin, skimmed milk powder, egg albumen, dietary fiber, calcium, isolated animal protein, calcium citrate (E333), glucosamine sulfate, chondroitin sulfate, ascorbic acid, nicotinic acid (PP), tocopherol acetate (vitamin E), pyridoxine hydrochloride (B6), thiamine bromide (B1), riboflavin (B2 E101), cholecalciferol (D3)) ➢ Water ➢ Salt ➢ Black or white pepper ➢ Nutmeg ➢ Pimento

Table 12. Amino acid and fatty acid balance of recipe compositions for cooked sausages

Parameters	Cooked sausage		FAO/WHO reference
	Recipe 1	Recipe 2	
Mass fraction of protein, g/100 g	13.0	13.2	—
Mass fraction of fat, g/100 g	10.25	10.05	
Minimum amino-acid score,%	0.99	0.98	→1
Comparable redundancy coefficient, g/100 g of protein	3.12	3.1	→0
Rationality coefficient, U	0.89	0.93	→1
Fatty acids, g/100 g			
Σ SFA	39.86	38.75	
Σ MUFA	37.31	38.56	
Linoleic fatty acid	14.7	14.8	
Linolenic fatty acid	10.25	9.78	
Arachidonic fatty acid	0.2	0.25	
Coefficient of fatty acid balance R_{1-3}, U	0.82	0.84	
Coefficient of fatty acid balance R_{1-6}, U	0.57	0.58	
ω6: ω3 ratio	1.5:1	1.4:1	

Conclusion

Development of food products with given composition and properties primarily depends on scientifically based information and principles and biomedical requirements for each determined group. This information should be in the knowledge base for the functional foods design system.

Considering these requirements, the choice of the main raw material for the recipe of the future product is carried out by clustering methods according to one or more significant descriptors. This requires a database of the chemical composition of food products and ingredients. Next, the recipe dendrogram and mathematical dependencies for the main food nutrients are generated, taking into account the preservation of the corresponding food nutrient during heat treatment. At the final stage, a complex solution of the equation system using mathematical programming methods and analysis of the nutritional value of the optimal balanced recipe considering the target function and the given restrictions takes place. The example of two products shows the possibility of product simulation, which significantly reduces the time spent on the optimal recipe development and the selection of ingredients. The described systemic approach may be applied for the development of a food product with any properties.

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