***Розроблені рецептури екструдованих продуктів на основі зерна цукрової кукурудзи, голозерного ячменю, кореneплодів моркви, кореню солодки та гідролізату колагена.***

***Визначено фізико-хімічні показники (намокаємість, перетравлювальність, мікроструктура) отриманих екструдатів, представлено апаратурно-технологічну схему виробництва, проведено аналіз таких показників як намокання та перетравлюваність. Дослідження складу мікронутрієнтів показало, що споживання 100 г паличок «Кукурудзянка» задовольняє потреби людини в вітамінах А та $B_6$ на 76,62 та 75,76 % відповідно, а «Кукурудзянка+» на 80 та 79,25 %. З отриманих даних можна побачити, що при збільшенні температури та pH середовища здатність до намокання розроблених паличок підвищується в середньому на 14...15 %.***

***Дослідженнями in vitro встановлено, що розроблені продукти мають досить високий ступінь засвоюваності, який сягає майже 85 %.***

***Отримані дані дослідження якісних показників показали, що при зберіганні протягом 6 місяців при температурі (15±5) °С вологістю 70–75 % в поліпропіленовій упаковці, вміст санітарно-показових мікроорганізмів відповідає санітарно-гігієнічним вимогам до сухих сніданків.***

***Розроблені продукти мають високий вміст білкових речовин, що є досить важливо з точки зору забезпечення потреб організму сучасної людини. Споживання 100 г паличок забезпечить організм людини незамінними амінокислотами в загальному майже на 24,1 %. Представлені в дослідженні продукти відрізняються досить високим вмістом основних, необхідних для організму людини мікронутрієнтів, а саме кальцію, фосфору та калію.***

***Розроблені екструдати можуть бути рекомендовані для вживання підлітками, дітьми, дієтичному харчуванні, та споживання інших верств населення***

***Ключові слова: математичне моделювання, показники якості, кукурудзяна крупа, екструдовані продукти, білок, колаген, зберігання, переробка зерна***

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# DEVELOPMENT OF THE FORMULATION FOR EXTRUDED PRODUCTS BASED ON SUGAR CORN GRAIN AND DETERMINING THEIR QUALITY INDICATORS

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## 1. Introduction

We know that human health depends on the following main factors: a human factor, an anthropogenic condition and a social-pedagogical indicator. The human factor affects human health by 50 %. It consists of nutrition – 40 %, physical activity – 10 % and mental condition – 8 %. The anthropogenic condition affects health by 25 %. And the social-pedagogical indicator affects health by almost 30 % [1].

WHO statistics shows that we can consider only 20 % of the adult population as conditionally healthy people. The equal 20 % are in a state of pre-existing disease, and 22 % have more than two chronic diseases. The remaining 38 % are in a state of exhaustion. Their bodies cannot withstand a disease independently. Only 2 % of all school graduates are completely healthy among children [2].

Modern diet does not meet the basic principles of healthy eating and dietetics. There are a lot of bakery products and potatoes and few main sources of valuable protein (meat, fish and dairy products), fiber, micronutrients (vegetables, fruits, nuts, etc.) in the diet of a modern human [3, 4]. The results of studies on the actual state of nutrition in different regions of the world indicate that the structure of nutrition and food status of both children and adults shows serious violations. There is a shortage of full value (animal) proteins, polyunsaturated fatty acids, vitamins, macro- and micro- elements and food fibers among them. And, conversely, there is an excessive consumption of animal fats and easily digestible carbohydrates [3]. There is a shortage of consumption of most vitamins, microelements and food fibers, which are necessary for a human body [3, 5–7]. The prevalence of obesity is 52 % among people over 45 years old, and the prevalence of overweight is 32 % [3].

The priority directions of modern science include organization of healthy nutrition and creation of food products to prevent alimentary diseases. There is informa-




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tization about healthy nutrition among the population carried out with the help of communication resources for this purpose.

Production of low-calorie products for health-improving purposes becomes of increasing importance for solution of the problem of providing a population with rational nutrition in recent years [8–10]. As we know, healthy products should contain sufficiently balanced amounts of a variety of ingredients. Proteins, fats, carbohydrates, minerals, vitamins and other biologically active components exhibit specific physiological activity, which supplements sensory and nutritional properties of products [9, 10].

Therefore, it is important to increase nutritional and biological values of extruded products. We can achieve an increase by enriching them with protein substances. This will reduce the level of protein deficiency among different groups of the population.

## 2. Literature review and problem statement

Researchers consider functional food products as not only sources of plastic substances and energy, but also as a complicated non-drug complex, which provides a reliable therapeutic and prophylactic effect. They define the place of products of functional nutrition as the intermediate one between general food products, that is, products included in the diet of the main population groups, and products of medical nutrition [11–13].

One of the signs of a deficiency of the most important nutrients is the appearance of white spots on nails. Protein is a building material for all body structures. Its deficiency leads to development of destructive processes in bones, joints, nails, muscles and other systems of a human body. Protein deficiency affects also the state of the immune system suppressing its work.

The recommended daily protein intake determined by the physiological need of a body is 75...80 g for an adult. The ratio of plant and animal protein should be approximately 1:1 in a diet [14]. Different biological values of plant and animal proteins determine a need for their combination in a daily diet. Animal proteins (meat, milk and fish) have high biological values. Plant proteins are significantly limited by a number of amino acids. The main limited amino acids are lysine and threonine for wheat proteins, and lysine and tryptophan – for corn proteins [14]. In addition, the content of protein in cereals is not sufficient. Cereal products are low in the content of vitamins, in particular, fat-soluble ones, lipids, minerals and fiber. Therefore, it is important to combine cereal products with raw materials of plant and animal origin, which are rich in proteins, and can also be a source of other essential elements of nutrition. We can use meat, by-products, fish, dairy products and products of their processing as protein fortifiers of cereal products.

Fast food products, and products, which do not require cooking, such as breakfast cereals, snacks, muesli, etc., are widely popular in the world today. The method of their production is extrusion.

