Mathematical modeling of multicomponent beverages with a balanced composition of nutrients

A A Varivoda\textsuperscript{1}, M V Temerbaeva\textsuperscript{2}, T I Uryumtseva\textsuperscript{2}, L A Gerashchenko\textsuperscript{3} and A G Svirina\textsuperscript{3}

\textsuperscript{1}Kuban State Agrarian University named after I.T. Trubilin, 13, Kalinin St., Krasnodar, 350044, Russia
\textsuperscript{2}Innovative University of Eurasia, 45, Lomov st., Pavlodar, 140003, Republic of Kazakhstan
\textsuperscript{3}K G Razumovsky Moscow State University of Technologies and Management (the First Cossack University), 73 Zemlyanoy Val, Moscow, 109004, Russia

E-mail: nesterenko-aa@mail.ru

Abstract: The article assumes that formulas for multicomponent beverages based on dairy and vegetable raw materials were developed according to the principles of food combinatorics using methods of mathematical and computer modeling. The whey was used as a basis, plant materials were spinach and pumpkin, and chia seeds were used as a source of unsaturated fatty acids. Mathematical planning was used to form criterion equations for beverages characterizing the maximum content of essential nutrients. The formulas for beverages "Spinach" and "Pumpkin" were obtained; the content of the main nutrients is 18.889 g and 17.664 g, respectively. The analysis of the chemical composition showed that the ratio of proteins, fats and carbohydrates is 1: 1.45: 3.03 for "Pumpkin" and 1: 1.34: 2.57 for "Spinach". The storage terms of the developed beverages were determined taking into account changes in organoleptic and microbiological indicators. The optimal storage terms based on organoleptic changes suggests that the developed beverages will be competitive. The study of changes in the microbiota of ready-made beverages during four hours at a temperature of 4 ± 20C in a sealed glass container showed that the beverages meet the current regulatory requirements for the presence of opportunistic microorganisms. The developed integrated approach to the production of multicomponent beverages can be used by any market operator in the production of not only beverages, but also various food products.

1. Introduction
The nutrition of a modern human determines his health, well-being and life expectancy [1-7]. The compliance by parents with a balanced diet and the principles of a healthy lifestyle provides a basis for maintaining the health of an unborn child during the prenatal period.

Nutritionists recommend to intake adequate amounts of the required calories from a balanced dietary mix every day. A healthy diet is based on balanced essential nutrients. The ratio of proteins, fats and carbohydrates should be 1: 1: 4 in the diet of a healthy adult. As a result of technological processing, a human body does not receive the required amount of the necessary components in the native state. This has led to an urgent need to develop innovative technologies for the production of multicomponent food products with a balanced ratio of nutrients from local dairy and vegetable raw materials.
Dairy and vegetable raw materials are sources of macro- and microelements. Their combination makes it possible to create new dairy products for dietary and prophylactic nutrition of various consistencies with organoleptic properties attractive to consumers. However, the use of plant materials in beverages is problematic from the point of view of obtaining a certain consistency with high safety indicators. Therefore, the technology development for the production of milk-containing beverages with dietary fiber is a promising and urgent direction in the food industry [8-11].

Currently, diseases such as endocrine disorders, digestive and metabolic disorders have increased. Also, there is also a tendency towards gaining overweight, increasing obesity, cardiovascular diseases and cancer. According to statistics, the number of newly registered cases of endocrine disorders in 2019 decreased by 0.77 times compared to 2010, and the number of gastrointestinal diseases decreased by 0.83 times. This can be explained by the fact that the main part of the population begins to worry about their health and pay attention to the quality of food.

It should be noted that the development of nutritional science in recent years both in Russia and around the world is closely related to the theory of balanced nutrition. On the basis of this theory, the biological role of fats, proteins, carbohydrates, vitamins and macro- and microelements was determined, as well as the physiological needs of the human organism, food norms and diets for many age and professional groups of the population [12-17].

A balance of the hormonal system requires the consumption of four groups of foods for one meal three times a day: proteins, fats, carbohydrates and low-starch vegetables. Proteins and fats are necessary for the regeneration of cells and tissues, the synthesis of hormones and enzymes. Carbohydrates are sources of energy, first of all. Low-starch vegetables are essential sources of vitamins, mineral nutrients, and fiber. It is advisable to add some vegetables that are low in starch, such as celery, carrots, tomatoes, cucumbers, peppers, broccoli, pumpkin, spinach, cauliflower and others for each meal [18]. Leading doctors in Europe and the United States have declared that various unbalanced "trend" diets (e.g., Hollywood, Kremlin, vegetarianism, starvation, separation, Atkins, etc.) are destructive [19, 20].

