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NUTRITIONAL VALUE, MICROBIOLOGICAL SAFETY, AND STORAGE STABILITY OF EXTRUDED BREAKFAST CEREALS BASED ON PLANT POWDERS

[1]M.Zh. Sultanova, [1]N. Akzhanov, [1]A.S. Saduakas, [1]A.S. Kamali, [2]K.O. Dodaev

[1]Kazakh Scientific Research Institute of Processing and Food Industry, Astana, Kazakhstan,
[2]Tashkent Institute of Chemical Technology, Tashkent, Uzbekistan

Corresponding author: nurtore0308@gmail.com

The article presents a study on the quality and food safety of extruded breakfast cereals developed on the basis of cereal grains with the addition of plant powders.

The relevance of the study is associated with the increasing consumer demand for functional and safe food products. Although extruded breakfast cereals are widely consumed, their content of vitamins and biologically active compounds is often insufficient. Therefore, improving the nutritional value of such products through the use of natural plant raw materials is of scientific and practical interest. In addition, the influence of plant powders on the microbiological stability, physical properties, and vitamin composition of extruded products during storage has not been sufficiently studied, which justifies the need for a comprehensive assessment of their quality characteristics.

A mixture of cereals (rice, corn, and barley) was used as the main raw material, while carrot, beetroot, and pumpkin powders were applied as functional ingredients. The purpose of the study was to comprehensively evaluate the effects of plant powders and storage conditions on the vitamin composition, microbiological safety, and physical properties of extruded food products.

The content of B vitamins and vitamin C was determined by high-performance liquid chromatography, as well as by titrimetric and fluorimetric methods in accordance with the requirements of GOST 31483-2012. The microbiological safety of the product was assessed by the number of mesophilic aerobic and facultative anaerobic microorganisms, E. coli bacteria, yeast and mold fungi, as well as the presence of pathogenic microorganisms. The physical properties of the extruded products were characterized by the parameters of bulk density, brittleness, and color in the CIELab system.

It contributed to an increase in the vitamin value of the extruded breakfast cereal due to the introduction of vegetable powders. The content of B vitamins and vitamin C in the test samples was higher than in the control sample. The high growth was manifested in vitamin C. During 3 months, a slight decrease in the vitamin content was observed during storage, and it was higher in the samples of herbal powder additives.

During the analysis of microbiological examinations, the microbiological safety indicators on the samples corresponded to sanitary and hygienic requirements. During the 3 months of storage, there was a slight increase in the number of microorganisms, yeast and mold fungi, the values did not exceed the permissible standards.

The analysis of physical parameters showed that the bulk density of the samples was observed in the range of 0.45-0.49 g/cm3, fragility -in the range of 29.6-33.1 H. During storage, the physical characteristics changed, which did not affect the quality of the products.

The use of vegetable powders has increased the nutritional value of the extruded breakfast cereal. The developed products were characterized by stable physical properties and met food safety requirements, confirming safe storage for at least 3 months.

Keywords: extruded breakfast cereals, cereals, vegetable powders, recipe, vitamin composition, microbiological safety, physical properties, food storage.

ӨСІМДІК ҰНТАҚТАРЫ НЕГІЗІНДЕГІ ЭКСТРУДИРЛЕНГЕН ҚҰРҒАҚ ТАҢҒЫ АСТЫҢ

ТАҒАМДЫҚ ҚҰНДЫЛЫҒЫ, МИКРОБИОЛОГИЯЛЫҚ ҚАУІПСІЗДІГІ ЖӘНЕ САҚТАУ ТҰРАҚТЫЛЫҒЫ

[1]М.Ж. Султанова, [1]Н. Акжанов, [1]Ә.С. Сәдуақас, [1]А.С. Камали, [2]К.О. Додаев
[1]Қазақ қайта өңдеу және тағам өнеркәсіптері ҒЗИ» ЖШС, Астана, Қазақстан,
[2]Ташкент химия-технология институты, Ташкент, Өзбекстан,
e-mail: nurtore0308@gmail.com

Мақалада өсімдік ұнтақтары қосылған дәнді дақылдар негізінде жасалған экструдирленген құрғақ таңғы астың сапасы мен тағамдық қауіпсіздігіне зерттеу жүргізілді.

Зерттеу тақырыбының өзектілігі қазіргі таңда халықтың функционалдық және қауіпсіз тағам өнімдеріне деген сұранысының артуымен байланысты. Экструдирленген құрғақ таңғы астар кеңінен тұтынылғанымен, олардың құрамындағы дәрумендер мен биологиялық белсенді заттардың мөлшері жеткіліксіз болып келеді. Осыған байланысты өнімнің тағамдық құндылығын табиғи өсімдік шикізаты есебінен арттыру ғылыми және практикалық тұрғыдан маңызды болып табылады. Сонымен қатар, өсімдік ұнтақтарын экструдирленген өнімдерге енгізудің сақтау кезіндегі микробиологиялық тұрақтылыққа, физикалық қасиеттерге және витаминдік құрамға әсері толық зерттелмеген. Бұл экструдирленген өнімдердің сапалық көрсеткіштерін кешенді бағалау қажеттілігін негіздейді.

Негізгі шикізат ретінде жарма қоспалары (күріш, жүгері және арпа), ал функционалды компоненттер ретінде сәбіз, қызылша және асқабақ ұнтақтары қолданылды. Зерттеу мақсаты өсімдік ұнтақтарының қоспалары мен сақтау жағдайларының экструдирленген тағам өнімдерінің витаминдік құрамына, микробиологиялық қауіпсіздігіне және физикалық қасиеттеріне әсерін кешенді түрде анықтау және бағалау болып табылады.