Producers add protein derivatives of animal origin to extruded products to increase nutritional and biological values and to improve their organoleptic parameters [15, 16]. A new direction in the technology of thermoplastic extrusion is a combination of proteins of fish raw materials and various plant raw materials (grain, vegetables and fruits).

Extrusion of food products is a relatively new technology in the food industry. Producers use it to produce a large number of products of various sizes, shapes, texture and taste [17]. Producers use extrusion to produce fast food, dry snacks, bread crumbs, bread snacks, cookies, pasta, baby food, dry soups, mixtures of dried beverages, etc. [18]. Functional properties of extruded food products play an important role for their acceptability. They include water absorption, water solubility, oil absorption rates, expansion index, bulk density and viscosity of dough.

Producers also use extrusion to preserve the content of antioxidants and color properties of extruded products obtained of purple potatoes and yellow peas flour using a double-screw extruder [19]. The total content of anthocyanins was from 0.166 to 0.228 mg of a sample of dry mass of malvidin-3-glucosides/g in extrudates. Significant losses were from 60 % to 70 % comparing with their raw formulations. Brown color indices such as brightness, color, and tint angle were consistent with the anthocyanin degradation in pressed products.

Authors of paper [20] studied a change in bioavailability of carotenoids in carrots and corn grain during extrusion [20]. In addition, they studied contents of phenols, antioxidant activity, β-carotene content and lutein content before and after the extrusion process. The bioavailability of β-carotene and lutein in vitro increased due to extrusion. Extrusion reduced antioxidant activity and a total content of phenolic substances, β-carotene and lutein.

There was a technology of obtaining of meat-and-plant extruded products with secondary meat raw materials as meat raw material, namely by-products (lungs, tripe, spleen, heart, kidneys, etc.), mass of mechanical boning of cattle and poultry and blood plasma in a paper [21]. There were corn and wheat flour, buckwheat groats and oatmeal as plant raw materials [21]. However, the authors did not investigate an influence of selected raw materials on quality and sanitary-indicative indices during storage.

There was formulation and technology for production of fish creeps proposed. Producers used dry mass of horse mackerel, hake and blue whiting for dry breakfasts. Previously they grinded it and dried using the sublimation drying method. Other components were corn grits, vegetable oil, sugar powder, tea extract, and salt. They got a mass of frozen carcasses of fish, dried fillet (minced), horse mackerel, hake, and blue whiting with added corn grits, vegetable oils, sugar powder, tannin-catechin complex, citric acid, vitamin C, kitchen salt and aromatizes. The ratio of proteins, fats and carbohydrates was close to optimal in all developed extrudates [22]. The use of oil led to its rancidity at prolonged storage; therefore, a product lost taste values after three months of storage in cardboard packaging. However, modern producers prefer polypropylene packaging, therefore, it would be necessary to carry out a study on the maintenance of quality indicators of finished products in this packaging.

Authors of paper [23] developed a technology for obtaining of extruded products based on fish-and-plant raw materials [23]. The main ingredients were: corn grits, rice, peas, dried mass of low-value fish and sugar, salt, citric acid, vanillin, cinnamon, etc. used as auxiliary ingredients. They established that the fish component (6...10 %) as a protein filler increases nutritional properties of a product. The use of sugar is not the best, especially for people with diabetes mellitus, so it would be advisable to develop a product containing natural substitutes for sugar.

Paper [24] proposed an extruded snack product on a grain basis enriched with hydrolyzed low-value fish, namely roach. Introduction of such additive increased the nutritional value of finished products and expanded the range of fish extruded products.

Authors of work [25] patented a method for production of a grain product with filling [25], which includes dry milk, sweetening matter and fat. The introduction of the proposed additives made it possible to obtain a product with improved organoleptic parameters and a high nutritional value [25]. High fat content unbalanced with other macronutrients affects sensory performance of a finished product negatively. The authors did not analyze this fact in their work.

Authors of work [26] proposed a method for extrusion of a milk-and-plant mixture based on milk protein and cereal flour. The product had high water- and fat-retaining ability, biological value and high degree of absorbency by a human body. However, scientists did not investigate an important indicator of the dynamics of wettability of a finished product, which affects its ability to recover and product indicators.

Authors of paper [27] proposed to introduce water-soluble milk-and-protein concentrates to increase the biological value of extruded products to their composition [27]. As a source of protein, they used caseinates obtained by precipitation of casein in pasteurized milk, washing, pressing and treatment with solutions of alkali metal hydroxides or their salts followed by drying. However, there was no modeling of a formulation regarding the content of milk protein, which may cause allergic reactions, carried out in paper [27].

There was a new product of a «pad» type obtained by extrusion developed in paper [28]. Authors used pollack minced and flaxseeds as a protein source and a shell stabilizer. The paper gave an analysis of technological parameters for production of semi-finished products for production of an extruded product of the «pads» type. It showed that introduction of hydrobionts into a mixture significantly influences rheological parameters and, therefore, reduces time required for extrusion. Authors used raw material (flaxseed), which was sufficiently saturated with oil. Its use led to a shorter shelf life, due to oxidative processes. But authors did not study dynamics of changes in fatty acid number depending on storage conditions.

Cartilage diseases, such as arthritis and arthrosis of joint and destruction of intervertebral discs in a spine, are the most common chronic diseases in the world. The aims of modern drugs are mainly reducing of pain and increasing of mobility of joints. Polypharmaceutics and bio pharmaceutics are developing along with traditional pharmacotherapy in recent years. Clinical nutritionology is one of the new directions of biopharmaceutics. Nutraceutical preparations, which contain collagen hydrolysate, glucosamine, chondroitin sulfate, hyaluronic acid, vitamin C and other substances became widely used. Currently, industrially processed hydrobionts represent a source of high biological value of protein, which resembles animal structure.

Thus, there are studies carried out on the use of various types of additives of animal and plant origin and meat of hydrobionts in extruded grain products to expand the range of products of functional purpose and to increase nutritional and biological value. Therefore, expansion of the range of extruded products by provision of them with a balance, an increase in protein content by introduction of fish collagen hydrolysates into formulations is perspective. It is important to note that the collagen hydrolysate is not a secondary product of hydrobionts processing. We obtained it by hydrolysis of secondary raw materials.

