Optimizing the Ingredients of Functional Foods

V M Kiselev¹a, T F Kiseleva¹b, E N Zubareva¹c, A V Petropavlovskaya¹d, L P Lipatova¹e, M A Afanasyev¹f
¹Plehanov Russian University of Economics, 36, Stremyanny lane, Moscow, 117997, Russia
²Kemerovo state University, 6, Krasnaya str., Kemerovo, Siberian Federal District, 650000, Russia

E-Mail: ¹kisselev.vm@mail.ru (corresponding author), ²kisseleva.tf@mail.ru,
³zubarevaen@yandex.ru, ⁴petraal@rambler.ru, ⁵llp_ital@mail.ru,
⁶afanasev.ma@rea.ru

Abstract. Conventional diets balance the multilevel, multifaceted needs by combining a
diversity of foods into a daily menu. Such diets are compensatory by their nature. To
compensate for the lack of some essential nutrients in foods, the body relies on the oversupply
of some foods. The resulting diet is functionally disastrous; such dietary habits result in
endemic and occupational diseases. Feeding on combined foods whose functional properties
have been thoroughly adjusted helps properly balance the daily menu to optimize the intake of
each nutrient, thus resulting in a higher quality of life, better health, saved foods, and lesser
environmental impact. To optimize the composition and quantity of ingredients by the
specified criteria so that the final functional food contains the required nutrient quantities, the
authors hereof apply vector combinatorics. The paper summarizes the results of many years of
research; it also articulates what else could potentially be researched further.

1. Introduction
The supervisor of this research project studied the prosperity of general population as well as that of
specific consumer groups in the context of the parity of requirements; as part of this research, he
analyzed the attainability of a stable Nash equilibrium in a multitude of non-cooperative stakeholders.
The theory behind this was developed John Forbes Nash Jr., a 1994 Noble Prize winner who was also
awarded the Abel Prize in 2015 for his contribution to the theory of nonlinear differential equations.
Essentially, this theory states there is always such point of equilibrium in a system of multiple
coordinate axes, in which the interests of multiple stakeholders are accommodated as much as possible
in the situation [1]. Under this study, consumers and producers of functional foods, suppliers and
producers of raw food materials, employers and public health agencies, as well as food supervision
agencies were defined as stakeholders whose demand vectors differed in direction. This enabled the
priority of needs [2].

Earlier the project participants devised a novel scientific discipline dubbed “commodity
economics”, enshrined in V.M. Kiselyov’s doctoral thesis (2005) [2]. Data and considerations under
this new approach were published in the monograph [3] Papers [4,5] describe the algorithm for
optimizing the components of functional foods. Paper [2] describes the core provisions of the
methodology based on the parity of needs of the parties in an integrated commodity distribution
system. The results of an earlier series of experiments [6,7] prove feasible optimizing the ingredients of functional foods by the priority scoring of nutrients based on physiological norms. Experiments proved the feasibility of using the developed mathematical model to optimize the ingredients of foods in terms of vital nutrients and energy content [2,3]. In the experiment, to attain a parity of needs between consumers and producers, the research team took into account the target audience’s (miners) needs of a variety of nutrients, the economic interests of their employers (the pricing of the foods), and the social criteria (decrease in occupational morbidity). The software prioritized the last criterion. This approach to formulating functional and therapeutic diets was then dubbed the Vital Concept [2,5]. Foods and menus created by the approach are functional in the sense that they produce foods parametrically fit to the consumer’s needs. Of several needs, the Vital Concept prioritizes the nutritional norms that enable the functional foods, when consumed, to make the consumer’s body more resistant and thus strengthen their health (including resistance to occupational diseases) while also improving their performance at work. Parity of needs was modeled mathematically by optimizing the total criteria for assessing needs of the target audience’s bodies’ for nutrients contained in the daily diet; these needs were rendered in absolute and relative values alike [4].

