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MATHEMATICAL DESIGN OF POLYCOMPONENT BEVERAGES WITH A BALANCED NUTRIENT COMPOSITION

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Abstract. Formulations of polycomponent drinks based on milk and vegetable raw materials have been developed on the principles of food combinatorics with the use of mathematical and computer modelling methods. Cow's milk was the base of the beverages; bananas, spinach, and pumpkin were the plant raw materials, and chia seeds were the source of unsaturated fatty acids. Mathematical planning was used to form criterial equations for the drinks to characterise the maximum content of the main nutrients. The drink formulations were modelled on a computer using the Excel Solver programme in the Microsoft Excel spreadsheet application, where the qualitative and quantitative parameters of mutually balanced nutrients were formalised. The computer designing involved optimisation of each of the parameters by comparing them with the nutrient content recommended by the FAO/WHO as standard. The formulations of the drinks *Harbuzovy*, *Shpynatny*, and *Bananovy* have been obtained, with the contents of the main nutrients in them 18.889 g, 17.664 g, and 21.329 g, respectively. The analysis of the chemical composition has shown that the ratio of proteins, fats, and carbohydrates is 1:1.45:3.03 for *Harbuzovy*, 1:1.34:2.57 for *Shpynatny*, and 1:1.5:4.27 for *Bananovy*. In the developed drinks *Harbuzovy*, *Shpynatny*, and *Bananovy*, these ratios are 1.07:0.25:1, 1.132:0.303:1, and 1.038:0.297:1, respectively. The storage conditions for the drinks developed have been determined by the ALST method, taking into account the changes in the sensory and microbiological parameters. The optimum storage conditions have been determined based on the changes of the sensory characteristics, which allows suggesting that the drinks developed will be competitive in Ukrainian public eating facilities. The changes in the microbiota of the finished drinks observed during 4 hours at 4±2°C in sealed glass containers have been analysed, and it has been shown that the drinks comply with the current standards as to the presence of opportunistic pathogens. The developed holistic approach to producing polycomponent drinks can be used by any market operator to produce not only drinks, but various food products, too.

Key words: mathematical design, quality parameters, beverages, plant raw materials.

Introduction. Formulation of the problem

The nutrition of present-day people effects on their health, well-being, and lifespan. Even a future child's health can be determined prenatally if the parents follow a balanced nutrition pattern and the principles of healthy lifestyle.

Nutritionists recommend consuming an adequate daily amount of necessary calories from a well-balanced variety of food products. The basis of healthy nutrition is diet including a balanced combination of the main nutrients. In a healthy adult's nutrition, the ratio of proteins, fats, and carbohydrates must be 1:1:4 [1]. As a result of technological processing, the human body does not receive the required amount of essential components in the native state. This has caused an acute need to create innovative technologies of polycomponent food products with a balanced nutrient ratio based on domestic dairy and plant raw materials.

Combining milk and plant raw materials, which are sources of macro and micronutrients, allows obtaining new milk-containing products for dietetic and preventive nutrition. These products are of various textures, and have sensory qualities attractive for a consumer. However, the problem that prevents using vegetable raw materials in drinks for catering establishments is how to obtain the required consistency with high safety characteristics. Therefore, development of the technology of milk-containing drinks with food fibre is a promising and topical direction in the sphere of food manufacturing in catering establishments.

Analysis of recent research and publications

In the years 1990-2008, as a result of malnutrition, the morbidity rates in Ukraine were twice as high of such diseases as endocrine disorders, digestive disturbances, and metabolic disorders. Besides, there is a tendency to gain overweight, an increase in obesity, cardiovascular disorders, and oncological diseases [2]. According to the statistical data [3], in 2017, the number of first-time registered cases of endocrine disorders decreased by 0.77 times compared to 2010, and gastrointestinal diseases decreased by 0.83 times. This can be explained by the fact that most people are becoming concerned about their health and are starting to pay attention to the quality of food.

It should be noted that in the last years, the development of nutritiology (science of nutrition) both in Ukraine and worldwide has been closely associated with the theory of balanced diet. This theory has become a base to determine the biological role of fats, proteins, carbohydrates, vitamins, and micronutrients, the human body's physiological requirements, and nutritional standards and diets for different social groups by age and occupation [1,3-6].

The balance of the hormonal system requires having meals three times a day, each meal including four groups of products: proteins, fats, carbohydrates, and low-starch vegetables. Proteins and fats are required for cell and tissue regeneration, synthesis of hormones and enzymes. Carbohydrates are primarily a source of energy. Low-starch vegetables are required as sources of vitamins, mineral nutrients, and cellulose. It is desirable to include some low-starch vegetables like celery, carrots, tomatoes, cucumbers, pepper, broccoli, pumpkin, spinach, cauliflower, etc. in each meal [7]. And various ill-balanced fad diets (like Hollywood, Kremlin, vegetarian, starvation, separation, Atkins, and other diets) have been declared destructive by leading physicians of Europe and the USA [8-10].