## 3. The aim and objectives of the study

The objective of this study is to develop a formulation of corn sticks with balanced protein-carbohydrate content and to analyze their qualitative indices.

We set the following tasks to achieve the objective:

– development of formulations and determination of the optimal level of variation of the mass fraction of formulation components;

– investigation of a nutrition composition of the obtained corn sticks;

– study on physical-and-chemical and physiological-and-hygienic indices of the obtained products;

– determination of terms and conditions for storage of the extrudates obtained.

## 4. Materials and methods for development of corn sticks

We carried out the study in modern scientific laboratories, such as:

– consulting laboratory of healthy nutrition;

– problem research laboratory of complex processing of plant raw materials into food and feed products;

– research laboratory for assessment of the quality of grain and bakery products;

– A. Kirilenko research laboratory for microbiological research.

We used the following equipment to make corn sticks:

– a laboratory extruder (PE, Germany), a laboratory crusher, electric scales (Rotex RSK 10-P, China);

– a spectrophotometer (V-1100D, China) to determine a degree of digestibility, it is a device for determination of the digestibility in vitro; and a laboratory mill.

We used the following raw materials in the study: sugar corn (GOST 6002), barley (DSTU 3769), carrots (DSTU 7035:2009), licorice root (GOST 22839-88), and collagen hydrolysate [29].

We performed optimization of the formulation of extrudates according to the basic indices of the internal composition by means of mathematical modeling [30]. We implemented the mathematical modeling of formulations by linear programming using MS Excel 2010 editor [30, 31].

We carried out the analysis of corn sticks for the presence of mycotoxins (B1 aflatoxin, zearalenone, and deoxynivalenol) using Veratox test system. The basis for operation of the test system is the immune-enzyme method. It means attachment of an enzyme mark to antibodies. This makes it possible to take into account the result of the antigen reaction, that is an antibody from detection of enzymatic activity or a change of its level [11]. The test is an enzyme linked immunosorbent assay (ELISA) method, which provides an accurate determination at retention of mycotoxins at several μg/kg (ppb) [11].

We performed sensory analysis by profiling using the developed score scale in accordance with GOST ISO 6658:2005.

We carried out determination of the microrelief of corn sticks by direct determination of a size of air pockets using AMCap program with subsequent photograph in Bandicam program. We made photographs under light with a zooming by 25 times.

We performed determination of quality indicators of corn sticks during storage under laboratory conditions at room temperature of air (+15...20 °C) and humidity of 70...75 % in a polypropylene packaging.

The microbiological parameters were determined by: MAFAM – according to GOST 10444.15, bacteria of the colon bacillus – according to GOST 30726-2001, Staphylococcus aureus – according to GOST 10444.2, pathogenic microorganisms, in particular bacteria of the Salmonella group – according to DSTU IDF 122C:2003, yeast and mold mushrooms – according to GOST 10444.12 and *S. aureus* – according to GOST 30347-97. We carried out the studies using the methods described in paper [32].

## 5. Results of the study of quality indicators of corn sticks

### 5. 1. Optimization of formulations of corn sticks

We paid considerable attention to the nutrition composition of raw material, its change in technological processing and its balance in development of the composition of corn sticks. The aim was to develop and optimize a formulation for production of a grain product and to provide an increase in nutritional and biological value of a finished product, as well as expansion of the range by introduction of an additional component and a cereal component.

The use of cereals of corn sugar, which contains a lot of carbohydrates (sugars), makes it possible to avoid the use of sugar and sugar powder in production of a product. Ripe sugar corn contains a small amount of starch (25–37 %), but many water-soluble polysaccharides (19–31 %). There are more proteins than in starchy subspecies of corn (14.2–16.1 % on dry matter). Sugar corn contains also (in mg %) 11.6–13.7 of vitamin C; 0.16 of vitamin $B_1$ (thiamine); 0.11–0.12 of vitamin $B_2$ (riboflavin); 1.97–2.25 of vitamin $B_5$ (niacin), and also vitamins $B_3$ (pantothenic acid), $B_6$ (pyridoxine), inositol, choline, biotin, vitamin E and provitamin A (carotene).

Licorice contains vitamins, minerals and other biologically active compounds. Producers use licorice as a sweetener of natural origin in the food industry. Licorice contains a large number of natural amino acids, polysaccharides, essential oils, resins and tannins. The introduction of grinded root of licorice into an extruded grain product promotes an increase of consumer properties of a finished product, namely, it gives it a sweet taste and enriches it with vitamins ($B_1$, $B_2$, $B_6$, $B_9$, PP, beta-carotene, vitamin A and vitamin E), macroelements (phosphorus, calcium, magnesium, sodium and potassium) and microelements (iron, iodine, manganese, fluorine, etc.). But addition of more than 4 % of licorice leads to a negative impact on a human body, as this plant is medicinal.

The introduction of cereals made of grain of bare-grained barley into an extruded grain product promotes an increase of consumer properties and enriches a product with microelements. There is a lot of ß-glucan in bare-grained barley, it helps to clear a body from cholesterol, slags and toxins. It also has a general strengthening and immunostimulating effect and contains a complex of vitamin E+, magnesium+, and omega-3 fats.

Previous studies showed that introduction of fortifying additives enhance the process of destruction of basic biopolymers, which in turn leads to an increase in enzymatic attack on starch. Assimilation of protein substances and activation of their cleavage by proteolytic enzymes increase.

The aim of optimization of formulations of new extruded products was to determine their optimal ratio in such a way that the ratio of protein to carbohydrates was 1: 3.0...5.0 at maximum protein content.

Table 1 shows the restrictions by the content of components for development of new types of corn sticks.