Healthy foods that have a physiological effect on the organism, in addition to providing general nutrition, are also recognized as "functional foods" [21-24]. Milk and dairy products containing biologically active peptides, vitamins, antioxidants, probiotic bacteria, mineral nutrients and oligosaccharides are associated with a healthy daily diet. Dairy refreshments have been adopted as an effective way to meet new consumer needs in the functional food market. Technologies for the production and milk-containing beverages are discussed. Also, physical and chemical properties and health benefits are considered. The list of beverages includes whey (with fruit or vegetable juices, fermented or unfermented), fermented milk (probiotic dairy products, kefir, buttermilk, kumis) and milk beverages enriched with biologically active compounds.

Milk beverages reduce the risk of cardiovascular disease and promote muscle rehydration after exercise, making these foods more promising for functional nutrition.

Various plant components are added to milk beverages to increase the functional properties, i.e. cereals, puree from fruits or berries or juices from them, extracts from medicinal plants, etc.

Plant materials are the main component of a healthy diet. However, its importance in maintaining health and maintaining homeostatic balance is often overlooked, and amounts consumed are significantly reduced compared to those recommended by regulatory bodies. The preparation and commercialization of fruit and vegetable beverages with balanced nutritional and phytonutrient profiles may be a promising alternative to direct consumption of fruits and vegetables, since such beverages provide easy and quick consumption [25].

The production and consumption of functional plant-based dairy beverages has become important as they provide health benefits that go beyond basic nutritional functions. Today, beverages are the most efficient functional food category due to their convenience and ability to meet consumer beverages for the content, size, shape and appearance of containers, as well as for ease of distribution and storage of food (cold and well stocked). Moreover, they are very good sources of nutrients and bioactive compounds, including vitamins, minerals, antioxidants, om-3 fatty acids, plant extracts and fibers,
prebiotics and probiotics. These beverages show functional and medicinal properties such as antidiabetic and anti-cancer effects.

Plant seeds are an innovative source of nutrients. This is a unique product due to the presence of polyunsaturated fatty acids, vitamins, and micro and macro elements. Omega-3 fatty acids remain one of the most effective and promising functional ingredients in the food industry. Innovative formulas and technological advances have resulted in the stabilization of ω-3 fatty acids in beverages with improved flavor and longer storage terms.

Technological processing leads to the fact that the human organism does not receive the required amount of biologically active components in their native state. That is why there exists a need to develop innovative technologies for the production of multicomponent beverages with a balanced ratio of nutrients from local dairy and vegetable raw materials.

The goal of the study is to develop a technology for the production of refreshments with a balanced composition.

The following tasks were outlined in accordance with the stated goal:

- optimize beverages formulations based on the requirements of a balanced dietary formula, taking into account their organoleptic properties;
- investigate the organoleptic and microbiological characteristics of processed products, both recently prepared and while storage.

2. Materials and methods

The development of beverages formula based on the main characteristics of the chemical composition in accordance with the recommended human beverages was carried out using mathematical modeling. Mathematical modeling of the composition of beverages was carried out by the linear programming method using MS Excel. The conditions for optimal temperatures of beverages were expressed as a set of inequalities.

The ASLT test was used to predict the actual storage terms of beverages. This test made it possible to study changes in organoleptic characteristics and safety indicators of products depending on the terms and temperature of storage. Organoleptic and microbiological indicators were used as the main quality indicators. All prepared beverages were stored at temperatures from 2 to 60°C during four hours.

Sensory analysis was carried through analytical descriptive evaluation (profiling method) and using scales and categories (numerical scale evaluation). Organoleptic evaluation was carried out directly after the production of the beverages using a taste panel consisting of 10 people.

In developing beverages compositions, special attention was paid to the nutritional structure of raw materials and its changes during technological processing, as well as its balance. The aim of optimizing the new beverages creation was to determine the optimal ratio of essential nutrients.