2. Research methodology
The fundamental approach towards the goal of this research is based on the theory of attaining a stable Nash equilibrium given a multitude of non-cooperative stakeholders [1]. To find the Nash equilibrium point (the parity of needs), the research utilizes food combinatorics and attempts to optimize functional food ingredients, whereby it prioritizes nutrient scores in terms of matching the nutritional norms for the target audience. The paper models the parity of the body’s needs for various nutrients when optimizing the feasibility-tested criteria for assessing the body’s needs both in absolute and relative values. It balances the ingredients of functional foods so that deviation from the Euclidean norm is minimum. This is a unique approach that has not been used before in this context.

As part of this study, the researchers have devised an algorithm and collected a database of nutrients in different food materials; the team has also developed software for interdisciplinary combinatorics that implements physiological, technological, chemical, biological, environmental, and economic criteria. This software can also be used in an applied manner for multifactorial optimization in related disciplines such as economics (logistics, finance, design, etc.), bioengineering, cybernetics, etc.

In their recommendations, the researchers reasonably state the importance of various functional factors for the body. According to them, core nutrients and energy content are of the utmost importance. These factors are ranked as the highest priority. The second most important factor group comprises polyunsaturated fatty acids and fat-soluble vitamins found in plant fats. This group is ranked 2nd. The third most important group comprises minerals and water-soluble vitamins. These are ranked 3rd.

In addition to nutrient factors, the parity of needs is adjusted for the economic feasibility or cost-effectiveness, which is a Priority Rank 4 in this Vital Concept. An important feature of this optimization method is that it combines natural foods in such a way as to hit the ‘perfect’ parameters as closely as possible while maximizing the diversity of organoleptic and technological parameters of the ready foods.

When selecting foods to add to the assortment of optimal diets, and components to make optimal food compositions of, the authors analyzed the chemistry of the primary components as well as their other properties in a manner consistent with the principle of holism discussed earlier as part of the parity of needs methodology. These other properties include esthetics, social nature, reliability and safety of the newly designed functional foods. In addition to these properties, the authors took into account the need to consume foods at food-specific recommended rates: a single food (meal) shall not be consumed more than once in two months (1.5 months if adjusted for non-working days), i.e. the assortment of functional foods for each consumer group must include at least 45 items.
Hygienically, it is important to determine important consumable sources of proteins, fats, and carbohydrates. Ingredients were selected with their chemical composition in mind, data on which was sourced from reference books [8-15]. This data is recommended by the Institute of Nutrition, Russian Academy of Medical Sciences, for calculating the chemicals in diets.

Mathematical modeling of how the parity of needs could be attained was applied to efficiently structure the ingredients of foods depending on their availability to the parties involved in the food distribution process, and on their specific needs. The methodology was based on the theory and practice of mathematical combinatorics [23-25]. The method involves optimizing the total criteria for assessing such needs in both absolute and relative values. The method optimizes the balance of needs (the composition of the whole diet or of a single meal) to the specified final requirements pertaining to such balance. Thus, the final balance could be represented by a vector per Eq. 1:

\[ d = (d_1, d_2, ..., d_k). \] (1)

where \( d_i \) are the optimization parameters.

The total need (\( m \)) is calculated by Eq. 2, while the integral estimate is calculated by Eq.3, where \( \alpha_i \) is the ingredient- or nutrient-specific value coefficient.

\[ m = \sum_{i=1}^{k} d_i. \] (2)

\[ Q = \sum_{i=1}^{k} \alpha_i \times d_i. \] (3)

\[ d_i = 100 \times \sum_{m=1}^{n} k_m \times a_{mi}. \] (4)

where \( i = 1, 2, ..., k \).

For the vector components, find the following values (Eq. 4), where \( k_m \) is the quantity of \( m \)-numbered products (a proportion of 100 %).