Healthy products that have a physiological effect on the body, besides being nutritive in general, are also recognised as "functional products" [11]. Milk and other dairy products that contain bioactive peptides, vitamins, antioxidants, probiotic bacteria, mineral nutrients, and oligosaccharides are associated with daily healthy diet. Milk-based drinks have become an effective way to satisfy consumers' new requirements on the functional food market. The manufacturing technologies and use of milk-based drinks, their physical and chemical properties and health benefits have become a matter of consideration. These drinks include the ones based on whey (with fruit or vegetable juices, fermented or non-fermented), fermented dairy products (probiotic dairy products and beverages, kefir, buttermilk, kumis), and milk-based beverages enriched with biologically active compounds [11].

Milk-based beverages, for example, reduce the risk of cardiovascular diseases and contribute to rehydration of the muscles after physical activity. This makes these products even more promising for functional nutrition [12].

In order to increase the functional properties of milk drinks, various vegetable components are added to them: cereals, mashed fruit or berries, or juices from them, extracts from medicinal plants, etc.

Vegetable raw materials are the main component of healthy nutrition. However, their importance for health and homeostatic balance is often disregarded, and their amounts consumed are significantly smaller than it is recommended. Cooking and commercialisation of fruit and vegetable drinks with balanced nutrient and phytonutrient profiles can be a promising alternative to the direct consumption of fruit and vegetables, because these drinks are consumed easily and quickly [13].

It has become important to produce and consume functional milk drinks containing vegetable raw materials. They improve health, which is beyond the main functions of nutrition. Today, beverages are the most efficient functional category of food: they are convenient and can satisfy consumers' requirements to the content, size, shape, and exterior of the containers, and besides, are simple in distribution and storage (have a long shelf life when cold-stored). They are also a very good source of nutrients and bioactive compounds, including vitamins, minerals, antioxidants, ω-3 fatty acids, vegetable extracts and fibres, prebiotics and probiotics. These drinks have functional and medical properties, such as antidiabetic and anticarcinogenic action [14].

Plant seeds are an innovative source of nutrients. It is a unique product because of the presence of polyunsaturated fatty acids, vitamins, and micro and macronutrients. Omega-3 fatty acids are among the most effective and promising functional ingredients in the food industry. Innovative recipes and technological achievements have resulted in stabilisation of ω-3 fatty acids in drinks with improved flavour and a long shelf life [15].

For example, there is a beverage of the "drink-breakfast" type that contains sour milk cheese, skimmed cow's milk, walnut kernels, honey, spinach, bananas, psyllium (peelings of plantain seeds), and collagen hydrolysate [16]. Using psyllium in a drink gives it a stable foamy structure with foam bubbles of 0.05–0.15 mm in diameter, and also a high content of food fibres.

Flax seeds and pumpkin were used to make a gerodietetic milk-based smoothie [17]. The smoothie developed had high sensory qualities, was low in calories and high in food fibre, and also contained nutrients with geroprotective action: polyunsaturated fatty acids of the groups ω-3, ω-6, and ω-9 (wheat germ and linseed oil), food fibre (pumpkin, apples, sandthorn), vitamins, etc.

As a non-traditional protein source to make a fermented milk drink, chia seeds were taken [18]. A scientific rationale was given to the preparation method (soaking chia seeds in water, in the ratio 1:10, at 45°C for 30 min) and to the stage of introducing chia seeds while making thermostatic kefir.

Because of the importance of consuming dietary fibres, it was investigated how to make fruit-based beverages containing basil seeds as a food fibre source. The results of the investigation showed that adding basil seeds increased the absolute Z potential of the drink (the Z potential is the value of charge that exists on colloid particles; it is an indicator to estimate the stability of colloid systems), but the flavour and colour declined. The stability of the drinks increased, and their outward appearance improved with an increase in the content of hydrocolloids. It was proved that adding basil seeds in combination with 0.25% of gum arabic resulted in obtaining a drink with the required stability [19].

Vegetable proteins of amaranth, quinoa (an annual plant directly related to amaranth and placed in the *Amaranthaceae* family, cultivated in South America and other countries), and chia can be used as food ingredients to replace animal proteins in the human diet [20]. A complex analysis of amaranth, quinoa, and chia proteins was made, with emphasis on their solubility, on their superficial, jellifying, and texturing properties, and on the biological activity of enzymatic hydrolysates that allows using them in structured beverages.