В тобына жататын дәрумендер мен С тобындағы дәрумендер құрамын анықтау жоғары тиімді сұйықтықты хроматография әдісімен, сонымен бірге МЕМСТ 31483-2012 белгіленген талаптарына сай титриметриялық және флуориметриялық әдістер көмегімен жүргізілген. Өнімнің микробиологиялық қауіпсіздігі мезофильді аэробты және факультативті-анаэробты микроорганизмдерге (МАФАнМ) байланысты, яғни E. coli бактериялары, ашытқылар мен зеңдер, сондай-ақ қоздырғыштар бойынша бағаланады. Экструдирленген өнімдердің физикалық қасиеттері CIELab жүйесіндегі сусымалы тығыздық, сынғыштық және түс параметрлерімен сипатталды.

Зерттеу нәтижелеріне қарасақ, өсімдік ұнтақтарын енгізу арқылы экструдирленген құрғақ таңғы астың дәрумендік құндылығын көбейтуге жәрдем еткенін көрсетті. Сынақ үлгілеріндегі В тобындағы дәрумендер мен С витаминінің мөлшері бақылау үлгісімен салыстыра қарағанда жоғары болғанын байқаймыз. Ең айқын өсімді С дәруменінде көре аламыз.3 ай бойы сақтау процесі барасында дәрумендердің шамалы төмендеуі байқалды, бірақ олардың деңгейі өсімдік ұнтақтарының қоспалары бар үлгілерде жоғары болып қалғанын көрдік.

Микробиологиялық зерттеулер сараптамалары бойынша талдау жүргізу кезінде барлық үлгілерде микробиологиялық қауіпсіздік көрсеткіштері санитарлық-гигиеналық талаптарға сай келетінін көрсетті. Сақтаудың 3 айында микроорганизмдер мен ашытқылар мен зең саңырауқұлақтарының жалпы санының шамалы өсуі байқалды, алайда олардың мәндері рұқсат етілген нормалардан аспады.

Физикалық көрсеткіштерді талдау үлгілердің үйінді тығыздығы 0,45-0,49 г/см^3 шектікте болғанын, ал сынғыштығы 29,6-33,1 Н аралығында өзгергені байқалды. Сақтау процесінде өнімнің сапасына біршама әсер етпейтін физикалық сипаттамалардың өзгергенін аңғаруға болады.

Нәтижелер өсімдік ұнтақтарын пайдалану экструдирленген құрғақ таңғы астың тағамдық құндылығын одан сайын арттыруға мүмкіндік беретінін көрсетеді. Әзірленген өнімдер тұрақты физикалық қасиеттерімен сипатталады, сонымен қоса тағам қауіпсіздігі талаптарына сай келеді, бұл

оларды ең кем дегенде санасақ 3 ай бойы қауіпсіз сақтау мүмкіндігін растайды.

Түйін сөздер: экструдирленген құрғақ таңғы ас, жарма, өсімдік ұнтақтары, рецептура, витаминдік құрамы, микробиологиялық қауіпсіздігі, физикалық қасиеттері, өнімді сақтау.

ПИЩЕВАЯ ЦЕННОСТЬ, МИКРОБИОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ И СТАБИЛЬНОСТЬ ПРИ ХРАНЕНИИ ЭКСТРУДИРОВАННЫХ СУХИХ ЗАВТРАКОВ НА ОСНОВЕ РАСТИТЕЛЬНЫХ ПОРОШКОВ

[1]М.Ж. Султанова, [1]Н. Акжанов, [1]Ә.С. Сәдуақас, [1]А.С. Камали, [2]К.О. Додаев

[1]Казахский научно - исследовательский институт перерабатывающей и пищевой промышленности, Астана, Казахстан,
[2]Ташкентский химико-технологический институт Ташкент, Узбекистан,
e-mail: nurtore0308@gmail.com

В статье проведено исследование качества и пищевой безопасности экструдированных сухих завтраков, разработанных на основе зерновых культур с добавлением растительных порошков.

Актуальность темы исследования связана с возрастающим спросом населения на функциональные и безопасные пищевые продукты. Несмотря на широкое распространение экструдированных сухих завтраков, содержание витаминов и биологически активных веществ в них зачастую остается недостаточным. В связи с этим повышение пищевой ценности продукции за счет использования натурального растительного сырья представляет научный и практический интерес. Кроме того, влияние растительных порошков на микробиологическую стабильность, физические свойства и витаминный состав экструдированных продуктов в процессе хранения изучено недостаточно, что обосновывает необходимость комплексной оценки качественных показателей таких продуктов.

В качестве основного сырья использовали смесь круп (рисовой, кукурузной и ячменной), а в качестве функциональных компонентов — порошки моркови, свеклы и тыквы. Целью исследования является комплексная оценка влияния растительных порошков и условий хранения на витаминный состав, микробиологическую безопасность и физические свойства экструдированных пищевых продуктов.

Определение содержания витаминов группы В и витаминов группы С проводилось с помощью высокоэффективного метода жидкостной хроматографии, титриметрического и флуориметрического методов в соответствии с требованиями ГОСТ 31483-2012. Микробиологическая безопасность продукта зависит от мезофильных аэробных и факультативно-анаэробных микроорганизмов (МАФАнМ), Е. бактерии coli, дрожжи и плесень оценивались на уровне патогенов. Физические свойства экструдированных продуктов характеризовались параметрами сыпучей плотности, хрупкости и цвета в системе CIELab.

Способствовал увеличению витаминной ценности экструдированного сухого завтрака за счет введения растительных порошков. Содержание витаминов группы В и витамина С в тестовых образцах было выше, чем в контрольной выборке. Высокий рост проявился в витамине С. В течение 3 месяцев в процессе хранения наблюдалось незначительное снижение содержания витаминов, в образцах добавок растительных порошков было выше.

При проведении анализа экспертиз микробиологических исследований показатели микробиологической безопасности на образцах соответствовали санитарно-гигиеническим требованиям. За 3 месяца хранения наблюдалось незначительное увеличение количества микроорганизмов, дрожжей и грибков плесени, значения не превышали допустимых норм.