Eq. 5 describes the variation constraints for each ingredient. Eqs. 6 and 7 describe the conditions of fitting the reference vector (\( d^* \)). Besides, there are constraints (Eq. 8).

\[ a_m \leq k_m \leq b_m. \] (5)

\[ M = \sum_{i=1}^{k} d_i^*. \] (6)

\[ Q = \sum_{i=1}^{k} \alpha_i \times d_i^*. \] (7)

\[ M = 100 \times \sum_{m=1}^{n} k_i. \] (8)

Eqs. 9 to 15 show the mathematical model of the balance of needs.

\[ a_m = (a_{m1}, a_{m2}, ..., a_{mk}). \] (9)

where \( m = 1, 2, ..., n \), provided that \( a_{mi} \geq 0 \). (10)
\[ \sum_{i=1}^{k} a_{mi} = 100. \] (11)

Eq. 12 describes the objective vector:
\[ d^* = (d^*_1, d^*_2, \ldots, d^*_k). \] (12)

and the linear combination of vectors \( a_1, a_2, \ldots, a_n \) with the coefficients \( k_1, k_2, \ldots, k_n \).
Under these conditions
\[ d = k_1 a_1 + k_2 a_2 + \ldots + k_n a_n. \] (13)

where \( d \) is also an \( n \)-dimensional vector.

Optimize the balance of needs by finding such values of \( k_i \) given the constraints
\[ a_i \leq k_i \leq \beta_i. \] (14)

where \( i=1,2,\ldots,n \) that the deviation norm \( \|d - d^*\| \) be minimum.

The norm used in this research was the generalized Euclidean norm (Eq. 15)
\[ \|d - d^*\| = \left[ \sum_{i=1}^{n} \lambda_i (d_i - d^*_i)^2 \right]^{1/2}. \] (15)

3. Results

Food combinations are a novel category of food security, the latest evolution of any conventional approach to optimal nutrition. Combinations help preserve the health in those differentiated consumer categories who need their nutrition fixed, as they supply the essential nutrients in optimal quantities and ratios. Thus, the novel product compositions design to have specific nutritional values are first and foremost prophylactic in function, making them fundamental to a healthy lifestyle.

This new research discipline (food design) will help certain consumer categories avoid diseases stemming from their environment. Therefore, potential target demographics include not only regional populations, but also specific cohorts who need specifically optimized nutrient compositions, e.g. elderly people in need of a balanced diet.

Optimal diets include compositions that comprise foods that enable the body to fully digest nutrients for better quality of life and a stronger immunity. Optimal diets are to be maintained systematically. These diets help preserve and improve health, reduce the risk of nutrition-related (alimentary) diseases thanks to providing functional nutrients capable of improving one or more physiological functions and metabolic reactions of the human body.

Optimal diets should enable the body to remove inhaled toxins and to improve the general body tonus while also making it less susceptible to inflammatory diseases. Among other things, such diets offer optimal calcium intake and best ratios of calcium to other minerals, which, given that the content of other nutrients is optimized as well, improves the digestibility of calcium. As a result, the body becomes less prone to bone fracturing. Another distinctive feature of optimal diets configured to have specific properties is that they have the required quantities of vitamins and other biological agents for best performance and preventive of rheumatisms. Regular intake of such foods decreases disease incidence rates in various demographics.
Furtherance of this hypothesis will enable hygienists to optimize diets for best prophylactic performance in order to prevent multiple blood diseases by enriching foods with iron so as to increase hemoglobin levels. This ultimately leads to better oxygenation.

On the other hand, optimal diets help prevent glycemia, ultimately reducing the risk of diabetes. There is yet another application of such foods that we deem a success: they can help the consumer to adapt to occupation-related stress, reducing the risk of cardiovascular diseases as a consequence.

Last but not least, optimal diets provide occupation- and habitat-necessitated detoxication by timely and painlessly removing heavy-metal salts the body accumulates while at work.

The chemical composition of a demographic-specific diet should boost the vitality and make the body resistant to aggressive environments, including the occupational environment. This ultimately keeps the consumer healthy and able-bodied for a long time.