Because of technological treatment of raw materials, the human body does not receive the required amounts of essential components in their native state. This is why it is urgent to create innovative technologies of making polycomponent drinks with a balanced nutrient ratio, based on local dairy and plant raw materials.

The purpose of the work was to develop a technology of manufacturing beverages with a balanced composition to be retailed in catering facilities. According to the stated purpose, the following **objectives** were set:

– to optimise the recipes of drinks according to the standards of a balanced diet formulation, with account of their organoleptic properties;

– to investigate the organoleptic and microbiological parameters of the final products, immediately after the production and during the following storage.

Research materials and methods

The research was carried out in the following modern scientific laboratories:

1. Healthy Food Consulting Laboratory;
2. O. Ya. Kyrylenko Academic and Research Laboratory of Microbiology in the ONAFT.

Mathematical modelling was used to design the formulations of the beverages by the main features of the chemical composition according to recommended human requirements. The drinks' composition was mathematically modelled by means of linear programming using MS Excel. The conditions of optimising the formulations of the drinks were expressed as a complex of equations [21].

The accelerated shelf life testing method (ASLT) [22] was used to predict the actual storage life of the drinks. It allowed studying the changes in the products' marketability and safety characteristics depending on the duration and temperature of storage. The main quality parameters used were the sensory and microbiological ones. All the prepared beverages were divided into samples of 100 litres each and stored at 2–6°C for 4 hours.

The sensory analysis was done according to DSTU (State Standard of Ukraine) ISO 6658:2005 by analytical descriptive estimation (profiling method) and by using scales and categories (estimation by a rating scale). The organoleptic evaluation was made by a taste panel of 10 people immediately after the beverages were ready.

Results of the research and their discussion

When developing the beverage compositions, attention was paid to the nutrient composition of the raw materials, to its changes under technological treatment, and to how balanced it was. The purpose of optimising the recipes of the new drinks was the determination of the optimal ratio of the main nutrients.

Table 1 describes a data matrix for designing the beverage formulations. It includes the following blocks: formulation ingredients (FI), acceptable range of FI variation, content of FI dry matters, and indexed variables.

Table 2 shows the nutritional value of the FI. The limits introduced were based on the human body's normal physiological need in biologically active substances [23].

The recipes were optimised using the Excel Solver programme intended for solving certain equation systems, linear and nonlinear problems of optimisation. In order to solve a linear programming problem in the Microsoft Excel table editor, the following steps must be taken [25]:

1. Enter the data of the problem:

1. make a table for the data of the problem: variables, target function (TF), limits, boundary conditions;

2. enter the initial data in the table: TF coefficients, variable held coefficients in the limits, right sides of the limits;

Table 1 – Information data matrix for designing the beverage formulations

Formulation ingredient	Index, x_i	FI dry matter content, %	Acceptable range of variation, g/portion		
			***Harbuzovy* (pumpkin)**	***Shpynatny* (spinach)**	***Bananovy* (banana)**
Cow's milk	x_1	10.2	120-160	140-160	130-150
Walnut	x_2	94.2	12-20	12-14	4-12
Honey	x_3	86.6	5-15	5-15	5-15
Chia seeds	x_4	90.1	1-3	1-3	1-3
Pumpkin	x_5	9.8	50-70	–	–
Spinach	x_6	6.6	–	30-50	–
Banana	x_7	26.7	–	–	30-50

Table 2 – Main nutrients of the FI of the beverages [24]

Nutrients	Amount of the main FI nutrients, g/100 g						
	Milk	**Nuts**	**Honey**	**Chia**	**Pumpkin**	**Spinach**	**Banana**
Proteins	2.9	16.2	0.8	15.6	1.0	2.9	1.5
Fat	2.5	60.8	0	30.8	0.1	0.3	0.5
Carbohydrates (mono and oligosaccharides)	4.8	11.1	80.3	0	6.5	2	21
Starch	0	0	5.5	6	0.2	0.1	2
ω-3	0.1	2.6	0	4.9	3	0.1	0
ω-6	0	10.8	0	1.6	2	0	0
Total	10.5	101.5	86.6	58.9	12.8	5.4	25

3. enter the relations in the screen form from the mathematical model: formula for TF calculation, formulae to calculate the left sides of the limits;

4. define the TF (in the Solver window): target cell, direction of the TF optimisation;

5. enter the limits and boundary conditions (in the Solver window): cells with the values of the variables, boundary conditions for permissible values of the variables, ratio between the left and right sides of the limits.

2. Solve the problem:

– specify the parameters of solving (in the Solver window);
– start the problem solving process (in the Solver window);
– choose a format of displaying the solution (in the Solution results window).