Table 1

Restrictions on formulation content (g per 100 g of finished product)

| Formulation component | Content in the composition of «Kukurudzyanka» sticks, g | | Content in the composition of «Kukurudzyanka+» sticks, g | |
|---|---|---|---|---|
| | Minimum | Maximum | Minimum | Maximum |
| Sugar corn grits | 70 | 80 | 60 | 80 |
| Cereals of bare-grained barley | 15 | 25 | 10 | 20 |
| Licorice root | 1 | 2.5 | 1 | 3 |
| Blanched carrots | 2 | 5 | 2 | 5 |
| Collagen hydrolysate | – | – | 5 | 10 |

Fig. 1 shows calculations in MS Excel. We performed optimization of formulations in Excel Solver program. It is an additional add-on for MS Excel table processor intended to solve certain systems of equations and linear and nonlinear optimization tasks. We fulfilled the following steps to solve the LP task in the Microsoft Excel [31]:

1. Entering a condition for the task:

a) creation of an on-screen form for entering of task conditions, such as variables; target function (TF); restrictions; boundary conditions;

b) entering the initial data, such as coefficients of TF; coefficients for variables in restrictions; right parts of restrictions into the on-screen form;

c) introduction of the dependence of the mathematical model into the screen form, that is, a formula for calculation of TF; formulas for calculation of values of left parts of restrictions;

d) setting of TF (in the «Excel Solver» window): target cell; a direction of optimization of TF;

e) entering the restrictions and boundary conditions (in the «Excel Solver» window): cells with values of variables; boundary conditions for admissible values of variables; correlations between right and left parts of restrictions.

2. Solution to the task:

a) setting of parameters for the task resolution (in the «Excel Solver» window);

b) running the task for the solution (in the «Excel Solver» window);

c) selection of the format for solution output (in the «Solver Results» window).

Fig. 1 presents the matrix for planning of optimization of the formulation of «Kukurudzyanka+» corn sticks.

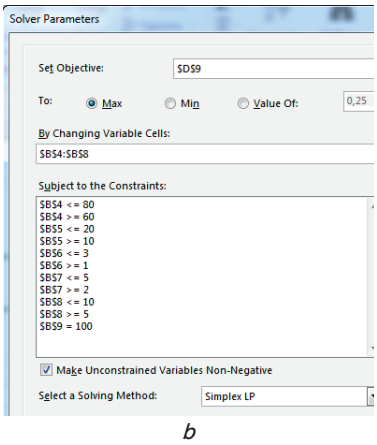
There were batches of «Kukurudzyanka» and «Kukurudzyanka+» corn sticks with developed compositions produced according to the technological scheme presented in Fig. 2.

The proposed scheme for the production of extrudates of combined cereals raw materials (Fig. 2) includes the following steps:

– preparation of components of raw materials (control);
– grinding of cereals;
– humidification and distilling of cereals;
– dosage and mixing of cereals, and introduction of aromatizing components if necessary;
– extrusion;
– cooling and control of extrudates;
– prepacking and packing.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | Kukurudzyanka+ | | | | | |
| 3 | | content of components, g | protein content? g/100g | protein content in the mixture, g | content of carbohydrates, g/100g | content of carbohydrates in the mixture, g |
| 4 | sugar corn grits | 80 | 22 | =B4*C4/100 | 40 | =E4*B4/100 |
| 5 | cereals of bare-grained barley | 20 | 19,4 | =B5*C5/100 | 0 | =E5*B5/100 |
| 6 | licorice root | 1 | 0 | =B6*C6/100 | 0 | =E6*B6/100 |
| 7 | blanched carrots | 5 | 0,8 | =B7*C7/100 | 1,3 | =E7*B7/100 |
| 8 | collagen hydrolysate | 5 | 70 | =B8*C8/100 | 0 | =E8*B8/100 |
| 9 | output of a finished product, g | 100 | | =СУММ(D4:D7) | | =СУММ(F4:F8) |

*a*




*b*

Fig. 1. The matrix of planning and parameters for solution of the formulation of «Kukurudzyanka+» corn sticks (*a* — the matrix of planning of the formulation, *b* — conditions of restrictions for planning of the formulation)

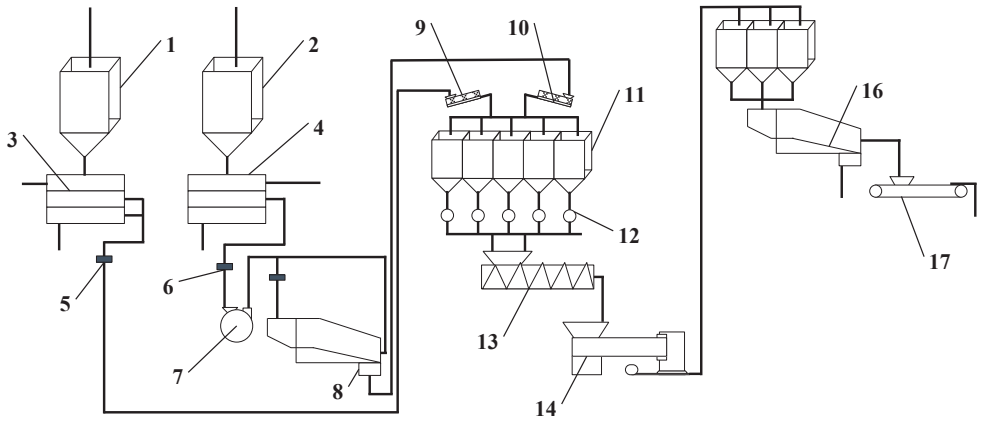



Fig. 2. Hardware and technological scheme of production of extrudates of combined cereals raw materials: 1, 2 — bunkers; 3, 4 — sowing; 5, 6 — magnetic column; 7 — crusher; 8 — sieve; 9, 10 — humidifier; 11 — bunkers; 12 — dispensers; 13 — mixer; 14 — extruder; 15 — bunkers; 16 — sieve; 17 — conveyor

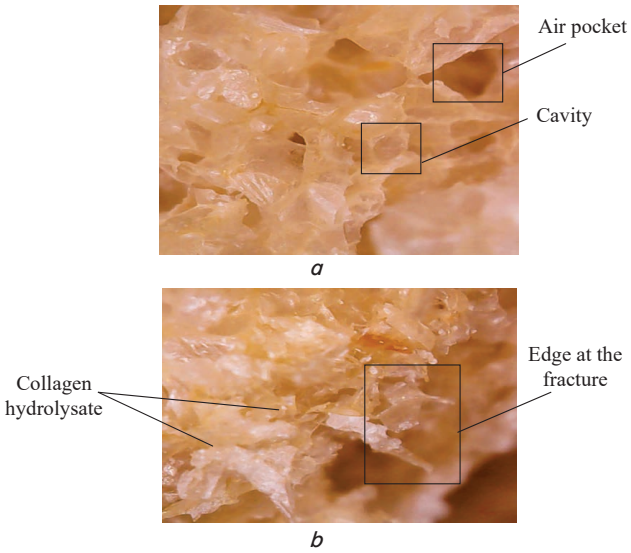
**5. 2. Determination of quality indicators of corn sticks**

We investigated the microstructure of the obtained corn sticks (Fig. 3) using an electron microscope. The results of the study gave an idea on the porosity and structure of a surface of the product obtained.