Table 1 provides a data matrix for beverages formula development. It includes the following blocks: formula ingredients (FI), possible FI variation range, F1 solids content and indexed variables.

| Ingredients     | Index, Xi | F1 dry matter content, % | Possible range of variation, g/one beverage | spinich | pumpkin |
|-----------------|-----------|--------------------------|---------------------------------------------|---------|---------|
| Whey            | X1        | 10.2                     | 120–160                                     | 140–160 |         |
| Walnut          | X2        | 94.2                     | 12–20                                       | 12–14   |         |
| Honey           | X3        | 86.6                     | 5–15                                        | 5–15    |         |
| Chia seeds      | X4        | 90.1                     | 1–3                                        | 1–3     |         |
| Pumpkin         | X5        | 9.8                      | 50–70                                       | -       |         |
| Spinach         | X6        | 6.6                      | -                                            | 30–50   |         |
Table 2 shows the nutritional value. Restrictions were introduced based on normal levels of biologically active substances that are physiologically necessary for the human organism [23].

| Components          | Nutrients amount of the main nutrients FL, g/100 g |
|---------------------|-----------------------------------------------|
|                     | Whey  | Walnut | Honey | Chia  | Pumpkin | Spinach |
| Protein             | 2.9   | 16.2   | 0.8   | 15.6  | 1.0      | 2.9      |
| Fats                | 2.5   | 60.8   | 0     | 30.8  | 0.1      | 0.3      |
| Monocarbohydrates   | 4.8   | 11.1   | 80.3  | 0     | 6.5      | 2        |
| Starch              | 0     | 0      | 5.5   | 6     | 0.2      | 0.1      |
| ω-3                 | 0.1   | 2.6    | 0     | 4.9   | 3        | 0.1      |
| ω-6                 | 0     | 10.8   | 0     | 1.6   | 2        | 0        |
| Total               | 10.5  | 101.5  | 86.6  | 58.9  | 12.8     | 5.4      |

The formulas were optimized using the ExcelSolver program designed to solve some systems of inequalities, linear and nonlinear optimization problems.

3. Results and discussions
The beverages nutritional studies have shown that the formulated products are balanced in essential nutrients. The ratio of proteins, fats and carbohydrates is 1: 1.45: 3 for "Pumpkin" and 1: 1.34: 2.57 for "Spinach". The analysis of the content of basic microelements showed that the consumption of 100 g of the developed beverages fully covers the need for vitamin A, as well as almost 20% of the need for vitamin B2 and phosphorus. The ratio is 1.07: 0.25: 1 and 1.132: 0.303: 1 in the developed beverages “Pumpkin” and “Spinach", respectively. The decreased magnesium content can be corrected using magnesium-rich foods such as wheat bran, pumpkin seeds, sesame seeds, almonds, and pine nuts.

In accordance with the formulas obtained, a batch of refreshments was produced, and their sensory evaluation was carried out. The sensory characteristics of the obtained products are presented in table 4. The sensory evaluation was carried out by the sensory method according to such characteristics as appearance, consistency, color, smell and taste.

| Indicators          | Value                                                                 |
|---------------------|-----------------------------------------------------------------------|
| External view       | beverage, milky homogeneous                                             |
| Colour              | orange                                                                |
| Smell               | pleasant, milky pumpkin homogeneous, with inclusions of walnuts and chia without pumpkin clots |
| Consistency         | component specific                                                     |
| Taste               | component specific                                                     |

The study of the sensory indicators of the developed beverages (table 3) showed that they have high consumer and functional and technological properties.

Microbiological safety is one of the most important indicators of the quality of processed food, since it is inextricably linked to the health of consumers.

The studies of changes in microbial biomass in beverages during storage are shown in tables 4-5. The beverages were stored in a closed glass container at a temperature of 4 ± 20°C during four hours.

Some biotransformation processes may occur in the products if they are not sold on time. Therefore, changes in the microbiota and sensory characteristics of prepared beverages have been scientifically determined during four-hour storage.
Table 4. Microbiological indicators of the quality of the beverage "Pumpkin".

| Indicators                                      | Storage term, h |
|------------------------------------------------|-----------------|
|                                                 | 1   | 2   | 3   | 4   |
| Coliform bakteria, in terms of 0.01 g is not allowed |     |     |     |     |
| Pathogenic microorganisms (salmonella), in terms of 25 g are not allowed |     |     |     |     |
| Coli-form, CFU / 1 g                             | 2,3*102 | 2,7*102 | 2,9*102 | 3,1*102 |
| Yeast, CFU / 1 g                                 | 2,4*101 | 2,7*101 | 2,9*101 | 3,1*101 |
| Staphylococcus aureus, in terms of 0.01 g is not allowed |     |     |     |     |

Table 5. Microbiological indicators of the beverage "Spinach" quality.

| Indicators                                      | Storage term, h |
|------------------------------------------------|-----------------|
|                                                 | 1   | 2   | 3   | 4   |
| Coliform bakteria, in terms of 0.01 g is not allowed |     |     |     |     |
| Pathogenic microorganisms (salmonella), in terms of 25 g are not allowed |     |     |     |     |
| Coli-form, CFU / 1 g                             | 2,3*102 | 2,7*102 | 2,9*102 | 3,1*102 |
| Yeast, CFU / 1 g                                 | 2,4*101 | 2,7*101 | 2,9*101 | 3,1*101 |
| Staphylococcus aureus, in terms of 0.01 g is not allowed |     |     |     |     |

During the selected storage term, the microbiological indicators of the quality of the studied beverages changed insignificantly and did not exceed the levels specified in the Technical Regulations (TR).