The maximum content of the main nutrients in the designed products was taken as the target function in the beverage design. This content was defined as the total of the main nutrients of the FI the beverages were made of.

The target functions for the beverage design are the following:

– beverage *Harbuzovy*:

$F(x)=(10.5\cdot x_1+101.5\cdot x_2+86.6\cdot x_3+58.9\cdot x_4+12.8\cdot x_5)/100 \rightarrow \max$

– beverage *Shpynatny*:

$F(x)=(10.5\cdot x_1+101.5\cdot x_2+86.6\cdot x_3+58.9\cdot x_4+5.4\cdot x_6)/100 \rightarrow \max$

– beverage *Bananovy*:

$F(x)=(10.5\cdot x_1+101.5\cdot x_2+86.6\cdot x_3+58.9\cdot x_4+25\cdot x_7))/100 \rightarrow \max$

Based on the information matrix (Table 1) and the nutrition value (Table 2), we form a system of linear balanced equations by the protein, fat, carbohydrate, dry matter, and fatty acid contents in the formulation, following the limits of the human physiological requirements.

The equation system for designing the drink *Harbuzovy* is the following:

Protein content no less than 3 g per 100 g:

$$2.9\cdot x_1+16.2\cdot x_2+0.8\cdot x_3+15.6\cdot x_4+1.0\cdot x_5\geq 3$$

Fat content no less than 4 g per 100 g:

$$2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.1\cdot x_5\geq 4$$

Monocarbohydrate content no less than 7 g per 100 g:

$$4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3+6.5\cdot x_5\geq 7$$

Starch content no more than 0.5 g per 100 g:

$$5.5\cdot x_3+6\cdot x_4+0.2\cdot x_5\leq 0.5$$

Omega-3 content (no less than 200 mg):

$$0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4+3\cdot x_5\geq 200$$

Omega-6 content (no less than 600 mg):

$$0\cdot x_1+10.8\cdot x_2+1.6\cdot x_4+2\cdot x_5\geq 600$$

The ratio $\omega_3:\omega_6 \leq 1.5$, $\omega_3:\omega_6 \geq 0.2$:

$$(0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4+5\cdot x_5)/(10.8\cdot x_2+1.6\cdot x_4+2\cdot x_5)\geq 0.2$$

$$(0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4+5\cdot x_5)/(10.8\cdot x_2+1.6\cdot x_4+2\cdot x_5)\leq 1.5$$

Carbohydrate content (monocarbohydrates and starch) – no more than 16 g, but no less than 8 g per 100 g:

$$(4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3+6.5\cdot x_5)+(5.5\cdot x_3+6\cdot x_4+0.2\cdot x_5)\geq 8$$

$$(4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3+6.5\cdot x_5)+(5.5\cdot x_3+6\cdot x_4+0.2\cdot x_5)\leq 16$$

Fat to carbohydrates (monocarbohydrates and starch) ratio – no more than 4 and no less than 2:

$$(2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.1\cdot x_5)/(4.8\cdot x_1+11.1\cdot x_2+85.8\cdot x_3+6\cdot x_4+6.7\cdot x_5)\geq 2$$

$$(2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.1\cdot x_5)/(4.8\cdot x_1+11.1\cdot x_2+85.8\cdot x_3+6\cdot x_4+6.7\cdot x_5)\leq 4$$

Conditions of standardisation (beverage yield 200 g):

$$x_1+x_2+x_3+x_4+x_5=200$$

Lower limits of the variables (the FI):

$$x_1\geq 120;\ x_2\geq 12;\ x_3\geq 5;\ x_4\geq 1;\ x_5\geq 50$$

Upper limits of the variables (the FI):

$$x_1\leq 160;\ x_2\leq 20;\ x_3\leq 15;\ x_4\leq 3;\ x_5\leq 70$$

The equation system for designing the drink *Shpynatny* is the following:

Protein content no less than 2.5 g per 100 g:

$$2.9\cdot x_1+16.2\cdot x_2+0.8\cdot x_3+15.6\cdot x_4+2.9\cdot x_6\geq 2.5$$

Fat content no less than 3.5 g per 100 g:

$$2.5\cdot x_1+60.8\cdot x_2+0\cdot x_3+30.8\cdot x_4+0.1\cdot x_6\geq 3.5$$

Monocarbohydrates no less than 7 g per 100 g:

$$4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3\geq 7$$

Starch content no more than 1 g per 100 g:

$$5.5\cdot x_3+6\cdot x_4+0.1\cdot x_6 \leq 1$$

Omega-3 content (no less than 200 mg):

$$0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4+0.1\cdot x_6\geq 200$$

Omega-6 content (no less than 600 mg):

$$10.8\cdot x_2+1.6\cdot x_4\geq 600$$

The ratio $\omega_3:\omega_6 \leq 1.5$, $\omega_3:\omega_6 \geq 0.2$:

$$(0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4+0.1\cdot x_6)/(10.8\cdot x_2+1.6\cdot x_4)\geq 0.2$$

$$(0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4+0.1\cdot x_6)/(10.8\cdot x_2+1.6\cdot x_4)\leq 1.5$$