Анализ физических показателей показал, что насыпная плотность образцов наблюдалась в пределах 0,45-0,49 г/см3, хрупкость-в пределах 29,6-33,1 Н. В процессе хранения менялись физические характеристики, что несколько не влияло на качество продукции.

Использование растительных порошков повысило питательную ценность экструдированного сухого завтрака. Разработанные продукты характеризовались стабильными физическими свойствами, отвечали требованиям безопасности пищевых продуктов, подтверждая безопасное хранение не менее 3 месяцев.

Ключевые слова: экструдированные сухие завтраки, крупы, растительные порошки, рецептура, витаминный состав, микробиологическая безопасность, физические свойства, хранение продукта.

Introduction. According to the studies conducted by Boukid F. and Rosell C.M., changes in modern lifestyles, increasing awareness of healthy nutrition, and continuous technological advancements have transformed breakfast cereals from simple grain-based products into a diverse and widely consumed food category. Today, these products encompass a broad range of ingredients, processing technologies, and product formats, enabling manufacturers to address the nutritional needs and dietary preferences of various consumer groups. In addition, the nutritional value of breakfast cereals has been enhanced through fortification with dietary fiber, proteins, vitamins, and minerals. However, their potential health benefits largely depend on the specific formulation and the nature of the ingredients incorporated into the product. The authors further emphasize the significant influence of technological innovation, globalization of food markets, and the growing consumer demand for plant-based alternatives and clean-label products on the ongoing development of the breakfast cereal sector [1].

Savkina O.A., Lokachuk M.N., and Pavlovskaya E.N. investigated the microbial contamination of raw materials used in muesli production. Their study assessed microbiological safety indicators in both raw materials and finished muesli samples. The results demonstrated that the total count of mesophilic aerobic and facultative anaerobic microorganisms (TAMC) complied with the requirements established by TR CU 021/2011. At the same time, an increased content of mold fungi was detected, highlighting the importance of microbiological monitoring and quality control of raw materials intended for breakfast cereal production [2].

Dzyuba N.A. and co-authors presented the results of comprehensive studies on the organoleptic, physicochemical, and microbiological characteristics of finely ground corn grits used in breakfast cereal manufacturing. The authors provided detailed information on the chemical composition, nutritional value, and quality characteristics of corn grits. To evaluate organoleptic properties, a profiling method was employed, resulting in the development of color, taste, and aroma profilograms. The findings demonstrated that the use of fine corn flakes in breakfast cereal production contributes to an attractive appearance, a pronounced aroma, a pleasant yellow color, and a balanced taste profile of the final product. Furthermore, corn-based ingredients enhance the nutritional value of breakfast cereals by enriching them with B-group vitamins, vitamin PP (niacin), and essential macro- and microelements required for normal human physiological functions [3].

Śliżewska K. and co-authors investigated the microflora of ready-to-eat breakfast cereals available in retail markets and evaluated the influence of packaging on the microbiological quality of these products. The cereal samples examined in the study included both hermetically packaged products and cereals sold in bulk by weight. Microbiological analyses involved the determination of the total count of mesophilic microorganisms, aerobic bacteria and molds, coagulase-positive bacteria belonging to the Enterobacteriaceae family, including *Escherichia coli*, as well as the detection of *Salmonella* and *Shigella* species. The results revealed that the predominant contaminating microflora of cereal products consisted of bacterial spores and mold fungi belonging mainly to the genera *Aspergillus* and *Penicillium*. No coagulase-positive staphylococci, *Salmonella*, or *Shigella* were detected in the analyzed samples. The highest levels of microbial contamination were observed in bulk-

sold cocoa cereal balls and wheat flakes containing rice. Overall, hermetically packaged breakfast cereals exhibited significantly lower levels of microbial contamination, confirming the important role of appropriate packaging in maintaining the microbiological safety and quality of cereal-based products during storage and distribution [4].

Singh R. and co-authors evaluated the storage stability of a ready-to-eat breakfast cereal developed from pearl millet. The researchers formulated and standardized the product, after which storage studies were conducted for a period of three months under ambient conditions (25 ± 2 °C and relative humidity of 65 ± 10%). The breakfast cereal was packaged in 1.36 mm metallized pouches and monitored throughout the storage period. At 15-day intervals, moisture content, water activity (aw), free fatty acid content (FFA), peroxide value (PV), overall acceptability, and microbiological parameters, including yeast and mold counts, were assessed.

The results demonstrated only minor increases in most quality indicators during storage, while the overall acceptability score remained high at 7.29. No significant deterioration of product quality was observed, indicating that the breakfast cereal remained acceptable for consumption throughout the three-month storage period in metallized packaging. Although gradual increases in moisture content, water activity, free fatty acids, and peroxide value were recorded, no substantial changes in sensory characteristics were detected. Furthermore, none of the measured parameters indicated the onset of spoilage, and no yeasts, molds, or significant microbial growth were detected during storage. These findings confirm the microbiological safety and storage stability of millet-based breakfast cereals under the tested conditions [5].

Although breakfast cereals are generally considered microbiologically safe because of their low moisture content, it should be noted that certain ingredients, including cereal grains, dried fruits, and cocoa products, may serve as potential sources of contamination. Among the most significant hazards are mycotoxins, which are secondary metabolites produced by filamentous fungi. To assess the occurrence of these contaminants, 140 breakfast cereal samples collected from the Istanbul market were analyzed using liquid chromatography coupled with mass spectrometry (LC–MS/MS), providing valuable information on the prevalence of mycotoxins in commercially available breakfast cereal products.

The study revealed that 71% of the analyzed samples contained at least one type of mycotoxin. Aflatoxin B1 was detected in 17% of the samples, while total aflatoxins were identified in 31% of the products, with several samples exceeding the maximum permissible limits established by food safety regulations. The authors emphasized the necessity of continuous monitoring of mycotoxin contamination and highlighted the importance of developing regulatory standards that consider the co-occurrence of multiple mycotoxins in food products, as simultaneous exposure may pose additional risks to consumer health [6].

