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New grain concentrates with increased biological value in the structure of modern nutrition

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Abstract. Nutrition of modern people is the main controllable factor that determines their state of health, quality of life, efficiency and active longevity. It has been established that excessive consumption of animal fats, simple carbohydrates, table salt and a significant reduction in the diet of vegetables and fruits, which are sources of vitamins, minerals, dietary fibre and minor biologically active substances, results in the development of cardiovascular diseases, metabolic disorders, cancer, etc. Thus, the priority task of scientists and practitioners is to develop products of high biological value as an important factor in preserving human health and disease prevention. The development, introduction into production, and popularisation of such products will optimise the nutritional structure of Ukrainians, overcome the adverse trends in the health of the nation caused by nutritional status disorders, improve the quality of life of the population, and improve the demographic situation in Ukraine. The research substantiates the expediency and necessity of establishing new products with improved properties and provides a list of used additives of natural origin, which are a source of essential nutrients. The results of the conducted tests confirm the optimisation of the chemical composition of new grain concentrates, improvement of their organoleptic properties, and prolongation of shelf life, which indicates the correct choice of prescription components, and their rational ratio. The characteristics of the nutritional and biological value of new grain concentrate Extrapolivitamix enriched with vegetable powders, wheat germ, iodine and raisins are presented. The properties of grain concentrates were explored, and it was proved that they can be included in the group of functional foods due to the correlation of chemical composition. The optimal concentrations of functional ingredients that can be used in new products were determined. New concentrates "Extrapolivitamix" are recommended for industrial production and use in the daily diet

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Introduction

Currently, a significant number of results of comparative analysis of the incidence of chronic non-communicable diseases and diets in many regions of the world have been accumulated. Many nutritional risk factors for cardiovascular diseases, cancer, diabetes mellitus, obesity, and bone and joint damage have been explored, and it has been concluded that the development and progression of most diseases depend on nutrition. Studies conducted by the O.M. Marzeev Institute of Public Health of the National Academy of Medical Sciences of Ukraine state that the diet of the majority of the population of Ukraine is high in calories. The energy value of the diet is satisfied by carbohydrates and fats that come from low-quality foods. Therewith, the countries that have managed to achieve a significant reduction in mortality from cardiovascular diseases over the past 30 years (USA, Australia, Finland), during the development and implementation of prevention programs, placed significant emphasis on changing the nature of nutrition (Bal-Prylypko, Dubina, Baranivskyi, 2012; Danilova, Tkachenko & Vitryak, 2017).

The issue of rational nutrition is complex and large-scale. It – a kind of reflection of the social welfare of the country and the population and is currently not solved in Ukraine, as there is no unified national policy in the field of nutrition. (Antiushko & Bozhko, 2021). The analysis of the nutritional dynamics of different population groups in Ukraine demonstrates significant deviations from the formula of balanced nutrition, primarily in terms of the level of consumption of vitamins, chemical macro- and microelements, biologically valuable nutrients of plant origin and other biologically active substances that are important in maintaining regular metabolism, structure and functions of various organs (Bal-Prylypko, Tolok, Nikolaenko, 2021; Mamenko, 2020). Thus, an unbalanced diet can cause severe disorders in the human body, and the clinical signs of such disorders are individual excess or deficiency of a particular element or compound in the body. Therefore, the prevention and treatment of diseases caused by insufficient intake of necessary biologically active substances – compounds that have a high pharmacological effect in micro quantities are becoming increasingly significant.

The issue of improving the structure of nutrition, quality and safety of food products as the foundation of human life is one of the most crucial nowadays, both within one country and at the international level. The search for alternative ways to solve this extremely important task has brought scientists and practitioners to the idea of the necessity of developing and implementing new, much more advanced technologies of food production, appropriate to the requirements of modern people. The establishment of a new generation of food products and their introduction into the diet of consumers can be performed only based on scientifically sound and proven medical and biological principles, new technologies for processing agricultural and medicinal raw materials into health products and guaranteeing the absolute safety of such products for consumers (Dzyundzya & Burak, 2018).

The issues of healthy nutrition are now dealt with by specialists in numerous scientific fields – technologists, nutritionists, biochemists, microbiologists, etc. A significant contribution to the development of the scientific foundations of the design of food products was provided by domestic and foreign scientists: S.N. Astranov, L.V. Kapreliants, P. Karpenko, V.Korzun, M. Peresichny, O. Cherevko etc.

The problem of developing new functional products is being explored by scientists from the National University of Life and Environmental Sciences of Ukraine, the National University of Food Technologies, the Kyiv National University of Trade and Economics, the Chebotarev Institute of Gerontology of the National Academy of Medical Sciences of Ukraine, the Scientific Center for Preventive Toxicology, Food and Chemical Safety named after Academician L.I. Medved (Nikolaienko & Bal-Prylypko, 2020).

The general conclusion of scientists is that almost all food products consumed by the population can be given functional properties and, thus, make their food into medicine. For this purpose, it is necessary to find natural sources of the most effective functional ingredients, explore the properties of various biologically active components of food (vitamins, mineral elements, polysaccharides, amino acids, fats, etc.) and to develop new technologies for the production of health food products.

The results of observations demonstrate that more than 50% of the population of Ukraine eats poor-quality food. Incomplete quantitative and qualitative composition and unbalanced energy value nutrition contribute to the development of alimentary and alimentary-dependent diseases. The imbalance of modern nutrition and the inability to provide the human body with the necessary amount of essential vitamins and minerals (micronutrients) is a problem that requires the development of new and modernisation of conventional food products with well-defined targeted functional properties. Food technologies of the future – are new raw materials and new properties of conventional raw materials, new ways of converting agricultural raw materials, plant and animal origin into food products, and new food recipes. The development of recipes for new functional products is an urgent and timely issue, as such products provide maximum mobilisation of the adaptive forces of the human body designed to protect against pathological changes under the influence of adverse factors of various origins.

Materials and Methods

Food concentrates are a group of products that have a long shelf life, convenient for transportation, easy to prepare. These are quite conventional products that are popular among a large part of the population, their assortment is a quite limited, and nutritional and biological value often leaves much to be desired. For using them in functional food, it is advisable to improve the recipes by optimising their chemical composition, improving taste characteristics, and extending shelf life. The basic samples were grains – oatmeal, buckwheat, rice and semolina, as conventional for Ukrainian consumers. New grain concentrates for functional food are enriched with several components that have a wide range of useful characteristics.