The study of the microstructure of corn sticks with zooming by 25 times gave possibility to detect fragments of components of sticks composition in the form of particles up to 0.1 mm in size. The microrelief of sticks showed that the sticks have cavities and sharp edges provided by extrusion in the fracture. The photo shows the uniform distribution of all components of the formulation throughout the volume of a stick. The dimensions of holes and structure of the microrelief confirm the integrity of a surface of the product and a high degree of homogeneity (Fig. 3).

One of the physical-and-chemical indicators of dry breakfast for storage and consumption is the index of wettability. We chose pH indicators to study a degree of wettability, which were appropriate for liquid food systems (fruit and vegetable juices and milk). The temperature for the study varied from 10 to 25 °C at an interval of 5 °C (Fig. 4).

It is evident from the data obtained (Fig. 4) that when the temperature and pH of the medium increase, the wetting ability of the developed sticks increases by 14...15 % on average. Comparing the wetting abilities of «Kukurudzyanka» and «Kukurudzyanka+» corn sticks, it is clear that this indicator is higher for «Kukurudzyanka+». We can explain this by the additional introduction of the collagen hydrolysate into the formulation. The collagen hydrolysate is capable of binding of moisture in food systems.




*a*

*b*

Fig. 3. The microstructure of corn sticks×25: *a* — «Kukurudzyanka» sticks, *b* —«Kukurudzyanka+» sticks

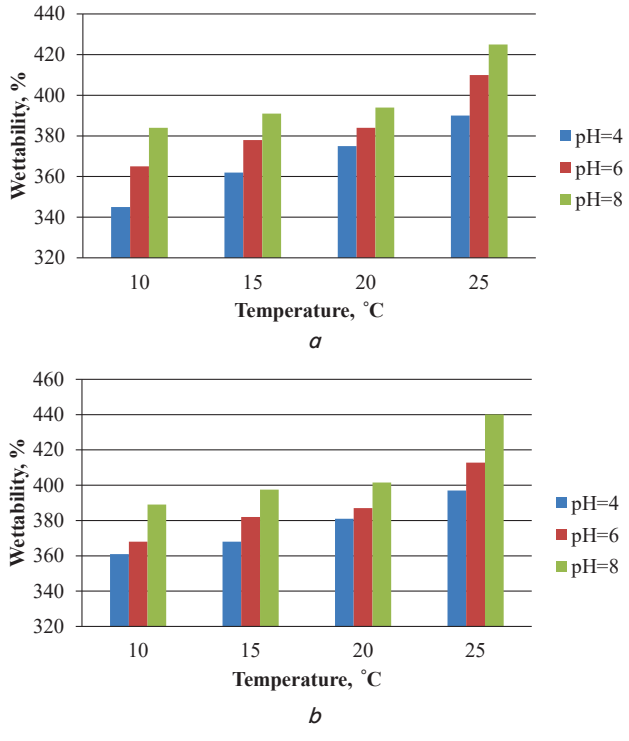



Fig. 4. Determination of the dependence of wettability of corn sticks depending on technological parameters of production: *a* – «Kukurudzyanka» sticks, *b* – «Kukurudzyanka+» sticks

Table 2 presents the estimation of sensory indices of the obtained products. We performed the organoleptic evaluation by the sensory method according to the indicators stipulated by DSTU 2781-98 standard: appearance, consistency, color, smell and taste.

A tasting commission performed the organoleptic evaluation. The board included faculty members of the departments – 15 people:

– technologies of restaurant and health nutrition;

– grain processing technologies;

– grain storage technologies;

– representatives of «Restaurant 112» production and training plant (Odessa National Academy of Food Technologies).

Table 2 presents the sensory analysis of indicators. The data from Table 2 evidences a rather pleasant appearance, taste and color.

The next stage of the study was investigation of the nutritional composition of the developed corn sticks.

**5. 3. Analysis of the nutritional composition of «Kukurudzyanka» and «Kukurudzyanka+» corn sticks**

The results presented in Table 3 indicate that the products developed have high protein content, which is very important in terms of meeting needs of an organism of a modern person.

Table 3

Macronutrient composition of corn sticks (g/100 g)

| Name of macronutrient | «Kukurudzyanka» | «Kukurudzyanka+» |
|---|---|---|
| Moisture | 5.0 | 3.0 |
| Protein | 12.5 | 19.5 |
| Fat | 2.8 | 2.1 |
| Carbohydrate | 63.2 | 63.7 |
| Ash | 1.7 | 2.15 |

We should note that the developed products differ in rather high content of all basic micronutrients necessary for a human body, namely calcium, phosphorus and potassium (Table 4).