Optimal diets are demographic-specific. Such food combinations are designed to protect people from the harmful effects of their habitat so as to prevent alimentary diseases. Optimal nutrition improves general body resistance, well-being, and performance; it reduces general and occupational morbidity.

From the standpoint of the holistic principle of making a nutritionally optimal assortment of foods, it is recommendable to make a list of nutritional properties adjusted for the empirical properties of each food to be included in such an optimal combination. We believe that foods should have not only nutritional, but also sensory and semantic properties. From this standpoint, an optimal diet should meet not only the biological, but also the social and spiritual needs of a person. The diet needs to be adjusted for the ontogenetic, family, and national customs of the persons, their lifestyle and health.

Thus, an optimal diet must become its target demographic’s sociocultural trait, a part of the whole set of social, biological, and physiological rules that dictate the person’s behavior in the biosphere.

To attain the parity of needs within the Vital Concept, the research team set the boundaries of the specific weight of each nutrient. These boundaries stem from the hypothetical effects such ingredients might have on the organoleptic quality of the optimal diets made for different demographics. In case a specific ingredient must be consumed in greater quantities to attain the parity of needs, special techniques need to be applied to balance the organoleptic properties, which have historically been shown to be more conservative compared to other traits of foods.

Thus, adjustments for the target demographic’s nutritional habits are often based on their conservative attitude towards foods, their appearance, taste, and smell, often compromising the nutrient balance [16-18].

Such limitations apply to a lesser extent to the economic factors e.g. the cost of the assortment. As noted earlier, consumers tend to associate higher costs with higher quality, and vice-a-versa [2]. Where economic factors take priority over hygiene, the Vital Concept will most likely fail to attain parity of needs.

The results of the technological experiment present herein are of practical interest to the producers of food, including canned foods, to the kitchens present in retail stores, etc. The cybernetic experiment results, the design algorithm, and other tools of modeling innovative foods can be used in the training of Management masters specializing in food industry.

The following results of the forthcoming study are patentable:
- Optimization software based on the combinatory theory of choice;
- The algorithm for designing functional foods to have specific properties;
- The results of the cybernetic experiment and those of the technological experiment;

These results are in demand in the food industry, sports, and functional food industry.

The scientific novelty of this research lies in the development of a methodological tooling for designing innovative foods to have specific functional properties.

The following results of the forthcoming study are novel:
- Mathematical optimization methods based on the combinatory theory of choice;
- Optimization software based on the combinatory theory of choice;
- The algorithm for designing functional foods to have specific properties;
The results of the cybernetic experiment and those of the technological experiment.

As Russia’s population and companies continue expanding into previously unsettled areas, e.g. the Arctic, a substantial population of workers will have to spend long periods of time in a habitat they are not used to. This trend makes research presented herein ever more relevant. All this time, the body of each a worker will need proper nutrition to be resistant to the negative effects the aggressive environment may exert upon it: cold, unusual solar radiation, etc. Conventional diets are suboptimal for the Arctic due to both logistics and nutritional physiology. There is need for special therapeutic and prophylactic foods similar to the special foodstuffs produced for astronauts, miners, metallurgists, etc.—functional foods designed to affect the body in a desirable manner by providing the necessary qualities. All these properties need to be confirmed by biomedical trials to be carried out by certified research centers using commonly recognized evidence-based methods. These trials will help conclude whether the proposed functional foods are safe, healthy, and suitable as a staple diet for Arctic workers. When selecting specific functional foods for therapeutic and prophylactic diets for crews scattered in the Arctic, one needs to bear in mind the individual features of each consumer’s body as identified when deciding on the feasibility of providing an Arctic worker with such a diet. This will help prevent occupational diseases in Arctic workers, preserve their health, and improve their quality of life on an individual and collective scale. Since the numbers of workers deployed in the Arctic are on the rise, and this trend is not expected to buckle any time soon, such research will have a profound social and economic impact.