Thus, it is known that vitamins and minerals are essential components of food, to other components contained in microdoses, but are crucial for human health and longevity. Their deficiency or absence provokes several diseases and pathologies. Thus, it is advisable to additionally enrich new functional products with naturally concentrated compounds that are sources of these

nutrients. In the course of research, discussions and approvals, were identified as enriching recipe components vegetable powders (carrot and pumpkin), wheat germ and raisins.

Vegetable powders are used in therapeutic and prophylactic nutrition due to their active antioxidant and immunomodulatory properties. In addition, wheat germs are becoming popular due to their rich vitamin and mineral composition, they are a source of valuable fats and proteins.

For human health, particularly essential mineral components are a sufficient amount in the diet and optimal absorption of calcium and iodine by the body.

Calcium – is vital for the development of the body, healthy bones and teeth. In the body of an adult, the calcium content is from 1 to 2.2 kg. Approximately 99% of calcium is the base of the human skeleton, while 1% of this mineral circulates in the blood. In addition, calcium is necessary for the contraction of the heart muscles, regulation of the heartbeat and is necessary for the development of blood cells.

The staff of the Nutrition Hygiene Laboratory of the Institute of Gerontology of the National Academy of Medical Sciences of Ukraine established that in different regions of Ukraine, the level of calcium in the diet does not exceed 30-40% of the standard. Lack of calcium results in stimulation of bone resorption. The consequence of long-term calcium deficiency is almost always a decrease in bone mineral density (BMD), which can contribute to an increased risk of osteoporosis in older age.

As a natural calcium enricher of new grain concentrates, in addition to skimmed milk powder, eggshells (pre-processed and ground) are used as a source of calcium carbonate, which is fully absorbed by the body. The chemical composition of the shell is almost identical to that of our bones and teeth. In addition, eggshells stimulate the hematopoietic function of the bone marrow. It contains about 30 other microelements necessary for a person: copper, fluorine, iron, manganese, molybdenum, phosphorus, sulfur, zinc, silicon, etc. Particularly crucial is the significant content of silicon and molybdenum in the shell – without them, the proper course of biochemical reactions in the body is impossible (Watanabe *et al.*, 2019).

One of these biologically active substances is iodine, the lack of which in diets is one of the pathogenic factors of unbalanced nutrition, and endemic goitre and thyroid cancer in adults and children, as its main manifestation, ranks first among non-communicable diseases by regional characteristics and the number of patients living in contaminated areas. Most residents of Ukraine consume only 40...80 μg of iodine per day, while the physiological requirement is 90...300 μg (depending on age, gender, and living conditions) (Motuzka & Koshelnyk, 2019).

In Ukraine and abroad, the problem associated with iodine deficiency in diets was partially solved by iodised salt with potassium iodide. This method appeared to be easy and effective since everyone uses salt in general. However, over time it was understood that using iodised salt does not solve the problem.

Recent studies demonstrate that daily long-term use of iodised salt slightly reduces the incidence of endemic goitre but does not eliminate it. In addition, there are known data on the adverse effects of long-term prophylaxis with iodised salt. For salt iodisation, cheap but volatile iodine compounds are used, which are destroyed during storage and heat treatment (Zheplinska & Mushtruk, 2021).

Attempts to eliminate iodine deficiency by using iodised salt, iodised yeast, starch-iodine complex and other compounds using

chemical iodine have not yielded significant results. In addition, products enriched with inorganic iodine compounds have a pronounced unpleasant taste and smell (Ponomarov, Merzlikina & Gladneva, 2008).

Organic iodine sources are required to eliminate iodine deficiency. Organic iodine – a complex compound of iodine with organic matter (sugar, polysaccharides, amino acids). Organic iodine, unlike mineral iodine, is contained in a bound state and does not enter into most chemical reactions with organic substances in the body.

Iodcasein – iodised milk protein is a yellow powder that is well soluble in water the mass fraction of iodine is 7…9%.

Main properties of iodcasein:

• is based on natural milk protein, which is easily digested;

• provides individual regulation of iodine metabolism in the body;

• iodine is tightly bound to protein and does not degrade during prolonged storage and heat treatment, withstands high temperatures;

• iodine overdose is excluded;

• using as a food additive "Iodcasein" in milk, dairy products, bakery products, etc. does not require material costs for the reconstruction of production due to the scanty amounts of the recommended drug and ease of use (2.5…..5 g/t,);

• using iodcasein does not affect the organoleptic properties of the finished product (Naumenko, Danylenko & Bal-Prylypko, 2020).

The uniqueness of "Iodcasein" is that in case of iodine deficiency, the liver produces enzymes that decompose the milk protein molecule, and iodine enters the human body. When there is enough iodine in the body, the enzymes stop working, and all the remaining iodine is excreted from the body along with protein naturally (Grek, Onopriichuk & Tymchuk, 2019).

Research results

New concentrates of increased biological value "Extrapolivitamix", enriched with wheat germ and dried fruits or vegetables (depending on the recipe) and "Extrapolivitamix-2", additionally enriched with eggshells, are characterised by a high content of vitamins and some minerals.

Grain concentrate "Extrapolivitamix" based on oat or pearl barley flakes "Extra" is characterised by the presence of biologically active ingredients:

- Wheat germ – 15-30%;
- Raisins – 20-30%;
- Vegetable powders – 5-10%.

However, these compositions contain a small amount of iodine (up to 8% of the daily requirement). Therefore, it was decided that some recipes of the developed products of increased biological value should be enriched with iodcasein.

After conducting working tastings of various compositions with using the scoring, the recipes of the concentrate "Extrapolivitamix-2" were obtained (Fig. 1). Therewith, "Extra" oat flakes, wheat germ flakes and raisins were used as the main raw materials.

During the development of new recipes, it was considered that one portion of the finished product enriched with iodine should not exceed 50% of the daily requirement for this trace element, i.e. no more than 60 micrograms for an adult, as a variety of vegetables and fruits, milk, eggs, meat, sea fish, which are based on the diets of the population (including military personnel) contain a specific part of iodine in their composition.