Mardar M. and co-authors investigated the microbiological characteristics of instant breakfast cereals during storage. Product safety was evaluated immediately after production and throughout storage under different temperature conditions and packaging systems. The study examined the influence of flexible packaging, plastic cups with foil sealing, and metallized biaxially oriented polypropylene film (BOPF) packages on the preservation of consumer and microbiological quality attributes. The results demonstrated that the incorporation of natural fortifying additives contributed to an extension of shelf life and effectively inhibited microbial growth. A reduction in the total microbial count was observed in all samples during storage, with the most pronounced decrease (1.5-fold) recorded in products packaged in metallized BOPF bags. The findings further indicated that breakfast cereals packed in metallized BOPF materials could be safely stored for up to 12 months at room temperature and a relative humidity of 60–75%, while maintaining acceptable microbiological quality and consumer properties throughout the storage period [7].

Sá S.V.M. and co-authors reported that

breakfast cereals play an important role in the daily diet of children by contributing to nutrient intake and supporting healthy eating habits. However, the authors also emphasized that children are particularly vulnerable to food contaminants, especially mycotoxins, because of their lower body weight and higher dietary exposure relative to adults. The study investigated the occurrence and bioaccessibility of aflatoxin B1 (AFB1), enniatin B (ENNB), and sterigmatocystin (STG) in breakfast cereal products. An in vitro gastrointestinal digestion model simulating human digestive conditions was employed to evaluate the bioaccessibility of these mycotoxins when breakfast cereals were consumed alone or in combination with milk. The results demonstrated that the bioaccessibility of the investigated mycotoxins increased as the food matrix passed from the gastric to the intestinal phase of digestion. In addition, the presence of milk significantly influenced the release and availability of these contaminants, indicating that food matrix interactions may affect the potential exposure of consumers to mycotoxins present in breakfast cereals [8].

To improve the nutritional value and sensory quality of breakfast cereal products, Edima A.P. and co-authors developed formulations based on yellow maize, soybean, and ripe banana flour. Composite flour prepared from maize and soybean flour in a ratio of 70:30 was blended with banana flour at different inclusion levels ranging from 5% to 25%. The resulting products were evaluated for their proximate composition, vitamin and mineral content, microbiological quality, and sensory characteristics. The findings indicated that increasing the proportion of banana flour led to a reduction in protein and lipid contents, while dietary fiber and carbohydrate levels increased. A slight decrease in the overall energy value of the products was observed. Furthermore, the concentrations of potassium and magnesium increased, whereas vitamin A content decreased and vitamin C content increased with higher banana flour incorporation. Microbiological analyses confirmed that all samples complied with acceptable safety standards. Sensory evaluation revealed that samples F and A received the highest overall acceptability scores among the tested formulations. The authors concluded that the incorporation of banana flour positively influenced both the nutritional characteristics and sensory attributes of breakfast cereal products, thereby enhancing their consumer appeal and functional value [9].

Okoye J.I., Ebeh O.C., and Eze S.I. investigated breakfast cereal products formulated from blends of maize, soybean, and carrot flours, with particular emphasis on their nutritional composition, functional characteristics, microbiological quality, and sensory properties. The study demonstrated that the incorporation of soybean and carrot flours at levels ranging from 5% to 25% significantly enhanced the nutritional profile of the products. Increases were observed in moisture, protein, lipid, dietary fiber, mineral content (Ca, Mg, P, K, Fe, and Zn), and vitamins, including vitamins A, C, B-complex vitamins, and folic acid.

Microbiological evaluation indicated that the total viable microbial count ranged from 0.42×10^4 to 1.14×10^4 CFU/g. No coliform bacteria or fungal contaminants were detected in the analyzed samples, confirming that all products met acceptable microbiological safety standards. The researchers also reported improvements in several functional properties as the proportion of composite flour increased. These included bulk density, water absorption capacity, solubility, gelation characteristics, swelling capacity, and oil absorption capacity, all of which are important quality attributes influencing processing performance and consumer acceptance.

Sensory evaluation revealed that the sample produced from 100% maize flour achieved the highest overall acceptability score. Nevertheless, formulations containing soybean and carrot flours were also highly rated by the sensory panel and demonstrated satisfactory consumer appeal. Based on the obtained results, the authors concluded that the partial replacement of maize flour with soybean and carrot flours effectively improved the nutritional value and functional performance

of breakfast cereal products while maintaining acceptable sensory quality [10].

Kambarova A. and co-authors developed a multicomponent cereal formulation based on rice, buckwheat, oats, and corn with enhanced nutritional and functional properties. The composition of the blend was optimized through computer modeling to achieve a balanced profile of essential amino acids and an appropriate energy value. The technological process included raw material cleaning, sorting, hydrothermal treatment, processing, drying, cooling, milling, and blending. The developed product demonstrated favorable organoleptic characteristics and a balanced nutritional composition, containing 14.43 g of protein, 59.92 g of carbohydrates, and 4.48 g of fat per 100 g of product, with an energy value of 322.74 kcal/100 g. In addition, the cereal blend was a source of B-group vitamins as well as essential macro- and microelements. Microbiological analyses confirmed compliance with established food safety requirements, and the product maintained acceptable quality for up to 4–5 months of storage. These findings indicate its potential application as a nutritionally complete and health-promoting food product [11].

In another study, Daniels G.A. evaluated the sensory characteristics and storage stability of ready-to-eat breakfast cereals fortified with functional enzyme additives, including tolerance phosphatase (TolP) and tolerance lipase (TolL). The organoleptic properties of fortified and control samples were compared in terms of aroma, taste, and texture. The results demonstrated that the incorporation of these enzymes did not adversely affect the sensory quality of the products ($p > 0.05$). Furthermore, the fortified cereal samples exhibited substantially increased mineral bioavailability, with calcium, zinc, and iron levels increasing by 43.3%, 49.7%, and 56.7%, respectively, compared with the control. These findings confirmed the effectiveness of enzyme fortification in improving the nutritional quality of breakfast cereals. Stability studies further revealed that TolP retained its activity for up to 12 months of storage, whereas TolL remained active for approximately 9 months, indicating good long-term functionality of the incorporated enzymes [12].