To provide evidence, this paper presents the results of an attempt to optimize the ingredients of two meals that differ in consistency (a main course and a second course) and purpose (one is for the therapeutic and prophylactic diet of Labor Intensity Cat. 5 miners, and another one is for people in need of a low-calorie diet). Since miners’ medical histories are dominated by gastrointestinal pathologies, the diet to be made for this demographic had to be mechanically, chemically, and thermally easy to digest by adjusting the recipes, the processing, and the temperature of hot meals. Table 1 shows the optimized recipe of a functional meal for miners.

What made the parity of needs difficult to attain was the need to make such ingredient-optimized meals easily producible. To that end, the ingredients were processed in a procedure adequate to the foodstuffs involved and to the dietary requirements indicated above.

As for hygienic requirements, which were considered a priority for the parties involved in this product distribution process, the assortment optimized with such requirements in mind is shown in Table 2.

As can be seen there, the experiment did produce an optimized assortment of foodstuffs in such a way as to make the cumulative value (nutrients and energy) close to the recommended values. For most indicators, the deviation from the norm does not exceed 10% to 15%, which for this experiment was considered a sign of being close to attaining a perfect parity of needs under the Vital Concept.

| Table 1. Optimized ingredients of a potato soup with rice, a meal for a healthy diet. |
|---------------------------------------------|-----------|-----------|
| **Foods** | **Quantity, 10^{-3} kg** |
| | **Gross** | **Net** |
| Beef | 120 | 88 |
| Weight of prepared meat | - | 64 |
| Potatoes | 240 | 180 |
| Rice grains | 40 | 40 |
| Carrots | 31 | 25 |
| Onions | 30 | 25 |
| Salt | 3 | 3 |
| Cheese | 11 | 10 |
Table 2 shows an example of how the ingredients of the second course in a prophylactic and therapeutic diet for miners (Labor Intensity Cat. 5) could be optimized.

**Table 2. Optimized ingredients of boiled chicken and potatoes with sauce.**

| Foods                  | Quantity, $10^{-3}$ kg | Gross | Net |
|------------------------|------------------------|-------|-----|
| Eviscerated chicken    | 101                    | 70    |
| Carrots                | 19                     | 15    |
| Tomato puree           | 10                     | 10    |
| Onions                 | 18                     | 15    |
| Soft margarine         | 8                      | 8     |
| Potatoes               | 507                    | 380   |
| Salt                   | 3                      | 3     |
| Drinking water         | 212                    | 212   |
| Cheese                 | 42                     | 40    |
| Butter                 | 4                      | 4     |
| Boiled poultry weight  | -                      | 55    |
| Weight of potatoes and vegetables | - | 386 |
| **Total**              | -                      | 700   |

These ingredients were processed in a procedure suitable for the primary components. The regulations cover the recipes, acceptable limits of loss in cooking, the cooking technology, the delivery method, the organoleptic parameters, as well as the feasibility of and need for bread, hot beverages, and vitamin pills applicable to miners.

Table 3 lists the nutritional values of this meal and compares them against recommendations for this worker group.

As shown in Table 3, this optimized ingredient composition is strongly in line with the recommended nutrient and calorie intake, i.e. it meets the parity of needs by the social criterion. Deviation from norm are within 10% for most parameters, which in this experiment was a sign of being close to the parity of needs of the parties involved in this distribution channel.