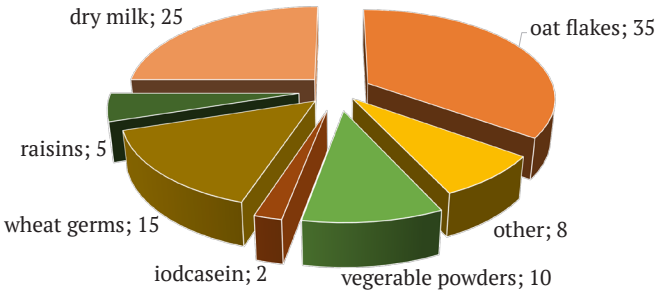

Figure 1. Recipes of "Extrapolivitamix-2" concentrates

Together with the specialists of the Scientific Center for Preventive Toxicology, Food and Chemical Safety named after Academician L.I. Medved, the chemical composition of the new concentrate was explored (Table 1). According to the data in Table 1, the new composition significantly increased the content of such important macronutrients as calcium and potassium in terms of protection of the human body in adverse environmental conditions. The main suppliers of calcium are skimmed milk powder, wheat germ flakes and in some compositions – egg shells. Thus, the calcium content increased almost 7 times (345.2 mg/100g vs 53.25 mg/100g) Potassium content doubled due to the introduction of raisins, dried apricots and partially wheat germ flakes.

Using a new component – iodcasein allowed increasing the iodine content in the new composition by almost 30 times, which is 50% of the daily requirement for this nutrient. Thus, the expediency of using iodcasein in the development of new types of concentrates of dinner dishes of increased biological value for functional purposes has been proved.

Table 1. *Chemical composition of the new concentrate of high biological value*

Indicator name	Oat flakes "Extra"	"Extrapolivitamix-2"
Proteins, %	12.15±0.61	15.52±0.78
Lipids, %	6.24±0.61	5.57±0.28
Carbohydrates Including dietary fibre, %	66.15±3.31 3.56±0.19	51.46±2.57 3.84±0.20
Min. substance, mg/100g Sodium	18.13±0.91	45.80±2.29
Potassium	331.50±16.58	675.2±33.76
Calcium	53.25±2.66	345.2±17.26
Magnesium	128.26±6.41	132.28±6.61
Phosphorus	325.0±16.25	238.8±11.94
Iron	3.65±0.18	4.16±0.20
Iodine	0.04±0.002	1.2±0.06

In addition to micronutrient deficiency, which affects all segments of the population, the results of studies indicating chronic protein deficiency in the diet, in particular, in childhood and the elderly, are alarming (Brovenko & Dzyundzya, 2019). In the new concentrates, skimmed milk powder was introduced into the recipe as the main protein-containing component. However,

considering the rapidly growing interest in the world and Ukraine, in particular, in dairy-free products, the next step of research is planned to use alternative substitutes for cow's milk powder. Among the most important reasons that encourage people to stick to a plant-based diet are the following: caring for animals, improving health, the adverse impact of meat and dairy production on the environment, the safety of such food products, cost, doubts about the reliability of labelling of animal products, etc (Vitorino *et al*., 2020; Kour, Singh & Saxena, 2019).

All varieties of plant milk are low-calorie products that are aqueous emulsions of extracts from nuts, grains, seeds and seedlings of some crops and are positioned as substitutes for natural milk of animal origin for vegans, people with lactose intolerance and simply followers of healthy eating (Bal-Prylypko & Nikolayenko, 2018).

These drinks contain biologically active protein complexes, peptides, free amino acids, lecithin, soluble sugars, dietary fibre, biogenic macro- and microelements, vitamins, phytohormones and other valuable components.

In a study by Pro-Consulting (Gómez-Cortés *et al*. 2019), it is noted that oat and soy milk are the most popular in the Ukrainian vegetable milk market, and local raw materials are used for their production. They are planned to be used as the base for establishing new recipes of grain concentrates for functional purposes.

Conclusions

A healthy diet prevents diseases, increases efficiency and prolongs people's life, while an unbalanced diet, on the contrary, causes many health problems. Therefore, it is timely and expedient to establish new products with improved properties, which both have excellent nutritional properties and have a targeted effect on the functional activity of individual organs, systems and the body in general, stimulating their work with a specific preventive and therapeutic purpose.

New grain concentrates can be included in the group of functional foods due to the correlation of their chemical composition, which allowed compensation for the deficiency of essential macro- and micronutrients necessary for the development, optimal functioning, recovery of the body after diseases and their prevention. The concentrations of functional ingredients used in the new products are close to optimal, physiological ones, thus, such products can be consumed for a long time (ensuring the daily requirement for basic nutrients does not exceed 50%, which allows using the new products in daily nutrition).

Using plant-based milk substitutes will allow the development of new products that, on the one hand, correspond to modern market demands, and on the other hand, will satisfy the body's demand for essential components.

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Нові круп'яні концентрати підвищеної біологічної цінності в структурі сучасного харчування

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Анотація. Харчування сучасної людини є головним керованим чинником, що визначає її стан здоров'я, якість життя, працездатність та активне довголіття. Встановлено, що наднормове споживання тваринних жирів, простих вуглеводів, кухонної солі і суттєве зменшення в раціоні овочів і фруктів, що є джерелами вітамінів, мінеральних речовин, харчових волокон і мінорних біологічно активних речовин, призводить до розвитку хвороб серцево-судинної системи, порушень обміну речовин, онкологічних захворювань тощо. Саме тому пріоритетним завданням науковців і практиків є створення продуктів підвищеної біологічної цінності як вагомого фактору збереження здоров'я людини і профілактики захворювань. Розробка, впровадження у виробництво, популяризація таких продуктів дозволять оптимізувати структуру харчування українців, подолати негативні тенденції у стані здоров'я нації, зумовлені порушенням харчового статусу людини, підвищити якість життя населення, поліпшити демографічну ситуацію в Україні. У статті обґрунтовано доцільність і необхідність створення нових продуктів із поліпшеними властивостями, наведено перелік використаних добавок природнього походження, що є джерелом важливим нутрієнтів. Наведені результати проведених апробацій підтверджують оптимізацію хімічного складу нових круп'яних концентратів, покращення їхніх органолептичних властивостей, подовження терміну придатності, що свідчить про правильність вибору рецептурних компонентів , їх раціонального співвідношення. Наведена характеристика харчової й біологічної цінності нових круп'яних концентратів Екстраполівітамікс, збагачених овочевими порошками, пшеничними зародками, йодказеїном і родзинками. Досліджено властивості круп'яних концентратів, та доведено, що їх можна включити до групи функціональних продуктів харчування завдяки кореляції хімічного складу. Визначено оптимальні концентрації функціональних інгредієнтів, що можуть бути використані в нових продуктах. Нові концентрати «Екстраполівітамікс» рекомендуються для промислового виробництва і використання в щоденному раціоні