Table 4

The degree of satisfaction of daily human needs in the main vitamins, % (when consuming 100 g of sticks)

| Vitamins | Daily need, mg | «Kukurudzyanka» | | «Kukurudzyanka+» | |
|---|---|---|---|---|---|
| | | Sticks, per 100 g | Satisfaction of the daily need, % | Sticks, per 100 g | Satisfaction of the daily need, % |
| A | 0.1 | 0.08 | 76.62 | 0.08 | 80.00 |
| $B_1$ | 1.5 | 0.22 | 14.93 | 0.29 | 19.27 |
| $B_2$ | 1.8 | 0.25 | 13.82 | 0.28 | 15.31 |
| $B_6$ | 0.2 | 0.15 | 75.76 | 0.65 | 79.25 |
| E | 15 | 0.44 | 2.93 | 0.56 | 3.73 |
| PP | 20 | 4.78 | 23.90 | 5.475 | 27.38 |
| C | 80 | 0.61 | 0.77 | 0.65 | 0.81 |
| Calcium (Ca) | 3000 | 314.74 | 10.5 | 392.63 | 13.1 |
| Magnesium (Mg) | 800 | 99.89 | 12.5 | 127.75 | 16.0 |
| Phosphorus (P) | 400 | 255.32 | 63.8 | 297.95 | 74.5 |
| Potassium (K) | 2500 | 181.97 | 7.3 | 212.38 | 8.5 |
| Sodium (Na) | 400 | 99.89 | 25.0 | 52.36 | 13.1 |
| Iron (Fe) | 18 | 2.67 | 14.8 | 3.48 | 19.3 |

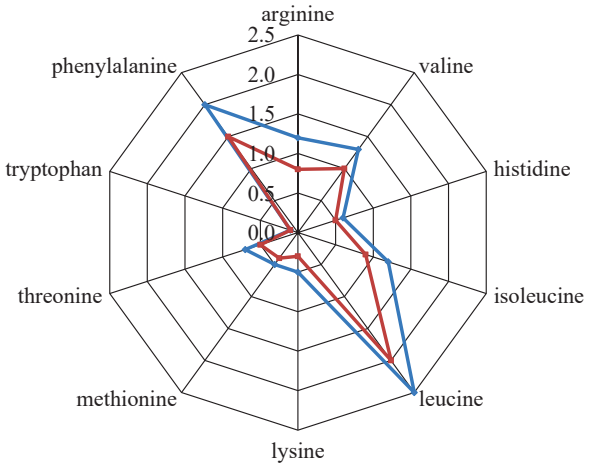
Table 2

Sensory indicators of corn sticks (GOST 15113.3)

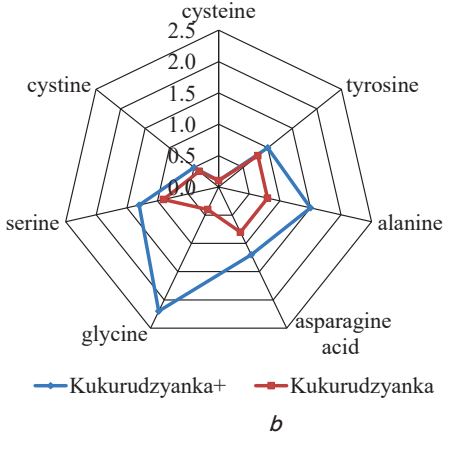
| Name of indicator | «Kukurudzyanka» | «Kukurudzyanka+» |
|---|---|---|
| Appearance | The shape is correct, the surface is rough, without deformations and tears, the products have the appropriate sizes and attractive appearance | The shape is correct, the surface is rough, without deformations and tears, the products have the appropriate sizes and attractive appearance |
| Consistency | Particles of plant raw material are evenly distributed throughout the volume (inclusions), sticks are dry and brittle, crispy and tender | Particles of plant raw material are evenly distributed throughout the volume, sticks are dry and brittle, crispy and tender |
| Color | Light yellow with orange and brown inclusions | Light yellow with orange and brown inclusions |
| Aroma | Pure, corn with a delicate carrot aroma, no foreign smells. Pleasant, pronounced | Pure, corn with a delicate carrot aroma, no foreign smells. Pleasant, pronounced |
| Taste | Sweet, without foreign smacks | Sweet, without foreign smacks |
| Structure | Brittle, even, porous and tender | Brittle, even, porous and tender |

Since the ready to use corn sticks contain protein, it was necessary to carry out an analysis of the amino acid composition. The results of studies (Fig. 5) showed that the protein component contains nineteen amino acids, including all essential ones Fig. 5.

We performed investigation of the biological value of corn sticks by calculation of the amino acid score presented in Fig. 6.




*a*




*b*

Fig. 5. Amino acid content in the finished product, g/100 g: *a* — content of essential amino acids; *b* — content of the substitutable amino acids

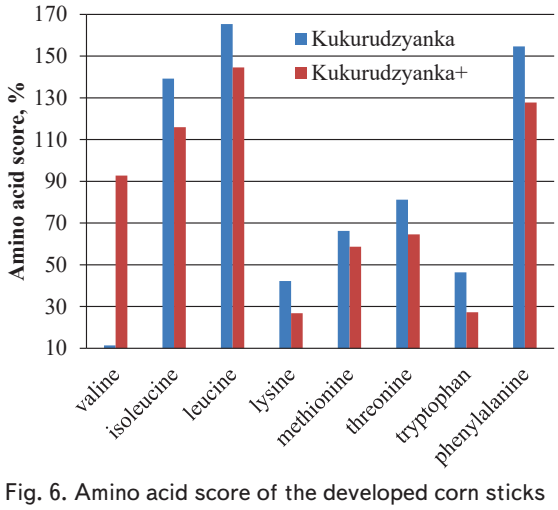



Fig. 6. Amino acid score of the developed corn sticks

Table 5 presents the daily need of a human body in essential amino acids due to the consumption of 100 g of sticks. Consumption of 100 g of sticks will provide a human body with essential amino acids by almost 24.1 % in total.

Table 5

Degree of satisfaction of daily needs in amino acids, % (at consumption of 100 g of sticks)

| Amino acid | Daily need in *g* | «Kukurudzyanka» | | «Kukurudzyanka+» | |
|---|---|---|---|---|---|
| | | Content, g per 1 portion | Satisfaction, % | Content, g per 1 portion | Satisfaction, % |
| valine | 3 | 1.0 | 33.09 | 1.3 | 44.37 |
| isoleucine | 3 | 0.9 | 30.67 | 1.2 | 40.86 |
| leucine | 5 | 2.0 | 40.14 | 2.5 | 50.5 |
| lysine | 4 | 0.3 | 7.307 | 0.5 | 11.6 |
| methionine | 3 | 0.4 | 13.58 | 0.5 | 17.92 |
| threonine | 2 | 0.5 | 25.63 | 0.7 | 36.06 |
| tryptophan | 2 | 0.1 | 2.7 | 0.1 | 2.82 |
| phenylalanine | 3 | 1.5 | 50.7 | 2.0 | 66.37 |
| arginine | 6 | 0.8 | 13.17 | 1.2 | 19.83 |
| histidine | 2 | 0.5 | 23.94 | 0.6 | 30.09 |

Not only amino acid composition, but also by a degree of digestibility determines the biological value of proteins. The intensity of the process of digestion of proteins in the digestive tract of a person depends on the activity of proteolytic enzymes and the biological form of the protein component of a product.