Conditions of standardisation (beverage yield 200 g):

$$x_1+x_2+x_3+x_4+x_6=200$$

Lower limits of the variables (the FI):

$$x_1\geq 140;\ x_2\geq 4;\ x_3\geq 5;\ x_4\geq 1;\ x_6\geq 30$$

Upper limits of the variables (the FI):

$$x_1\leq 160;\ x_2\leq 12;\ x_3\leq 15;\ x_4\leq 3;\ x_6\leq 50$$

Carbohydrate (monocarbohydrates and starch) content – no more than 10 g, but no less than 7 g per 100 g:

$$(4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3+2\cdot x_6)+(5.5\cdot x_3+6\cdot x_4+0.1\cdot x_6)\geq 7$$

$$(4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3+2\cdot x_6)+(5.5\cdot x_3+6\cdot x_4+0.1\cdot x_6)\leq 10$$

Ratio of fat and carbohydrates (monocarbohydrates and starch), no more than 4 and no less than 2:

$$(2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.1\cdot x_6)/(4.8\cdot x_1+11.1\cdot x_2+85.8\cdot x_3+6\cdot x_4+11.1\cdot x_6)\geq 2$$

$$(2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.1\cdot x_6)/(4.8\cdot x_1+11.1\cdot x_2+85.8\cdot x_3+6\cdot x_4+11.1\cdot x_6)\leq 14$$

The equation system for designing the *Bananovy* drink is the following:

Protein content no less than 3 g per 100 g:

$$2.9\cdot x_1+16.2\cdot x_2+0.8\cdot x_3+15.6\cdot x_4+1.5\cdot x_7\geq 3$$

Fat content no less than 3.5 g per 100 g:

$$2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.5\cdot x_7\geq 3.5$$

Monocarbohydrate content no less than 10 g per 100 g:

$$4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3\geq 7$$

Starch content no more than 1.5 g per 100 g:

$$5.5\cdot x_3+6\cdot x_4+2\cdot x_7 \leq 1.5$$

Omega-3 content (no less than 200 mg):

$$0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4+0\cdot x_7\geq 200$$

Omega-6 content (no less than 600 mg):

$$10.8\cdot x_2+1.6\cdot x_4\geq 600$$

The ratio $\omega_3:\omega_6\leq 1.5$, $\omega_3:\omega_6\geq 0.2$:

$$(0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4)/(10.8\cdot x_2+1.6\cdot x_4)\geq 0.2$$

$$(0.1\cdot x_1+2.6\cdot x_2+4.9\cdot x_4)/(10.8\cdot x_2+1.6\cdot x_4) \leq 1.5$$

Conditions of standardisation (beverage yield 200 g):

$$x_1+x_2+x_3+x_4+x_7=200$$

Lower limits of the variables (the FI):

$$x_1\geq 130;\ x_2\geq 4;\ x_3\geq 5;\ x_4\geq 1;\ x_6\geq 30$$

Upper limits of the variables (the FI):

$$x_1\leq 150;\ x_2\leq 12;\ x_3\leq 15;\ x_4\leq 3;\ x_6\leq 50$$

Carbohydrate content (monocarbohydrates and starch) – no more than 16 g and no less than 8 g per 100 g:

$$(4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3+6.5\cdot x_7)+(5.5\cdot x_3+6\cdot x_4+23\cdot x_7)\geq 8$$

$$(4.8\cdot x_1+11.1\cdot x_2+80.3\cdot x_3+6.5\cdot x_7)+(5.5\cdot x_3+6\cdot x_4+23\cdot x_7)\leq 16$$

Ratio of fat and carbohydrates (monocarbohydrates and starch), no more than 4 and no less than 2:

$$(2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.5\cdot x_7)/(4.8\cdot x_1+11.1\cdot x_2+85.8\cdot x_3+6\cdot x_4+23\cdot x_7)\geq 2$$

$$(2.5\cdot x_1+60.8\cdot x_2+30.8\cdot x_4+0.5\cdot x_7)/(4.8\cdot x_1+11.1\cdot x_2+85.8\cdot x_3+6\cdot x_4+23\cdot x_7)\leq 4$$

As a result of using mathematical programming, we do the optimal solution: find the extremum of the linear target function under limits of variables to be found. The system of linear balance equations was solved using the Solver in the MS Excel programme.