Ключові слова: харчування людини, раціональне харчування, функціональні харчові продукти, профілактика захворювань, круп'яні концентрати, екстраполівітамікс, йодказеін, овочеві порошки, пшеничні зародки, рослинне молоко

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Improvement of technology of fish semi-finished products with addition of non-conventional raw materials

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Abstract. Considering the results of studies of the scientific literature on the nutritional value and biological effectiveness of cranberries and goji berries, it was established that the development of technology of semi-finished products with their use is relevant and has practical significance in the technology of fish product production. The technology for the production of moulded fish semi-finished products opens up new opportunities in the field of rational use of secondary fish raw materials, making it possible to expand the range of functional fish products based on natural components, which will to some extent expand the current problem of processing raw materials of inland waters of Ukraine. The purpose of the research is to determine the biological value of new fish semi-finished products based on a combination of freshwater fish and non-conventional raw materials. The research presents the results of studies of the chemical composition, organoleptic evaluation and physicochemical changes of semi-finished products with the addition of non-conventional raw materials and the establishment of their shelf life. It was established that the control sample after 90 days of storage undergoes hydrolytic deterioration, which indicates intensive hydrolysis of lipids and accumulation of free fatty acids in this sample. In experimental samples, hydrolytic deterioration gradually increases and reaches a critical point only by the end of the shelf life. Oxidation processes in lipids of semi-finished products were explored by changes in the accumulation of primary oxidation products – peroxides and secondary products – carbonyl compounds. According to the dynamics of changes in the peroxide number of lipids of semi-finished products, it was established that the control sample during 60-135 days is not subject to storage, and in the experimental samples after 135 days the quality of fat deteriorates and is described as not subject to storage. The authors have established that the developed technology

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of fish semi-finished products will significantly expand the range of functional products based on natural components, which will allow expanding the current problem of processing raw materials in inland waters of Ukraine to some extent

Keywords: fish sticks, non-conventional raw materials, cranberries, goji berries, semi-finished products, organoleptic evaluation

Introduction

In the fishing industry, the rational use of raw materials plays an important role, as the fish comes to production with mechanical damage, different sizes, with defects. The technology for the production of moulded fish semi-finished products offers new opportunities in the field of rational use of secondary fish raw materials and allows expanding the range of fish products (Ivaniuta *et al*., 2021).

Biologically active food substances belong to the natural components of food and have a pronounced physiological and pharmacological effect on the main regulatory and metabolic processes of the body. Therewith, they are an effective way to combat vitamin deficiency (Holembovska *et al*., 2021; Kondratiuk et al., 2021). Biologically active food substances are contained in modern technology of food production of plant raw materials: wild and cultivated berries, which are widespread in the country. In general, wild raw materials should be considered as a source of dietary fibre in the human body.

Nowadays, the enrichment of the daily diet with biologically active substances is a relevant subject. They effectively eliminate the deficiency of vitamins, organic acids and minerals. Eating foods that have adverse effects on our bodies requires reconsideration of the rules of modern nutrition (Manoli *et al*., 2021).

Using non-conventional plant raw materials, such as cranberries, and goji berries and their introduction into the recipe allows for enriching the diet with biologically active substances, obtaining high-quality products with good organoleptic characteristics, and expanding the range of existing dishes (Golembovskaya, 2019).

Quick-frozen convenience foods such as fish cutlets, cakes, meatballs, and others, most often made from minced fish, and a variety of ready meals, hot and cold snacks, are becoming increasingly popular with consumers.

The preparation of conventional minced fish products (cutlets, meatballs, cakes) is almost identical, the main differences are in the recipes of minced mixtures, shape and weight of the products.

Natural cut products include steaks, fillets, schnitzels, kupati, kebabs and others. The range of cutlet mass products includes various types of cutlets and cakes (homemade, moskovskie, beef, etc.), meatballs, zrazy, rolls and others. In the last twenty years, many scientists have proposed a large number of bread substitutes in the cutlet mass, such as grains, vegetables, fruits and their processed products (da Silva *et al*., 2019; Lansing *et al*., 2018).

The problem of finding supplements for chopped masses with specific technological properties and, therewith, high biological value is still relevant. Scientists continue research on improving minced meat production

technologies, finding ways to increase the duration of their storage, improving quality through the introduction of supplements and expanding the range (Fernandez *et al.*, 2019; Cherednichenko & Bal-Prylypko, 2019).

The problem of antioxidant deficiency in nutrition can be solved, through the establishment, of new combined products containing natural mineral and vitamin supplements in the form of vegetables and fruits, and non-conventional plant raw materials (Nikolaienko, M., Bal-Prylypko, L., 2020; Menchynska *et al.*, 2019).

In recent years, after the discovery of the antioxidant properties of some substances (vitamins, bioflavonoids, etc.), some researchers have proved the feasibility of using plant raw materials as the main source of antioxidants in minced products, which allows for extending their shelf life and enriching them with biologically active substances.

The introduction of blanched Menchynska carrots and onions into quick-frozen chopped semi-finished products packed in polymeric materials allows them to be stored at a temperature of -18°C for three months. Scientists explain this fact by the content of antioxidants (carotenoids) in carrots and phytoncides (quercetin, myricetin, kaempferol) in onions (Eveleva & Cherpalova, 2019).

Thus, the introduction of herbal supplements, as a rule, reduces the shelf life of semi-finished products (frozen – up to 1 month), except for those with antioxidant properties.