Materials and Methods. Cereal grains were used as the primary raw materials for the production of extruded breakfast cereals, including rice, corn, and barley groats. The formulation of the cereal base consisted of 65% rice groats, 10% corn groats, and 10% barley groats. A control sample was prepared without the addition of vegetable powders. The formulation of the control sample was identical to that of the cereal base and included 65% rice groats, 10% corn groats, and 10% barley groats. The control sample was produced under the same technological conditions as the experimental samples. Prior to processing, the raw materials were cleaned, sieved, conditioned, and subjected to extrusion.

The cereal raw materials complied with the requirements of the relevant regulatory standards: rice groats according to GOST 6292-93, corn groats according to GOST 6002-2022, and barley groats according to GOST 26312.1-84.

To enhance the nutritional and biological value of the developed products, pumpkin, carrot, and beetroot powders were incorporated as plant-based ingredients. The vegetable raw materials were thoroughly washed, cleaned, and mechanically reduced in size before drying. Convective drying was carried out at a temperature of 55–60 °C until a residual moisture content of 8–10% was achieved. The dried materials were subsequently milled under laboratory conditions to obtain powders with a particle size of less than 0.5 mm. Prior to use, the powders were stored in airtight opaque containers at room temperature to protect them from moisture and light exposure.

Formulations of Experimental Samples. Several formulations of extruded breakfast cereals were developed based on the cereal mixture, differing in the type and proportion of vegetable powder incorporated into the formulation:

Formulation № 1 - 10% carrot powder;

Formulation № 2 - 10% beetroot powder;

Formulation № 3 - 10% pumpkin powder;

Formulation № 4 - 5% carrot powder and 5%

beetroot powder;

Formulation № 5 - 5% carrot powder and 5% pumpkin powder;

Formulation № 6 - 5% beetroot powder and 5% pumpkin powder.

All ingredients were thoroughly blended until a homogeneous mixture was obtained. Prior to extrusion, the cereal blends were conditioned, and the moisture content of the raw material was adjusted to 18%. The mixtures were then held for 20–30 min to ensure uniform moisture distribution throughout the material.

Extrusion processing was carried out using a laboratory-scale single-screw extruder (Model D-PHJ-I, Shandong Honor Automation Technology Co., Ltd., China). The technical specifications of the extruder were as follows: power consumption – 7.3 kW, operating voltage – 380 V, 50 Hz, production capacity – 40–50 kg/h, screw length – 550 mm, and screw diameter – 40 mm.

The extrusion process was performed at a barrel temperature of approximately 170 °C and a screw rotation speed of 180 rpm. During processing, the material was exposed to elevated temperature, pressure, and mechanical shear forces, resulting in starch transformation and the formation of a porous structure characteristic of expanded breakfast cereal products. The extrudates emerging from the die were cooled to room temperature and subsequently packed in airtight containers. The resulting samples were used for further physicochemical and microbiological analyses.

Storage Conditions of the Samples. To evaluate product stability and establish a safe shelf life, the breakfast cereal samples were stored at a temperature of 23 ± 2 °C and a relative humidity of 60–65%. Microbiological and chemical parameters were determined after 0, 3, and 6 months of storage.

The moisture content was determined by the oven-drying method to constant weight in accordance with GOST 15113.4-77.

The content of vitamins (B-group vitamins and vitamin C) was determined using high-performance liquid chromatography (HPLC), as well as titrimetric and fluorometric methods according to GOST 31483-2012.

Microbiological Analysis. The microbiological safety of the samples was assessed using the following indicators:

Total mesophilic aerobic and facultative anaerobic microorganisms (TAMC) – according to GOST 10444.15-94;

Coliform bacteria – according to GOST 31747-2012;

Yeasts and molds – according to GOST 10444.12-2013;

Salmonella spp. – according to GOST 31659-2012;

Escherichia coli – according to GOST 30726-2001;

Staphylococcus aureus – according to GOST 10444.2-94.

All microbiological analyses were performed in accordance with the sanitary and hygienic requirements established for food safety assessment.

Determination of Physical Properties. The physical characteristics of the extruded products were evaluated using the following parameters:

Bulk density – according to GOST 15113.6-77;

Texture (fracturability/crispness) – determined using an instrumental texture analysis method with a texture analyzer;

Color characteristics – determined by the colorimetric method.

All experiments were conducted in triplicate. The obtained data were processed using methods of mathematical statistics. Results are presented as mean values and standard deviations. Statistical analysis of the experimental data was performed using Microsoft Excel software.

Results and Discussion. A comprehensive evaluation of the quality and nutritional safety of the developed extruded breakfast cereals was conducted by assessing their vitamin composition, microbiological characteristics, and physical properties. Particular attention was given to the influence of formulation composition and

storage conditions on these quality parameters. The analyses were performed immediately after production and throughout storage at a temperature of 23 ± 2 °C and a relative humidity of 60–65%.

Microbiological investigations were carried out to determine the sanitary and hygienic safety of the extruded products during storage. In addition, physical characteristics, including bulk density, textural properties, and color parameters, were evaluated as indicators of structural changes occurring in the products throughout the storage period.

The obtained results made it possible to assess the effect of vegetable additives on the nutritional value of the breakfast cereals and to evaluate the stability of their quality and safety indicators during storage.

To determine the nutritional value of the developed extruded breakfast cereals, the contents of B-group vitamins and vitamin C were analyzed. Vitamin determination was performed using high-performance liquid chromatography (HPLC), together with titrimetric and fluorometric methods in accordance with GOST 31483-2012. The results of the vitamin analysis are presented in Figure 1.