**Table 3. Nutrient and calorie content of the ingredient-optimized potato soup with rice for a healthy miner diet.**

| Indicator               | Nutrients in 700 g of the mix | Deviation from the norm, % |
|-------------------------|-------------------------------|-----------------------------|
| Core nutrients, g:      |                               |                             |
| Protein                | 21.0                          | 5.25                        |
| Indicator                                      | Nutrients in 700 g of the mix | Deviation from norm, % |
|-----------------------------------------------|-------------------------------|------------------------|
| **Core nutrients, g:**                        |                               |                        |
| Protein                                       | 30.8                          | 28.0                   |
| including animal protein                      | 17.7                          | 16.0                   |
| Fat                                           | 29.9                          | 33.0                   |
| including plant fat                           | 8.0                           | 8.0                    |
| Digestible carbohydrates                      | 103.0                         | 115.0                  |
| including starch                              | 83.2                          | 85.0                   |
| Non-digestible carbohydrates                  | 13.0                          | 20.0                   |
| Ash                                           | 12.0                          | unlimited              |
| Fat:protein                                   | 1.0                           | 1.4                    |
| Carbohydrates:protein                         | 3.3                           | 5.0                    |
| **Minerals, mg:**                             |                               |                        |
| Potassium                                     | 1,466.7                       | unlimited              |
| Calcium                                       | 148.5                         | 180.0                  |
| Phosphorus                                    | 355.6                         | 300.0                  |
| Sodium                                        | 1,530.9                       | minimum                |
| Magnesium                                     | 90.3                          | 100.0                  |
| Iron                                          | 5.0                           | 3.0                    |
| Potassium:calcium                             | 9.9                           | 4.0                    |
| Phosphorus:calcium                            | 2.4                           | 1.7                    |
| Magnesium:calcium                             | 0.6                           | 0.6                    |
| Potassium:sodium                              | 1.0                           | minimum                |
| **Vitamins, mg:**                             |                               |                        |
| A+β-carotene                                  | 1.5                           | 0.4                    |
| C                                             | 20.2                          | 20.0                   |
| D, µg                                         | 0.3                           | 0.5                    |
| PP                                            | 5.6                           | 4.5                    |
| E                                             | 2.6                           | 3.5                    |
| B₁                                            | 0.3                           | 0.8                    |
| B₂                                            | 0.3                           | 0.8                    |
| B₆                                            | 0.7                           | 0.6                    |
| B₁₂, µg                                       | 1.5                           | 0.6                    |
| Energy, kJ                                     | 2,304.5                       | 2,400.0                |

Table 4. Nutrients and energy of the ingredient-optimized boiled chicken and potatoes with sauce.
Potassium 2,690.2 unlimited -
Calcium 350.5 170.0 106.16
Phosphorus 669.6 300.0 123.20
Sodium 2,334.5 minimum -
Magnesium 166.7 95.0 75.52
Iron 7.9 2.8 186.97
Potassium:calcium 7.7 4.0 91.90
Phosphorus:calcium 1.9 1.3 46.98
Magnesium:calcium 0.6 0.5 4.84
Potassium:sodium 1.1 minimum -

Vitamins, mg:
A+β-carotene 1.1 0.4 169.88
C 32.9 21.5 53.17
D, µg 1.0 0.5 90.80
PP 8.2 5.5 49.54
E 4.2 4.0 4.46
B1 0.5 0.6 7.84
B2 0.5 0.6 -15.23
B6 1.2 0.8 56.41
B12, µg 0.4 0.6 -39.62
Energy, kJ 3,345.3 3,650.0 -8.35

4. Conclusions
The research team carried out optimization experiments to see if the methodology using the parity of needs and the Vital Concept was usable; the experiments showed that the methodology was indeed usable, necessary, and feasible in the practice of providing industrial workers with functional foods for therapeutic and prophylactic purposes to address important social and economic issues.

Given that employers agreed the optimized ingredient compositions were acceptable in terms of costs compared to other offers in the market, as well as in terms of the cost-effectiveness of using these meals to feed miners, the conclusion is that the parity of needs of the parties involved in the distribution of foods was indeed attained.

The developed algorithm, the collected database on the nutritional composition of source materials, and the software providing interdisciplinary combinatorics with physiological, technological, chemical, biological, environmental, and economic criteria can now be used to solve applied multifactorial optimization problems in related disciplines such as economics (logistics, finance, design, etc.), bioengineering, cybernetics, etc.

To implement the proposed scientific hypothesis, the research ran advanced testing of how cohorts of different categories could have their menus adjusted. Adopting foods specially configured to have the desired physiological properties to support the consumer’s body and keep their health in optimal condition is an optimistic scenario of future use of the methodology.

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