The purpose of the research is to determine the biological value of new fish semi-finished products (fish sticks) based on a combination of freshwater fish (carp) and non-conventional raw materials (cranberries and goji berries).

By the set purpose, were defined the following *tasks*: development of the recipe composition and technology of semi-finished products from freshwater fish using non-conventional raw materials; investigation of changes in the quality of semi-finished products during storage by organoleptic indicators; conducting a comprehensive assessment of the quality of finished products during storage.

Materials and Methods

The research was conducted in the laboratory of the Department of Meat, Fish and Seafood Technology of the National University of Life and Environmental Sciences of Ukraine.

As the main raw materials in the experimental research were used carp of spring and autumn catch according to DSTU 2284 (2010), which were grown in the reservoirs of PJSC "Cherkasy fish farm", cranberries according to DSTU 5035:2008 and goji berries according to TU U 15.8-00481181-018:2016.

The preparation of samples for organoleptic, physicochemical and microbiological studies was performed according to GOST 7636-85 (1985), and sampling was performed by GOST 7631-85 (1985).

The characterization of the chemical composition of fish semi-finished products was performed by the following methods: the mass fraction of moisture by drying the product sample to a constant mass at a temperature of 100-105°C; the mass fraction of ash – by weight method, after mineralisation of the product sample in a muffle furnace at a temperature of 500-600°C; the mass fraction of lipids by the Soxhlet method; the mass fraction of protein by determining the total nitrogen by the Kjeldahl method. Samples were ashing on Velp Scientifica DK6 series (Italy) and distilled on a Velp Scientifica UDK 129 steam distillation apparatus (Italy).

Results

In the first stages of work, studies of plant raw materials were performed. The results of studies of organoleptic characteristics of cranberries and goji berries are presented in Table 1. The physicochemical parameters of cranberries are presented in Table 2.

Table 1. *Organoleptic characteristics of cranberries and goji berries*

Indicators	Biologically active supplements	
	Cranberry	Goji
Appearance and consistency	the berry is dark red, spherical or ellipsoidal up to 12 mm in diameter, without visible inclusions and impurities.	
Flavour and odour	Juicy, sour	Pleasant juicy, sour flavour with a slightly bitter aftertaste
Colour	From light to dark red colour, homogeneous throughout the mass	Dark red, homogeneous throughout the mass.

Table 2. *Physicochemical parameters of cranberries*

Name of raw material	Dry substances, %	Vitamin C, mg/100 g	Pectini, g	Titrated acidity, %
Cranberry	24.2	7.04	0.84	2.75

The main component of dry substances – sugar. Monosaccharides presented in fruit and berry raw materials are always contained with mineral salts. The content of glucose and fructose in berries is approximately the same, sucrose is practically absent. The chemical composition of cranberries and goji berries is presented in Table 3.

Table 3. *Chemical composition of cranberries and goji*

Indicators name	Cranberry	Goji
Mass fraction of moisture, %	80.9	12
Sugar, %	6.2	-
Pectin substances, %	0.6-3.3	2.4
Fibre, %	1.4-1.6	3.1

Analysing the data presented, it can be concluded that the chemical composition of berries is diverse, depending on the species, variety, germination conditions and harvesting time. In developing the recipes, requirements standards recommended by the WHO FAO have been considered. A sample of semi-finished products made without vegetable supplements was used as a control. The recipe of the control and experimental samples is presented in Table 4.

Table 4. *Recipes of fish sticks with supplements*

Components name	Recipe composition, kg per 100 kg of products		
	Control	Sample 1	Sample 2
Minced fish	78.92	76.92	76.92

Table 4. Continued

Components name	Recipe composition, kg per 100 kg of products		
	Control	Sample 1	Sample 2
Salt	1	1	1
Eggs in minced meat	5	5	5
Bread	8	8	8
Water	5	5	5
Starch	2	2	2
Black pepper	0.06	0.06	0.06
Allspice pepper	0.02	0.02	0.02
Cranberry	-	2	-
Goji	-	-	2

In the production of moulded semi-finished products, the liquid dough was used, the recipe of which is presented in Table 5. Combining freshwater fish raw materials with vegetable raw materials allows for optimising the taste properties of the finished product, biological value and extending the shelf life. To assess the quality of finished products, their chemical composition was explored. The results are presented in Table 6.

Table 5. *Recipe of liquid dough*

Components name	Recipe composition of liquid dough, kg per 100 kg
Flour wheat	32
Starch	5
Salt	1.5
Chicken eggs	3
Water	60

Table 6. *General chemical composition of semi-finished products, % (n=5, p≤0.05)*

Name of indicators	Samples of semi-finished products		
	Control	Sample 1	Sample 2
Humidity content	83.81±2.4	75.04±2.3	69.64±2.7
Protein content	11.9±0.7	18.1±0.9	21.6±0.8
Fat content	3.21±0.22	3.27±0.21	3.24±0,23
Content of mineral substances	1.08±0.14	3.58±0.16	5.51±0.16

According to the analysis of the chemical composition, the humidity content in the samples ranges from 75.04 to 83.81%. The protein content ranges from 11.9 to 21.6%, the lowest content in the control sample. It can be explained by the ratio of raw materials and herbal supplements.

The fat content in the finished preserves ranged from 3.21 to 3.27%, which indicates a positive effect on the taste properties of the product.

The mineral content of the control contains 1.08%. In the experimental samples, their content varies from 3.58 to 5.51%. The test samples differ from the control in mineral content as herbal supplements contain a large number of minerals that enrich the finished product.

To determine the taste properties of semi-finished products, an organoleptic evaluation of the quality of the prototypes was performed during all stages of production before storage. The evaluation was performed on their developed 5-point scale.

The investigation of organoleptic quality parameters of the experimental samples of semi-finished products during the shelf life is presented in Table 7.