The untimely sale of products can lead to biotransformation processes, which are mediated by the presence of non-fibrous carbohydrates that can form dense gels. In order to predict changes in the quality of the developed products during storage, changes in sensory characteristics were studied using the ALST method. The products were stored in glass containers at a temperature of 4 ± 2 °C for four days.

The organoleptic and microbiological evaluation of the developed beverages during a storage term showed that the product retains relatively high organoleptic and microbiological indicators for all analyzed parameters for four days in a glass container. However, the viscosity of the drinks increased significantly after 5 days of storage due to the extraction of complex carbohydrates from chia seeds, and the product has taken on a new structure. Therefore, the recommended selling time for these drinks is four days.

Taking into account the studies carried out, it is possible to recommend a storage term of four days at a temperature of 4 ± 2 °C in a glass container. Although, the given changes in rheological properties will transfer into a new product structure, i.e., into mousse.

4. Conclusion

Formulations of multicomponent beverages have been developed. The formulas were mathematically modeled using a Solver spreadsheet processor (MS Excel 2010). The optimal content of all components was determined. The optimal content made it possible to obtain beverages balanced in biological value and improved nutritional properties. The analysis of the chemical composition of the beverages showed that the ratio of proteins, fats and carbohydrates is 1:1:4. The consumption of one portion of these beverages will provide at least 20% of your daily vitamin beverages.

It was found on the basis of the microbiological studies that these products have sufficiently high quantitative and qualitative characteristics. Taking into account microbiological safety, the developed
beverages are recommended to be stored for four days at a temperature of 4 ± 2 °C and they have a relative humidity of no more than 75%. However, a long-term storage affects the biotransformation processes in the product and it significantly changes the rheological properties with the formation of a new consistency, unusual for beverages.

References
[1] Rebezov M, Naumova N, Lukin A, Alkhamova G and Khayrullin M 2011 Food behavior of consumers (for example, Chelyabinsk) Voprosy Pitaniia 80(6) 23-6
[2] Ahsan S et al. 2020 Safety assessment of milk and indigenous milk products from different areas of Faisalabad J Microbiol Biotech Food Sci 9(6) 1197-203 DOI: 10.15414/jmbfs.2020.9.6.1197-1203
[3] Ashan S et al. 2020 Functional exploration of bioactive moieties of fermented and non-fermented soy milk with reference to nutritional attributes J Microbiol Biotech Food Sci 10(1) 145-9 doi:10.15414/jmbfs.2020.10.1.145-149
[4] Kulushayeva B, Rebezov M, Igenbayev A, Kichko Yu, Burakovskaya N, Kulakov V and Khayrullin M 2019 Gluten-free diet: positive and negative effect on human health Indian Journal of Public Health Research & Development 10(7) 906-9
[5] Gavrilova N, Chernopolskaya N, Rebezov M, Shchetinina E, Dogareva N, Likhodeevskaya O, Knyskh I and Sanova Z 2020 Specialized sports nutrition foods: review International Journal of Pharmaceutical Research 12(2) 998-1003
[6] Temerbayeva M et al. 2018 Technology of Sour Milk Product For Elderly Nutrition Research Journal of Pharmaceutical, Biological and Chemical Sciences 9(1) 291-5
[7] Vaskovsky A, Chvanova M and Rebezov M 2020 Creation of digital twins of neural network technology of personalization of food products for diabetics 4th Scientific School on Dynamics of Complex Networks and their Application in Intellectual Robotics (DCNAIR) 251-3 doi: 10.1109/DCNAIR50402.2020.9216776
[8] Gorelik O et al. 2017 Study of chemical and mineral composition of new sour milk bio-product with sapropel powder Annual Research & Review in Biology 18(4) 1-5 DOI: 10.9734/ARRB/2017/36937
[9] Serikova A, Smolnikova F, Rebezov M, Okushkanova E, Temerbayeva M, Gorelik O, Kharlap S, Baitukenova Sh, Baitukenova S and Tumbasova Y 2018 Development Of Technology Of Fermented Milk Drink With Immune Stimulating Properties Research Journal of Pharmaceutical, Biological and Chemical Sciences 9(4) 495-500 WOS:000438848100062
[10] Temerbayeva M et al. 2018 Development of Yoghurt from Combination of Goat and Cow Milk Annual Research & Review in Biology 23(6) 1-7 DOI: 10.9734/arrb/2018/38800
[11] Varivoda A, Kenijz N, Rebezov M and Okushkanova E 2018 Development Of Dietary Food With The Use Of Soy Protein Research Journal of Pharmaceutical, Biological and Chemical Sciences 9(4) 1005-13 WOS:000438848100137
[12] Chernopolskaya N, Gavrilova N, Rebezov M, Harlap S, Nigmatyanov A, Peshcherov G, Bychkova T, Vlasova K and Karapetyan I 2019 Biotechnology of specialized fermented product for elderly nutrition International Journal of Pharmaceutical Research 11(1) 545-50 DOI: 10.35940/ijrte.B3158.078219
[13] Abilmazhinova B, Rebezov M, Fedoseeva N, Belookov A, Belookova O, Mironova I, Nigmatyanov A and Gizatova N 2020 Study chemical and vitamin composition of horsemeat cutlets with addition of pumpkin International Journal of Psychosocial Rehabilitation 24(8) 7614-21 DOI: 10.37200/IJPR/V24I8/PR280773
[14] Gavrilova N, Chernopolskaya N, Rebezov M, Moisejkina D, Dolmatova I, Mironova I, Peshcherov G, Gorelik O and Derkho M 2019 Advanced Biotechnology of Specialized Fermented Milk Products International Journal of Recent Technology and Engineering 8(2) 2718-22 DOI: 10.35940/ijrte.B3158.078219
[15] Kuramshina N, Rebezov M, Kuramshin E, Tretyak L, Topuria G, Kulikov D, Evtushenko A,
Harlap S and Okuskhanova E 2019 Heavy metals content in meat and milk of Orenburg region of Russia International Journal of Pharmaceutical Research 11(1) 1301-5 DOI: 10.21668/health.risk/2019.2.04.eng