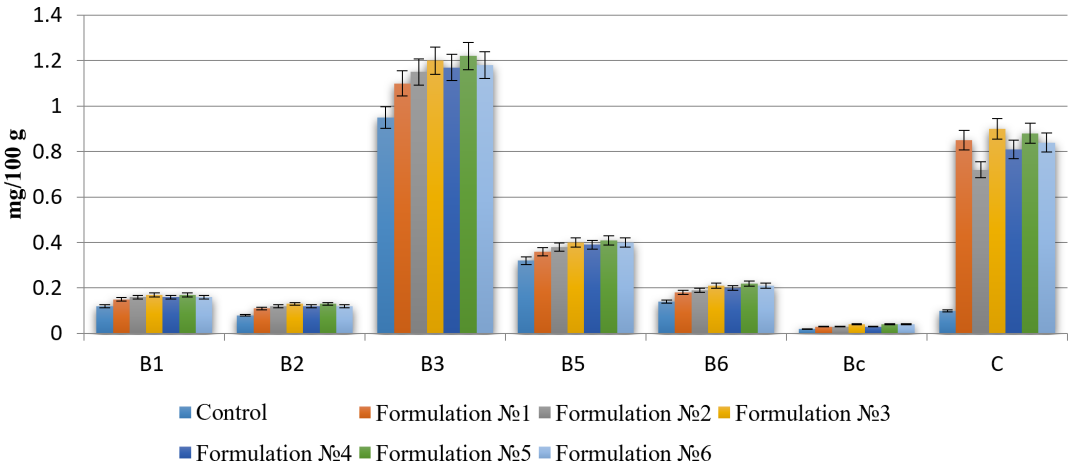


Fig.1 - Changes in vitamin content during 3 months of storage

The incorporation of vegetable powders contributed to an increase in the content of B-group vitamins in the developed extruded breakfast cereals. The concentration of thiamine (vitamin B1) increased from 0.12 mg/100 g in the control sample to 0.15–0.17 mg/100 g in the experimental formulations. A similar trend was observed for riboflavin (vitamin B2), the content of which increased to 0.11–0.13 mg/100 g. The highest concentrations of B-group vitamins were recorded in formulations containing pumpkin powder and combinations of vegetable powders.

A particularly pronounced increase was observed for vitamin C. In the control sample, the concentration of vitamin C was negligible (0.10 mg/100 g), whereas in samples enriched with vegetable powders, its content increased to 0.72–0.90 mg/100 g. This increase can be attributed to the natural presence of ascorbic acid in carrot, beetroot, and pumpkin powders.

Analysis of the data obtained after three months of storage revealed a slight reduction in vitamin content across all investigated samples. Vitamin C exhibited the greatest sensitivity to storage conditions, with losses ranging from approximately 8% to 15%, whereas B-group vitamins decreased by an average of 5–10%. Despite these reductions, samples containing vegetable powders retained considerably higher vitamin levels than the control sample. The results indicate that the incorporation of vegetable powders effectively enhances the vitamin value of extruded breakfast cereals and that the majority of vitamins remain relatively stable during three months of storage.

To evaluate the microbiological stability of the extruded breakfast cereals, the dynamics of

the principal microbiological safety indicators were investigated throughout the storage period. Analyses were performed immediately after production and after three months of storage at a temperature of 20 ± 2 °C and a relative humidity of 60–70%. The obtained results are presented in Table 1.

Table 1 - Dynamics of microbiological indicators of breakfast cereals during storage

Sample	Storage period	TAMC, CFU/g	Coliform bacteria	Yeasts and molds, CFU/g	Salmonella spp.	Escherichia coli	Staphylococcus aureus
Control	0 **months**	1,5×10³	Not detected	1,0×10²	Not detected	Not detected	Not detected
	3 **months**	1,8×10³	Not detected	1,2×10²	Not detected	Not detected	Not detected
Formulation №1	0 **months**	1,4×10³	Not detected	0,9×10²	Not detected	Not detected	Not detected
	3 **months**	1,7×10³	Not detected	1,1×10²	Not detected	Not detected	Not detected
Formulation №2	0 **months**	1,3×10³	Not detected	0,8×10²	Not detected	Not detected	Not detected
	3 **months**	1,6×10³	Not detected	1,0×10²	Not detected	Not detected	Not detected
Formulation №3	0 **months**	1,4×10³	Not detected	0,9×10²	Not detected	Not detected	Not detected
	3 **months**	1,7×10³	Not detected	1,1×10²	Not detected	Not detected	Not detected
Formulation №4	0 **months**	1,3×10³	Not detected	0,8×10²	Not detected	Not detected	Not detected
	3 **months**	1,6×10³	Not detected	1,0×10²	Not detected	Not detected	Not detected
Formulation №5	0 **months**	1,3×10³	Not detected	0,8×10²	Not detected	Not detected	Not detected
	3 **months**	1,6×10³	Not detected	1,0×10²	Not detected	Not detected	Not detected
Formulation №6	0 **months**	1,4×10³	Not detected	0,9×10²	Not detected	Not detected	Not detected
	3 **months**	1,7×10³	Not detected	1,1×10²	Not detected	Not detected	Not detected

The results demonstrated that all investigated samples exhibited low levels of microbial contamination at the beginning of the storage period. The total mesophilic aerobic and facultative anaerobic microorganism count (TAMC) ranged from 1.3 × 10³ to 1.5 × 10³ CFU/g, while the counts of yeasts and molds varied between 0.8 × 10² and 1.0 × 10² CFU/g. In addition, coliform

bacteria, *Salmonella* spp., *Escherichia coli*, and *Staphylococcus aureus* were not detected in any of the analyzed samples.