Table 7. *Organoleptic evaluation of fish semi-finished products based on vegetable raw materials, points (n=5, p⩽0.05)*

Name of the sample recipes	Shelf life, days	Evaluation of indicators, points				Overall score
		appearance	odour	consistency	flavour	
control	30	4.8±0.4	3.6±0.3	4.6±0.3	4.4±0.4	17.4
	60	4.8±0.4	3.6±0.3	4.6±0.4	3.8±0.3	16.8
	90	4.8±0.4	3.4±0.3	4.4±0.4	3.2±0.3	15.8
	135	4.6±0.4	3.0±0.3	4.0±0.3	2.6±0.3	14.2
	180	4.4±0.3	2.6±0.2	3.8±0.3	1.6±0.3	12.4
Sample 1	30	4.2±0.3	4.8±0.4	3.8±0.3	5.0±0.4	17.8
	60	4.4±0.4	4.8±0.4	3.8±0.3	4.8±0.3	17.8
	90	4.6±0.4	4.8±0.3	3.8±0.3	4.6±0.4	17.8
	135	4.4±0.3	4.6±0.3	3.8±0.3	4.4±0.4	17.2
	180	4.2±0.3	4.6±0.4	3.6±0.3	3.8±0.3	16.2
Sample 2	30	4.8±0.4	4.8±0.3	4.4±0.4	4.6±0.3	18.6
	60	4.6±0.4	4.8±0.4	4.2±0.3	4.6±0.4	18.2
	90	4.2±0.3	4.8±0.4	4.2±0.3	4.6±0.3	17.8
	135	4.4±0.3	4.4±0.3	4.0±0.3	4.4±0.4	17.2
	180	4.2±0.3	4.0±0.3	4.0±0.3	3.8±0.3	16.0

The data of Table 7 demonstrate that according to organoleptic indicators during 180 days of storage, all products had a uniform ruddy crust on the surface, and retained their shape. The odour of samples 1 and 2 were rated significantly higher than the prototype, in particular, sample 2 due to the presence of spices in its recipe. The odour of the prototype after storage for 90 days is characterised as specific, and fishy. The degree of accumulation of fatty acids as a result of hydrolytic decomposition of lipids of semi-finished products was explored by changing the acid number of lipids. The results of the research are presented in Fig. 1.

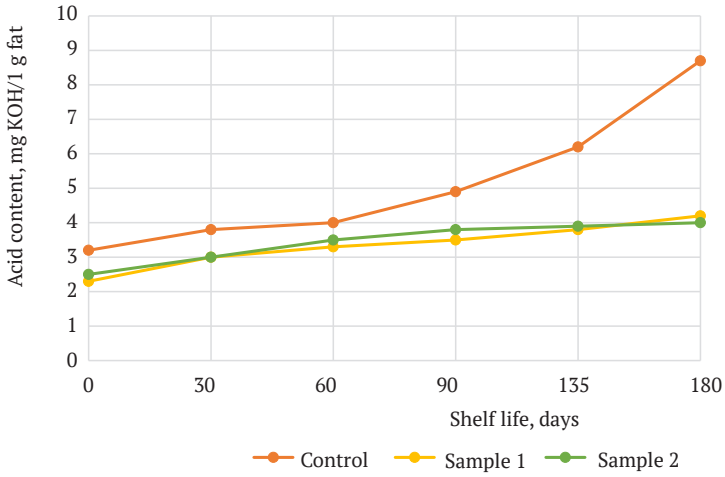

Figure 1. Dynamics of the acid number of lipids of semi-finished products

The data of Fig. 1 demonstrate that changes in the acid number of lipids of semi-finished products during storage for 180 days at a temperature of minus 18°C have a linear upward trend.

Acid numbers of lipids in the control sample after 90 days of storage reach 4.0 mg KOH/1 g of fat and continue to increase, indicating intensive lipid hydrolysis and accumulation of free fatty acids in these samples. The acid number of the lipids of samples 1, and 2 gradually increases during the 180 days of storage and only reaches 4 mg KOH/1 g fat at the end of the storage period (180 days).

Oxidative processes in lipids of semi-finished products were explored by changes in the accumulation of primary oxidation products – peroxides and secondary products – carbonyl compounds. The results of studies of changes in the lipid peroxide number of semi-finished products during storage are presented in Fig. 2.

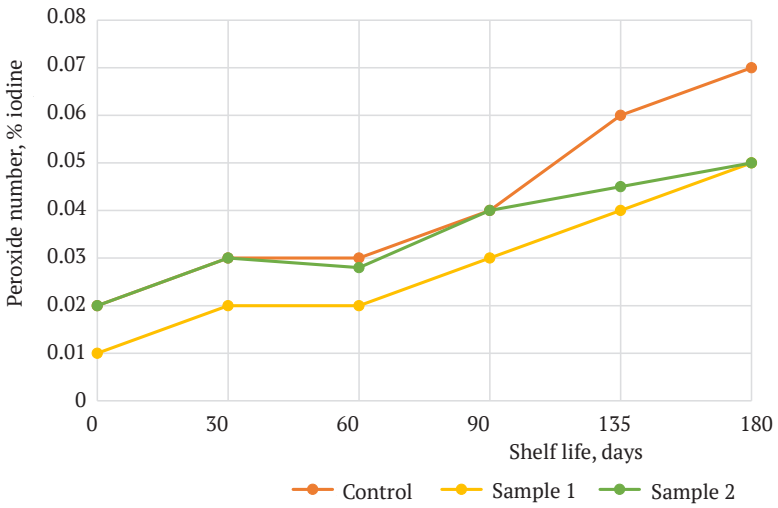

Figure 2. Dynamics of lipid peroxide number of semi-finished products

In the experimental samples, the accumulation of primary oxidation products was the slowest compared to the control. It is explained by the fact that the control samples of fish sticks contain more fat than the experimental ones, due to the high content of fish raw materials in the recipe.

Conclusions

The developed technology of fish semi-finished products will significantly expand the range of functional products based on natural components, which will, to some extent, expand the current problem of freshwater fish processing. The positive results obtained indicate the continuation of the study of this technology and require further development.