The calculation in the programme resulted in obtaining these values of the FI contents in the beverages:

– *Harbuzovy*: x_1=140; x_2=8; x_3=10; x_4=2; x_5=40, with $F(x)=(10.5\cdot 140+101.5\cdot 8+86.6\cdot 10+58.9\cdot 2+12.8\cdot 40)/100=37.77$

– *Shpynatny*: x_1=150; x_2=8; x_3=10; x_4=2; x_6=30, with $F(x)=(10.5\cdot 150+101.5\cdot 8+86.6\cdot 10+58.9\cdot 2+5.4\cdot 30)/100=35.32$

– *Bananovy*: x_1=140; x_2=8; x_3=10; x_4=2; x_7=40, with $F(x)=(10.5\cdot 140+101.5\cdot 8+86.6\cdot 10+58.9\cdot 2+25\cdot 40)/100=42.658$

Thus, the content of the main nutrients in the drinks *Harbuzovy*, *Shpynatny*, and *Bananovy* was estimated 18.889 g, 17.664 g, and 21.329 g, respectively, per 100 g.

The beverage recipes were composed according to the results obtained (Table 3). The determined norms of the raw material consumption in the production of the drinks were based on the norms of consumption and waste during cold and heat treatment of raw materials. These norms are specified in the *Recipe Book of National Dishes and Culinary Products for Catering Establishments* (approved by the Ministry of Foreign Economic Relations and Trade, Decree No. 484 of 06.07.99). Besides, the determination of the norms was based on the control study.

Investigations of the nutrient composition of the drinks have shown that the products designed have a balanced content of the main nutrients. The ratio of proteins, fats, and carbohydrates is 1:1.45:3.03 for *Harbuzovy*, 1:1.34:2.57 for *Shpynatny*, and 1:1.5:4.27 for *Bananovy*. Analysis of the main micronutrient content has shown that consuming 100 g of the designed drinks totally covers the need of vitamin A, and almost 20% of the need of vitamin B_2 and phosphorus. In the designed drinks *Harbuzovy*, *Shpynatny*, and *Bananovy*, this ratio is 1.07:0.25:1, 1.132:0.303:1, and 1.038:0.297:1, respectively. The decreased magnesium content can be corrected by consuming magnesium-containing products, like wheat bran, pumpkin seeds, sesame seeds, almond, and pine nuts.

According to the recipes obtained, a batch of beverages has been produced and tested for their sensory qualities. The results of the sensory evaluation of the products are shown in Table 4. The evaluation was carried out using the sensory method, by the parameters specified in DSTU ISO 6658:2005: outward appearance, consistency, colour, smell, and flavour.

The investigation of sensory parameters of the designed drinks (Table 4) has shown that they have high functional, technological, and consumer properties, and will be competitive in catering establishments.

Microbiological safety is one of the most important quality parameters of food products, since it is inextricably associated with consumers' health. Neglecting the microbiological tests entails not only a significant damage to the human health, but also economic losses for the manufacturer. Microorganisms that cause foodborne diseases usually do not cause organoleptic changes in the product, that is why microbiological testing of food is necessary.

The research data on changes in the microbial biomass in the drinks during storage are shown in Tables 5-7. The beverages were stored in closed glass containers at 4±2°C for 4 hours.

Table 3 – Formulations and raw material expenditure rates for beverage production (g/portion)

Raw material	**Losses, %**	***Harbuzovy***		***Shpynatny***		***Bananovy***	
		gross weight	**net weight**	**gross weight**	**net weight**	**gross weight**	**net weight**
Cow's milk	0	140	140	150	150	140	140
Walnuts	50	16	8	16	8	16	8
Honey	0.5	10.5	10	10.5	10	10.5	10
Chia seeds	0.5	2.01	2	2.01	2	2.01	2
Pumpkin	25	50	40				
Spinach	3			30.9	30		
Banana	40					56	40
Total			200		200		200

Table 4 – Sensory characteristics of the beverages produced

Beverage	**Outward appearance**	**Colour**	**Smell**	**Consistency**	**Flavour**
Harbuzovy	Orange-coloured drink, homogenous, with walnut and chia inclusions evenly distributed	Orange	Typical of the product, pleasant, milky	Homogenous, no lumps	Pumpkin, typical of the components
Shpynatny	Green-coloured drink, homogenous, with walnut and chia inclusions evenly distributed	Green	Typical of the product, pleasant, milky	Homogenous, no lumps	Milky, typical of the components
Bananovy	Cream-coloured cocktail drink, homogenous, with walnut particles evenly distributed	Cream-coloured	Typical of the product, pleasant, milky, banana	Homogenous, no lumps	Banana, typical of the components