After three months of storage, a slight increase in the total microbial population was observed. The TAMC values increased to 1.6 × 10^3–1.8 × 10^3 CFU/g, whereas yeast and mold counts rose to 1.0 × 10^2–1.2 × 10^2 CFU/g. Nevertheless, these changes remained well within the permissible sanitary and hygienic limits and did not show statistically significant differences compared with the initial values ($p > 0.05$).

Therefore, the obtained results demonstrate that the developed extruded breakfast cereals maintained their microbiological safety for at least three months under the recommended storage conditions of 20 ± 2 °C and a relative humidity of 60–70%.

The physical properties of the extruded breakfast cereals were evaluated based on bulk density, textural characteristics (fracturability), and color parameters. Analyses were performed immediately after production and at the end of the storage period. Bulk density is one of the key indicators characterizing the structural properties of extruded products, as it reflects the degree of expansion achieved during the extrusion process. The changes in bulk density observed in the investigated samples are presented in Figure 2.

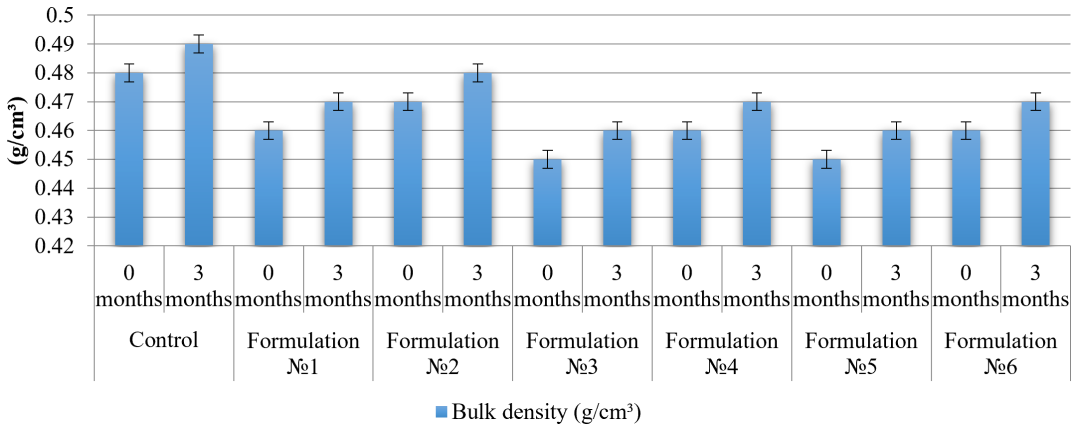


Fig.2 - Changes in the bulk density of extruded breakfast cereals during storage

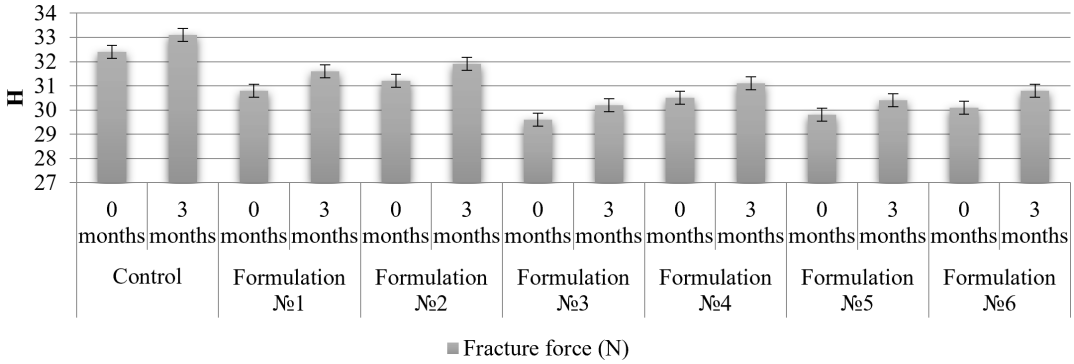


Fig.3 - Changes in the fracturability of extruded breakfast cereals during storage

Analysis of the obtained results showed that the bulk density values of all investigated samples ranged from 0.45 to 0.49 g/cm³. Lower bulk density values were observed in the experimental samples containing vegetable powders, indicating the formation of a more expanded and porous

structure in the extruded products.

During the three-month storage period, a slight increase in bulk density was recorded for all samples. This change may be attributed to partial structural compaction of the products and the redistribution of moisture within the matrix during storage. Nevertheless, the observed increase was relatively small, suggesting that the structural stability of the extruded breakfast cereals was largely maintained throughout the storage period.

The textural properties of the products were evaluated using the fracturability parameter. This indicator characterizes the mechanical strength and texture of extruded products and is closely associated with consumer perception of crispness. The changes in fracturability values observed during storage are presented in Figure 3.

According to the obtained results, the fracturability values of the extruded breakfast cereals ranged from 29.6 to 33.1 N. The control sample exhibited greater mechanical strength, whereas the experimental samples containing vegetable powders showed slightly lower fracture force values. This behavior can be attributed to the influence of vegetable additives on the porosity and textural characteristics of the extruded products.

A slight increase in fracturability was observed after three months of storage. This change indicates an increase in the mechanical strength of the products and may be associated with partial stabilization of the product structure and moisture redistribution occurring during storage.

The color characteristics of the products were determined using the CIELAB color space (L*, a*, b*), which enables objective and quantitative assessment of color changes in extruded products. In this system, L* represents lightness, a* describes the color coordinate ranging from green to red, and b* represents the color coordinate ranging from blue to yellow.