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Удосконалення технології рибних напівфабрикатів із додаванням нетрадиційної сировини

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Анотація. З огляду на результати досліджень наукової літератури щодо харчової цінності та біологічної ефективності ягід журавлини та годжі, встановлено, що розроблення технології напівфабрикатів із їхнім використанням є актуальною й має практичне значення в технології виробництва рибних продуктів. Технологія з виготовлення рибних формованих напівфабрикатів відкриває нові можливості в галузі раціонального використання вторинної рибної сировини, дає можливість розширити асортимент рибних продуктів функціонального призначення на основі природних компонентів, що дасть змогу певною мірою розширити актуальну проблему перероблення сировини внутрішніх водойм України. Метою проведених досліджень є визначення біологічної цінності нових рибних напівфабрикатів на основі поєднання прісноводної риби та нетрадиційної сировини. У статті представлені результати досліджень хімічного складу, органолептичної оцінки та фізико-хімічних змін напівфабрикатів із додаванням нетрадиційної сировини та встановлення їхнього терміну придатності. Було встановлено, що в контрольному зразку після 90 діб зберігання проходять процеси гідролітичного псування, що свідчить про інтенсивний гідроліз ліпідів і накопичення вільних жирних кислот у цьому зразку. У дослідних зразках поступово збільшується гідролітичне псування й лише до кінця терміну придатності досягає критичної точки. Окиснювальні процеси в ліпідах напівфабрикатів вивчали за змінами у накопиченні первинних продуктів окиснення – перекисів і вторинних продуктів – карбонільних сполук. За динамікою змін перекисного числа ліпідів напівфабрикатів встановлено, що контрольний зразок упродовж 60-135 діб не підлягає зберіганню, а в дослідних зразках після 135 діб якість жиру погіршується та характеризується як той, що не підлягає зберіганню. Авторами було встановлено, що розроблена технологія рибних напівфабрикатів, значно розширить асортимент продуктів функціонального призначення на основі природних компонентів, що дасть змогу певною мірою розширити актуальну проблему перероблення сировини внутрішніх водойм України

Ключові слова: рибні палички, нетрадиційна сировина, ягоди журавлини, ягоди годжі, напівфабрикати, органолептичне оцінювання

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Factors of transformation of the dairy subcomplex of the agro-industrial complex of Ukraine

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Abstract. One of the main ways to overcome the existing problem of providing the country's population with proteins of animal origin is, among other things, to increase the production and consumption of milk and dairy products. Based on this, consideration of the existing problems of the functioning of the dairy subcomplex of the agro-industrial complex of the country is extremely relevant. The purpose of the study is to assess the current state of the subcomplex and to develop practical recommendations for improving the efficiency of its functioning. The research was based on the application of methods: analysis and synthesis, induction and deduction, factor and economic and statistical comparative analysis, analytical and logical generalisations, etc. In contrast to the existing positive trend of growth in milk production in the world, in dairy farming in Ukraine, there is a constant reduction in the number of cows and milk production. Over the past 10 years alone, the number of cattle in the country has decreased by 1.952 million heads, including cows by 0.958 million heads, and milk production in 2020 amounted to 9.263 million tons of milk (17.64% less than in 2010). There was a reduction in the number of milk processing enterprises. Thus, in 2020, there were only 192 of them left (of which 178 worked) or only 29.86% of their number in 1990. All this resulted in the fact that the actual consumption of milk per capita in 2020 was only 53.13% of the scientifically based standards of consumption of milk and dairy products. According to the results of the research, it was established that the decrease in the number of cows, without considering the growth of their productivity in farms of all categories, reduced the production of dairy raw materials. The results of the research allow identifying the main factors that affect the reduction in the production of milk and its derivatives. After analysing the state and trends in the development of dairy farming, it can be argued that the increase in the production of quality and safe milk and its supply for processing requires the cooperation of farms

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and households. Together, they can ensure the stability of production of the necessary volumes of milk, appropriate quality and safety and ensure the supply of significant volumes of raw materials to large processors. Possible areas and innovative technologies of animal husbandry and milk production and processing require further research

Keywords: dairy farming, dairy industry, raw milk, milk processing, dairy market

Introduction

Milk and dairy products are valuable food products, the world consumption of which is constantly growing, both in connection with the general growth of the world population and in connection with the increase in their consumption in certain countries (China, Vietnam, etc.), which is associated with the growth of living standards of the population of these countries. According to research by IFCN experts, the growth of world milk production in 2019 was mainly due to India, Oceania, Africa and the Middle East (Vasylieva, Vinichenko & Katan, 2019). However, this growth was 1.4% and was significantly lower than the long-term average (2.3%).

In 1990, Ukraine ranked 6th in the world ranking of milk-producing countries, with milk production of 24.5 million tons. In 2020, the country ranked 22nd in the world ranking (among 123 countries – major milk producers (producing 98% of world production) (Cherevko, 2012; Cortés *et al.*, 2019). The reasons for such a current state of affairs in the dairy subcomplex of the agro-industrial complex of Ukraine and trends in its functioning require more research.

The comprehensive study, evaluation and analysis of the state of enterprises of the dairy subcomplex of the agro-industrial complex of Ukraine and the prospects for their development are considered in the works of many scientists. Among the studies are the works of N. Belinska, P. Berezivskyi, V. Boyko, I. Yevseyeva, M. Ilchuk, T. Mostenska, N. Oliadnychuk, M. Parkhomets, V. Radko, P. Sabluk, N. Shiyan, I. Fedulova and many others (Bhogal *et al.*, 2018; Atamurodov *et al.*, 2022). These scientists researched important issues on the development of the feed base, breeding work, conditions of keeping the dairy herd, optimisation of the organisational and economic mechanism of the subcomplex enterprises functioning and ensuring the growth of their competitiveness. However, dynamic changes in the global and domestic markets and the introduction of modern innovative products require constant identification and clarification of trends in the development of enterprises of the subcomplex to develop effective tools for managing their functioning and competitiveness.

The purpose of the study is to assess the current state of the dairy subcomplex of the agro-industrial complex of Ukraine, trends and factors of its transformation, and to develop practical recommendations for stabilising and improving the efficiency of its functioning and competitiveness.

Materials and Methods

The performed research was based on the application of methods: analysis and synthesis, induction and deduction, analytical and logical generalisations, etc.