Table 5 – Microbiological quality parameters of the drink *Harbuzovy*

Parameters	**Standard quantity**	**Storage duration, hours**			
		1	2	3	4
Coliforms, CFU per 0.01 g	Not allowed	Not detected			
Pathogenic microorganisms (*Salmonella*), per 25 g	Not allowed	Not detected			
Mould, CFU per 1 g	50	$2.3 \cdot 10^2$	$2.7 \cdot 10^2$	$2.9 \cdot 10^2$	$3.1 \cdot 10^2$
Yeast, CFU per 1 g	50	$2.4 \cdot 10^1$	$2.7 \cdot 10^1$	$2.9 \cdot 10^1$	$3.1 \cdot 10^1$
Staphylococcus aureus, per 0.01 g	Not allowed	Not detected			

Table 6 – Microbiological quality parameters of the drink *Shpynatny*

Parameters	**Standard quantity**	**Storage duration, hours**			
		1	**2**	**3**	**4**
Coliforms, CFU per 0.01 g	Not allowed	Not detected			
Pathogenic microorganisms (*Salmonella*), per 25 g	Not allowed	Not detected			
Mould, CFU per 1 g	50	$2.3 \cdot 10^2$	$2.7 \cdot 10^2$	$2.8 \cdot 10^2$	$3.0 \cdot 10^2$
Yeast, CFU per 1 g	50	$2.4 \cdot 10^1$	$2.7 \cdot 10^1$	$2.8 \cdot 10^1$	$3.0 \cdot 10^1$
Staphylococcus aureus, per 0.01 g	Not allowed	Not detected			

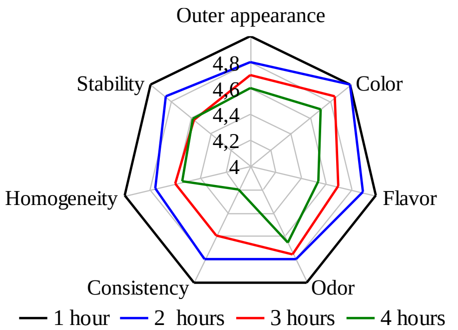
Table 7 – Microbiological quality parameters of the drink *Bananovy*

Parameters	**Standard quantity**	**Storage duration, hours**			
		1	**2**	**3**	**4**
Coliforms, CFU per 0.01 g	Not allowed	Not detected			
Pathogenic microorganisms (*Salmonella*), per 25 g	Not allowed	Not detected			
Mould, CFU per 1 g	50	$2.3 \cdot 10^2$	$2.6 \cdot 10^2$	$2.8 \cdot 10^2$	$3.0 \cdot 10^2$
Yeast, CFU per 1 g	50	$2.4 \cdot 10^1$	$2.7 \cdot 10^1$	$2.9 \cdot 10^1$	$3.0 \cdot 10^1$
Staphylococcus aureus, per 0.01 g	Not allowed	Not detected			

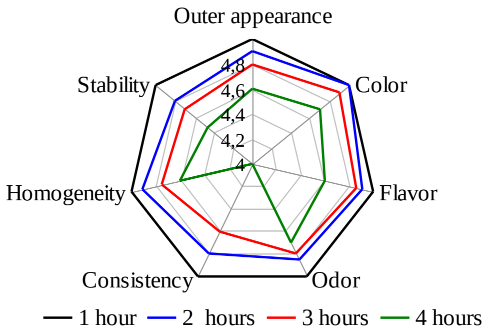
If the products are not sold timely, some biotransformation processes may occur in them, so the changes in the microbiota and sensory qualities of cooked drinks were scientifically determined in a 4-hour storage.

During the chosen storage period, the microbiological quality indicators of the beverages under study changed but slightly and did not exceed the levels specified in the *Sanitary Regulations and Norms* 2.3.2.1078-01 *Hygienic requirements to the safety and nutrition value of food*.If the products are not sold in time, it can result in the processes of biotransformation due to the presence of non-fibrous carbohydrates able to form dense gels. To predict how the quality of the products developed changes during storage, the changes of the sensory parameters have been studied by the ALST method. The products were stored in glass containers at 4±2°C for 4 hours.

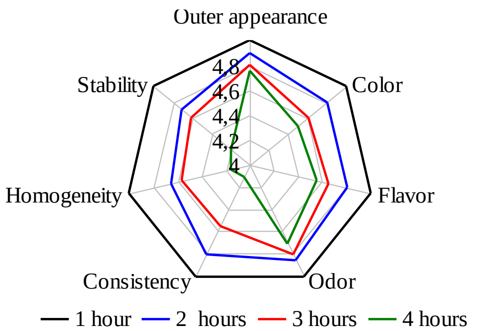
The dynamic pattern of the organoleptic changes estimated in points is shown in Fig. 1.