[16] Rozhnov E, Kazarskikh A, Shkolnikova M, Tretyak L, Voytsekhovskiy V, Maksimiuk N, Khayrullin M, Rebezov M and Yessimbekov Zh 2019 Investigation of the conditions for the formation of 5-Hydroxymethylfurfural in the production of honey wines and sea-buckthorn wine drinks Research Journal of Pharmacy and Technology 12(7) 3501-6 DOI: 10.5958/0974-360X.2019.00595.X

[17] Smolnikova F, Rebezov M, Shaydullin R, Knysh I, Yudina O, Nikolaeva N, Sorokin A, Zubtsova Yu and Kozlov V 2020 Vegetable stabilizers used in the production of fermented milk drinks and yogurts International Journal of Psychosocial Rehabilitation 24(6) 7663-7 DOI: 10.37200/IJPR/V24I6/PR260775

[18] Davidovich E A 2008 Fruit and vegetable drinks of functional purpose Food and processing industry 4 1173

[19] Kalinina T M 2008 New non-alcoholic drinks of increased biological value based on vegetable juices and mineral water Food industry

[20] Kochetkova A A, Vorobyova V M, Smirnova E A and Vorobieva E S 2011 Scientific substantiation of the composition and properties of functional drinks Beer and drinks 6 18-21

[21] Nesterova I N 2008 Modern trends in the market of juices and juice drinks Beer and drinks 4 60-1

[22] Gavrilova N, Chernopolskaya N, Rebezov M, Shchetinina E, Suyazova I, Safronov S, Ivanova V and Sultanova E 2020 Development of specialized food products for nutrition of sportsmen Journal of Critical Reviews 7(4) 233-6 DOI: 10.31838/jcr.07.04.43

[23] Chernopolskaya N, Gavrilova N, Rebezov M, Dolmatova I, Zaitseva T, Somova Y, Babaeva M, Ponomarev E and Voskanyan O 2019 Biotechnology of specialized product for sports nutrition International Journal of Engineering and Advanced Technology 8(4) 40-5 DOI: 10.35940/ijrte.B3158.078219

[24] Gavrilova N, Chernopolskaya N, Molyboga E, Shipkova K, Dolmatova I, Demidova V, Rebezov M, Kuznetsova E and Ponomareva L 2019 Biotechnology application in production of specialized dairy products using probiotic cultures immobilization International Journal of Innovative Technology and Exploring Engineering 8(6) 642-8

[25] Razvyaznaya I B 2008 Use of pumpkin when receiving functional drinks Beer and drinks 3 22-4