Table 2 - Changes in the color characteristics of extruded breakfast cereals during storage

Sample	Storage period (months)	L*	a*	b*
Control	0 **months**	72,5	1,8	18,3
	3 **months**	71,4	1,9	17,8
Formulation №1	0 **months**	69,4	6,7	21,5
	3 **months**	68,2	6,9	21,0
Formulation №2	0 **months**	64,8	9,6	16,7
	3 **months**	63,9	9,8	16,2
Formulation №3	0 **months**	70,3	5,4	23,1
	3 **months**	69,1	5,6	22,4
Formulation №4	0 **months**	67,2	7,8	20,4
	3 **months**	66,3	8,0	19,9
Formulation №5	0 **months**	68,5	6,2	22,6
	3 **months**	67,4	6,4	22,1
Formulation №6	0 **months**	66,1	8,3	19,2
	3 **months**	65,3	8,5	18,7

Note: L - lightness of the product; a* - color coordinate ranging from green to red; b* - color coordinate ranging from blue to yellow.*

The color characteristics presented in Table 2 were determined in triplicate (n = 3) and are expressed as mean values ± standard deviation. Statistical analysis of the obtained data was performed using Microsoft Excel software. The significance of differences among samples was evaluated at a confidence level of $p \leq 0.05$.

Analysis of the results showed that the L* parameter decreased by approximately 0.8–1.2 units in all samples during storage, indicating a slight darkening of the products. However, these changes were not statistically significant ($p > 0.05$). Higher a* values were observed in the samples containing beetroot powder, which can be attributed to the presence of natural red pigments. In contrast, samples enriched with carrot and pumpkin powders exhibited higher b* values due to the contribution of carotenoid pigments.

Only minor variations in the a* and b* parameters were observed throughout the storage period, with fluctuations ranging from 0.2 to 0.7 units. Statistical analysis demonstrated that most of these changes were not significant ($p > 0.05$), indicating that the color characteristics of the products remained relatively stable during the three-month storage period.

The obtained results demonstrate that the physical and color properties of the extruded breakfast cereals remained largely unchanged during storage. Furthermore, the incorporation of vegetable powders contributed to maintaining the stability of the products' consumer-oriented quality attributes throughout the storage period.

Conclusion. The present study provided a comprehensive evaluation of the nutritional value, microbiological safety, and physical properties of extruded breakfast cereals enriched with vegetable powders. The results demonstrated that the incorporation of vegetable powders significantly improved the vitamin composition of the products. The experimental samples contained higher levels of thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), and folic acid (Bc) compared with the control sample. A particularly pronounced increase was observed for vitamin C. Although its concentration decreased by approximately 8–15% during storage, the vitamin C content in the vegetable-enriched samples remained substantially higher than that of the control. The reduction in B-group vitamins during storage was relatively limited, averaging 5–10%.

Microbiological analyses confirmed that the total mesophilic aerobic and facultative anaerobic microorganism count (TAMC) in all samples remained within the permissible sanitary and hygienic limits throughout the storage period. In addition, *Escherichia coli*, *Salmonella* spp., and *Staphylococcus aureus* were not detected in any of the analyzed samples. Although a slight increase in microbial counts was observed during storage, the recorded values remained well below the established regulatory limits, confirming the microbiological safety of the developed products.

Evaluation of the physical properties of the extruded products revealed that the bulk density of the experimental samples ranged from 0.45 to 0.49 g/cm³, while fracturability values varied between 29.6 and 33.1 N. Slight increases in both bulk density and fracturability were observed during storage, which may be attributed to structural consolidation of the products and moisture redistribution within the matrix. Variations in color parameters (L*, a*, and b*) were also observed and were dependent on the type of vegetable powder incorporated into the formulation.

The scientific novelty of this study lies in the comprehensive assessment of the effects of carrot, beetroot, and pumpkin powders, applied individually and in combination, on the vitamin composition, microbiological stability, and physical properties of extruded breakfast cereals. The findings demonstrated that the incorporation of vegetable powders not only enhanced the nutritional value of the products but also contributed to maintaining the stability of their quality characteristics during storage.

Overall, the obtained results confirm that the use of vegetable powders in the production of extruded breakfast cereals is an effective approach for improving both nutritional quality and consumer-related properties. Furthermore, under the recommended storage conditions, the developed

products can be safely stored for at least three months while maintaining satisfactory quality and microbiological safety.

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Information about the authors

Sultanova M.Zh. - Project manager of Kazakh Scientific Research Institute of Processing and Food Industry LLP, Astana, Kazakhstan, e-mail: sultanova.2012@mail.ru;

Akzhanov N. - Senior researcher of Kazakh Research Institute of processing and food industries LLP, Astana, Kazakhstan, e-mail: nurtore0308@gmail.com;

Saduakas A.S. - Researcher, Kazakh Scientific Research Institute of Processing and Food Industry LLP, Astana, Kazakhstan, e-mail: aykon96@mail.ru;

Kamali A.S. - Junior researcher of Kazakh Research Institute of processing and food industries LLP, Astana, Kazakhstan, e-mail: akerke.kamali@bk.ru;

Dodaev K. - Doctor of Technical Sciences, Professor, Tashkent Institute of Chemical Technology, Tashkent, Uzbekistan, e-mail: Dodaev@rambler.ru.

Сведения об авторах

Султанова М.Ж. - руководитель проекта, ТОО «Казахский научно-исследовательский институт перерабатывающей и пищевой промышленности», Астана, Казахстан, e-mail: sultanova.2012@mail.ru;

Акжанов Н. - старший научный сотрудник, ТОО «Казахский научно-исследовательский институт перерабатывающей и пищевой промышленности», Астана, Казахстан, e-mail: nurtore0308@gmail.com;

Сәдуақас Ә.С. - научный сотрудник, ТОО «Казахский научно-исследовательский институт перерабатывающей и пищевой промышленности», Астана, Казахстан, e-mail: aykon96@mail.ru;

Камали А.С. - младший научный сотрудник лаборатории функционального питания и пищевых концентратов, ТОО «Казахский научно-исследовательский институт перерабатывающей и пищевой промышленности», Астана, Казахстан, e-mail: akerke.kamali@bk.ru;

Додаев К.О. - доктор технических наук, профессор, Ташкентский химико-технологи ческий институт, г. Ташкент, Узбекистан, Dodoev@rambler.ru.