Shpynatny



Harbuzovy



Bananovy

Fig. 1. Dynamic pattern of the changes in the organoleptic parameters of the beverages during storage

The intervals of the changes in the values of the organoleptic parameters were specified equal from 0 to 5 points: 0 to 1 – very poor quality, 1 to 2 – poor quality, 2 to 3 – medium quality, 3 to 4 – high quality, 4 to 5 – excellent quality.

The organoleptic and microbiological evaluation of the developed drinks during 4 hours of storage in glass containers has shown that the product retains relatively high organoleptic and microbiological characteristics in all the analysed parameters. After 5 hours of storage, though, due to extraction of complex carbohydrates from the chia seeds, the beverages' viscosity increased significantly, and the product took a new form. Therefore, for catering facilities, the recommended time of selling these beverages is 4 hours.

Based on the conducted research, the storage duration of 4 days at 4±2°C in glass containers can be recommended, although, due to the changes in the rheological parameters, these drinks can change into the form of another product – mousse.

Conclusion

1. Formulations of polycomponent beverages have been developed. The formulations have been mathematically modelled using the spreadsheet application Solver (MS Excel 2010), and the optimum content of all components has been determined, which allowed obtaining beverages balanced by their biological value and with improved nutritional properties. The analysis of the chemical composition of the beverages has shown that the ratio of proteins, fats, and carbohydrates is 1:1:4. Consuming one portion of these beverages will provide at least 20% of the daily vitamin requirement.

2. Based on the microbiological studies, it has been found that these products have quite high quantitative and qualitative characteristics when stored under controlled conditions. As to the microbiological safety, it is recommended to store the developed beverages for 4 hours at 4±2°C, with the relative humidity not exceeding 75%. However, long storage has an effect on the biotransformation processes in the product, which changes significantly the rheological parameters and results in the formation of a consistency different from that of drinks.

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МАТЕМАТИЧНЕ ПРОЕКТУВАННЯ ПОЛІКОМПОНЕНТНИХ НАПОЇВ ЗІ ЗБАЛАНСОВАНИМ НУТРІЄНТНИМ СКЛАДОМ

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Анотація. Із урахуванням принципів харчової комбінаторики з використанням методів математичного і комп'ютерного моделювання розроблено рецептури полікомпонентних напоїв на основі молочної та рослинної сировини. Основою напоїв було молоко коров'яче, в якості рослинної сировини використовували банани, шпинат та гарбуз, а в якості джерела ненасичених жирних кислот – насіння чіа. За допомогою математичного планування сформовано критеріальні рівняння для напоїв, що характеризують максимальний вміст основних поживних речовин. Компьютерне моделювання рецептур напоїв проводили у програмі Excel Solver в табличному редакторі Microsoft Excel, в якому формалізовано якісні та кількісні показники взаємозбалансованих нутрієнтів. При комп'ютерному проектуванні використовували оптимізацію за кожним вибраним показником шляхом парного порівняння з рекомендованим ФАО/ВОЗ вмістом нутрієнтів. Отримано рецептури напоїв «Гарбузовий», «Шпинатний» та «Банановий», в яких вміст основних поживних речовин склав 18.889 г, 17.664 г та 21.329 г на 100 г відповідно. Аналіз

хімічного складу показав, що співвідношення білків:жирів:вуглеводів дорівнює 1:1.45:3.03 для напою «Гарбузового», 1:1.34:2.57 для напою «Шпинатного» та 1:1.5:4.27 для напою «Бананового». В розроблених напоях «Гарбузовий», «Шпинатний» та «Банановий» це співвідношення дорівнює 1.07:0.25:1, 1.132:0.303:1, 1.038:0.297:1 відповідно. За допомогою методу ALST визначено умови зберігання розроблених напоїв з урахуванням зміни сенсорних та мікробіологічних показників. Визначення оптимальних умов зберігання за оцінкою зміни органолептичних показників дає можливість стверджувати, що розроблені напої будуть конкурентоздатними у закладах ресторанного господарства України. Проведене дослідження зміни мікробіоти готових напоїв впродовж 4 годин при температурі (4±2)°C в закритій скляній тарі показало, що за наявністю умовнопатогенних мікроорганізмів напої відповідають діючим нормативним вимогам. Розроблений комплексний підхід щодо виробництва полікомпонентних напоїв може бути використаний будь яким оператором ринку з виробництва не тільки напоїв, а й різних продуктів харчування.

Ключові слова: математичне моделювання; показники якості; напої; рослинна сировина.

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