We determined the degree of digestibility of protein substances of the developed corn sticks in the study (Fig. 7).

We evaluated the degree of digestibility of protein substances of products by the intensity of their hydrolysis by pepsin and trypsin enzymes in vitro. The analysis of kinetics of the enzymatic hydrolysis of the studied corn sticks showed that the hydrolysis occurs at almost constant rate.

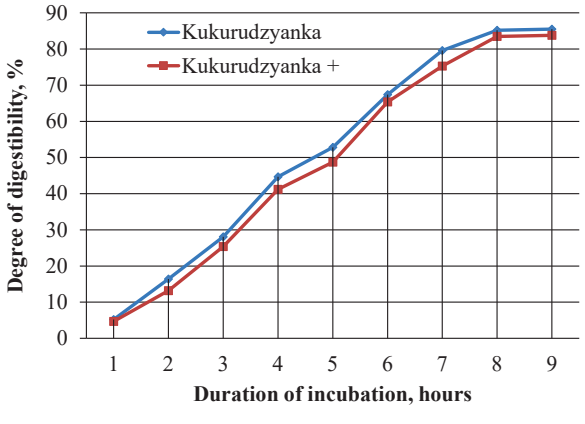



Fig. 7. Kinetics of digestion of corn sticks in the system of «pepsin-trypsin» (*in vitro*)

The degree of digestibility of protein components of the developed corn sticks is incomplete due to high content

of food fibers of plant raw material and presence of gluten, which leads to deterioration of peristalsis of intestine. In vitro studies showed that the developed products have a rather high degree of digestibility, due to a greater number of easily digestible albumin and globulin fractions in the composition of corn and bare-grained barley proteins.

**5. 4. Study of changes in quality indicators during storage**

We performed the study of qualitative and quantitative composition of microbiota of «Kukurudzyanka» and «Kukurudzyanka+» corn sticks with plant additives during their storage for the establishment of its safe storage periods by the presence of sanitary-indicative microorganisms (Table 6).

In addition, we carried out the analysis of the products obtained for presence of mycotoxins (B1 aflatoxin, zearalenone and deoxynivalenol) using Veratox test system. The content of aflatoxins, zearalenone and DON (dezoxynivalenol) did not exceed the permissible limits in all studied samples.

Fig. 8 shows the dynamics of changes in organoleptic parameters in the score system. We assigned scores from 0 to 5 to intervals of changes in values of organoleptic indicators as follows: 0–1 – very poor quality, 1–2 – poor quality; 2–3 – medium quality; 3–4 – good quality; 4–5 – excellent quality.

Thus, based on the results of the study, we can recommend storing the corn sticks for 6 months at the temperature of (18±2) °C and humidity not more than 74 % in polypropylene packaging.

## 6. Discussion of the results of determination of quality indices of «Kukurudzyanka» and «Kukurudzyanka+» corn sticks

The food system swells with formation of a porous structure, due to using of an extruder in the production of corn sticks. We can see on the fracture of «Kukurudzyanka» corn sticks (Fig. 3, *a*) that air pockets are large and have a rounded shape; edges of a product are sharp. The microstructure changes slightly after introduction of collagen hydrolysate into corn sticks. Thus, we can see on the fracture of «Kukurudzyanka +» sticks (Fig. 3, *b*), that air pockets are small, edges are sharp and particles of the collagen hydrolysate are clearly visible. The average size of air pockets of «Kukurudzyanka» is 0.2–0.6 mm, and «Kukurudzyanka+» – 0.06–0.2 mm. However, the size of 65 % of air pockets ranges within 0.5–0.6 mm in «Kukurudzyanka» sticks, while the size of 78 % of air pockets ranges within 0.15–0.2 mm in «Kukurudzyanka+» sticks.

The study of the wettability index showed that it increases when the temperature and pH of the medium increases. Thus, in «Kukurudzyanka» sticks, the wettability increased by 13 % at an increase in temperature at pH=4.0, at pH=6.0 – by 12.3 %, and at pH=8 – by 10.7 %. We observe the similar trend at the swelling of «Kukurudzyanka+» corn sticks: the wettability increases by 9.97 % at an increase in the temperature from 10 °C to 25 °C at pH=4.0, at pH=6.0 – by 12.2 %, at pH=8.0 – by 13.1 %.

Table 6

Dynamics of changes in physical-and-chemical and microbiological parameters of corn sticks when stored in polyethylene packaging

| Name of indicator | Characteristics of indicators after the end of the technological cycle | Storage duration, months | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Bacteria of the colon bacillus group in 1 g | Not found | Not found | | | | |
| Coagulase-positive staphylococcus | Not found | Not found | | | | |
| Pathogenic microorganisms, including Salmonella | Not found | Not found | | | | |
| MAFAM, CFU in 1 g, not more than | $2.1 \cdot 10^2$ | $2.3 \cdot 10^2$ | $2.7 \cdot 10^2$ | $2.9 \cdot 10^2$ | $3.1 \cdot 10^2$ | $3.2 \cdot 10^2$ |
| Mold fungi in 1 g, not more than | $2.1 \cdot 10^1$ | $2.4 \cdot 10^1$ | $2.7 \cdot 10^1$ | $2.9 \cdot 10^1$ | $3.1 \cdot 10^1$ | $3.2 \cdot 10^1$ |

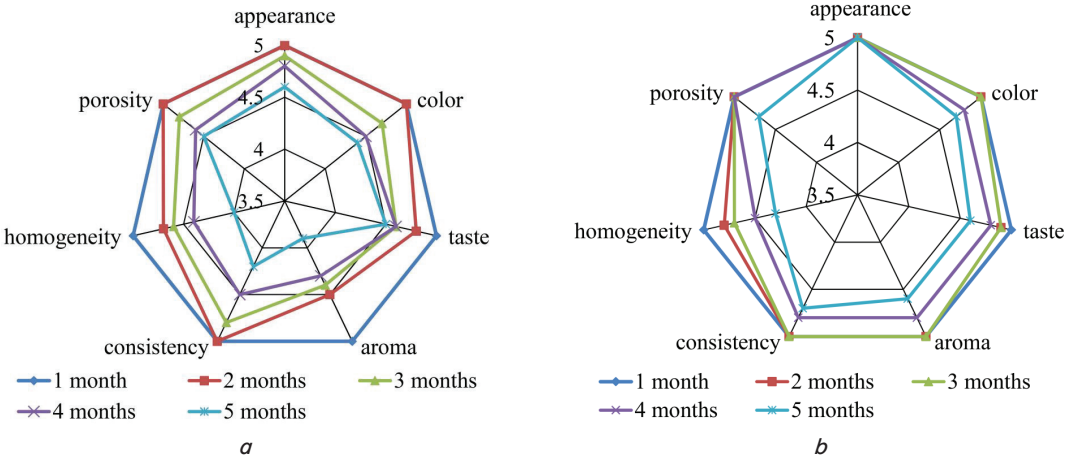



Fig. 8. Dynamics of changes in sensory parameters of corn sticks during storage: *a* – «Kukurudzyanka» corn sticks, *b* – «Kukurudzyanka+» sticks

However, comparing the dynamics of wettability of both types of sticks, it is evident that the rate of absorption of water by sticks decreases with the introduction of collagen hydrolysate into the formulation, due to the fact, that collagen hydrolysate is capable of absorbing of water molecules, and to form a gel structure at increasing temperature.

The study of micronutrient composition (Table 4) showed that the consumption of 100 grams of «Kukurudzyanka» sticks satisfies human needs in vitamins A and B6 by 76.62 and 75.76 %, respectively, and «Kukurudzyanka+» – by 80 and 79.25 %.

The obtained data showed that the first limiting amino acid is lysine for «Kukurudzyanka» (AC score=26.79 %), and tryptophan for «Kukurudzyanka+» (AC score=26.17 %). Moreover, the amino acid score increased by 46 % in «Kukurudzyanka+» corn sticks comparing to «Kukurudzyanka» sticks», due to the introduction of collagen hydrolysate into their composition.

The advantage of developed extrudates is the high protein content with a high degree of digestibility. As we can see in Fig. 7, the degree of digestibility of protein of all experimental samples during the enzymatic action was 85.2 and 83.5 % respectively for «Kukurudzyanka» and «Kukurudzyanka+» after 8 hours of incubation. Further incubation showed a slight increase in digestibility. Thus, after 9 hours of incubation, the digestibility of «Kukurudzyanka» and «Kukurudzyanka+» increased by only 0.35 and 0.36 %, respectively, in comparison with the digestibility indices for 8 hours. The digesting of «Kukurudzyanka+» corn sticks is slightly slower in comparison with «Kukurudzyanka» sticks», due to the introduction of collagen hydrolysate in their composition and it is about 2 %.

The results shown in Table 5 make it possible to establish that the number of bacteria decreases when duration of storage increases at prolonged storage of commercial samples of extruded grain products with the inclusion of plant additives under various temperature-humidity conditions. The absolute amount of spore-forming bacteria remained at the same level in the samples stored in the synthetic packaging, and their relative content in the total bacterial flora increased. The total sensory index decreased by about 30 % under conditions of storage of corn sticks in polypropylene package for 6 months.

It is possible to implement the developed composition under production conditions of enterprises of the grain processing industry. It is necessary to perform economic calculations with the definition of a commercial price, including material costs of advertising measures, and to determine competitiveness of the developed extrudates before implementation of the development in real conditions.

## 7. Conclusions

1. We developed the formulations of extruded products based on sugar corn grain. We optimized the extruder formulations using the Solver table processor (MS Excel 2010). We established the optimal content of all components. It became possible to get products, which are balanced in biological value and have improved consumer properties, namely «Kukurudzyanka» and «Kukurudzyanka +» corn sticks.

2. We studied the chemical composition of the developed corn sticks. We proved the balance on the content of the basic nutrients. We established that the protein content is 12.5 and 19.5 g/100 g, respectively, in the developed «Kukurudzyanka» and «Kukurudzyanka+» extrudates. The content of carbohydrates is 63.2 and 63.7 g/100 g in the developed «Kukurudzyanka» and «Kukurudzyanka+» products, respectively. We can explain such indicators by the fact that producers apply additives with the help of a special device (pelleting machine), which uses oil for application of taste additives or powdered sugar, in the production of corn sticks. Producers add all used additives of plant and animal origin at the mixing of components stage (before extruding), which makes it possible not to use vegetable oil, which, in the long-term storage, is capable of rancidification. The developed extruded products have sufficient content of micronutrients and macronutrients. Consumption of 100 g of the developed corn sticks will provide a body with almost 24.1 % of essential amino acids. The developed «Kukurudzyanka» and «Kukurudzyanka+» extruders satisfy human need for vitamin A by 76.62 and 80 % respectively, and vitamin $B_6$ by 75.76 % and 79.25 %, respectively.

3. Investigation of the microstructure of corn extrudates revealed fragments of components of the composition of sticks in the form of particles of a size up to 0.1 mm. The microrelief of sticks showed that they have cavities and sharp edges provided by extrusion in the fracture. The conducted study on the ability of the products obtained to wettability showed that the wetting ability increases by 14...15 % on average at an increase in temperature and pH of a medium. The degree of digestibility of developed corn sticks is about 85 %.

4. Based on the microbiological research, we established that the products have rather good quantitative and qualitative parameters (Tables 2, 5) when stored under unregulated conditions. The recommended storage duration is 6 months at the temperature (18±2) °C and relative humidity not more than 75 %.

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