Results

The results of the conducted research demonstrate that the root cause of the current state

of affairs in the dairy subcomplex of the agro-industrial complex of Ukraine is the existing trends in dairy cattle breeding, namely the reduction in the number of cows and milk production. Thus, at the beginning of 2021, the total number of cattle in Ukraine amounted to 2.874 million heads, which is 7.1% less than at the beginning of 2020 (Table 1). Therewith, the number of cattle in agricultural enterprises decreased to 1.008 million heads, and the number of dairy cows decreased, respectively, to 423.9 thousand heads, which is 2.6% less than at the beginning of 2020. All this has ensured that the adverse trend of a decline in the number of dairy farms (DFs), averaging 4.3% per year, and a decline in milk production, averaging 2.3%/year, continues, in contrast to the current positive trend in global milk production growth.

Table 1. *Dynamics of cattle population and cow productivity in Ukraine (end of the year) (Feniak, 2020; Vasilchenko, 2021)*

	1990	2010	2015*	2016*	2017*	2018*	2019*	2020*	2020/2010 yr.%
Cattle, thousands of head:	24 623	4826	3884	3750	3683	3531	3092	2874	59.55
Including cows thousand heads	8 378	2631	2167	2109	2018	1919	1788	1673	63.6
Milk yield per cow, kg of farms of all categories	2863	4082	4644	4735	4820	4922	4976	5129	125.6
Average annual milk yield of kg of milk from one cow in agricultural enterprises	2941	3975	5352	5643	6025	6190	6101	6634	166.9

Source: *excluding the temporarily occupied territory of Crimea, Sevastopol and part of the temporarily occupied territories in Donetsk and Luhansk regions*

Therewith, households at the beginning of 2021 reduced the number of cattle to 1.865 million heads, including the number of dairy cows to 1.249 million heads or by 6.4% compared to 2020 (Lysenko, 2014). Thus, the reduction of cattle and cows in households is faster than in cattle farms. Thus, it should be noted that the quantitative indicators of cattle and cows in private households raise some doubts since, for various reasons, the identification of livestock in them has not yet been completed, although the state should have ensured its implementation before 2015.

Analysis of the data in Table 1 allows concluding that only in the last 10 years the number of cattle in the country has decreased by 1.952 million heads, including cows by 0.958 million heads, which indicates the stability of the adverse trend in the development of meat and dairy cattle and in the volume of milk supply to processing enterprises (Table 2).

The reduction in the number of cows, despite their growing productivity in farms of all categories (on average by 2% per year), decreased the production of quality raw milk (Tables 1 and 2). Thus, according to the results of the research, in 2020 Ukraine produced 9.263 million tons of milk (7.1% less than in 2019). Among them, 2.761 million tonnes (1.2% more) were produced by agricultural enterprises and 6.502 million tonnes (6.3% less) by households

(Chernyakov, Usacheva & Chernyakova, 2021; Zadorozhna, 2014). All this reduced the actual per capita milk consumption by 2.2%, which is 2020 amounted to only 53.13% of the scientifically based standards of milk and dairy products consumption.

Table 2. *Dynamics of milk production and processing in Ukraine, (Feniak, 2020; Vasilchenko, 2021)*

Indicators	2010	2015	2016	2017	2018	2019	2020	2020 by 2010 years, %
Milk production, thousand tonnes	11249	10615	10382	10281	10064	9963	9 263	82.34
The total amount of milk supplied to processing enterprises, including thousand tonnes:	4793	4251	4183	4348	4179	3868	3299	68.8
from enterprises, ths. tonnes	2193	2744	2512	2689	2720	2750	2566	117.12
from the population, ths. tonnes	2544	1346	1198	1239	1089	870	733	28.8
The level of marketability, %	42.6	40.0	40.2	42.3	41.2	38.8	35.61	83.6
Milk consumption per capita, kg/year	206.4	209.9	209.5	200.0	197.7	200.5	201.9	97.8

The largest amount of milk in 2020 was produced in the Poltava region – 734.2 thousand tons (3.2% less than in 2019), Vinnytsia region (728.4 thousand tonnes, 4.6% less) and Khmelnytskyi region (651.5 thousand tonnes, 2.5% more). The lowest volumes of milk production in 2020 were demonstrated in Luhansk, Donetsk and Zaporizhzhia regions. The results of the analysis of the dynamics of milk production volumes allow concluding that there was a transformation of the raw material base of the dairy industry both in terms of volumes and quality of milk supplied to processing enterprises (Tables 2 and 3). If 10 years ago the ratio of milk volumes supplied by different categories of producers for processing to dairy processing enterprises was about 50:50, in 2020 the share of households in the total volume of milk transferred to processing enterprises was only 22.8%.

Table 3. *Dynamics of the quality structure of milk received for processing from agricultural enterprises in 2020, %% of the total volume (Feniak, 2020; Vasilchenko, 2021)*

Year	Extra	Top quality	First quality	Second quality	Non-quality
2010	4.4	31.3	59.3	4.1	0.9
2015	10.3	35.2	49.6	4.7	0.2
2017	16.4	36.7	37.9	8.7	0.3
2018	21.6	38.1	32.9	7.1	0.3
2019	27.2	35.9	32.3	3.7	0.2
2020	34.6	34.2	30.4	0.6	0.2
2020 to 2010, %	7.46 times	109.26	51.26	14.6	22.2

Source: *(Feniak, 2020; Vasilchenko, 2021)*

Thus, there was a rapid reduction in the volume of supplies for processing low-quality, but cheap milk from farms that are unable to compensate agricultural enterprises by increasing the supply of quality raw materials.

Therewith, the quality and safety of milk supplied for processing by agricultural enterprises are steadily increasing. According to the results of the analysis, there was an increase in the share of "extra" and "first quality" milk (Table 3). Thus, the share of raw milk of "extra" quality in the total volume of milk received for processing increased from 27.2% in 2019 to 34.6% in 2020. However, the share of "top" quality milk decreased, respectively, from 35.9% to 34.2% and "first" quality – from 32.3% to 30.4%. The share of "second" quality decreased sharply from 3.7% to 0.6%.

Therewith, notably, there was a leap in milk quality in households, but only "on paper". The share of second-quality milk supplied for processing by households decreased from 83.2% to 18.4%, while the share of first-quality milk, on the contrary, increased from 12% to 79.9% without any significant changes in the technology of milk production, storage and delivery (Petrichenko, 2018a; Petrichenko, 2018b). Thus, dairy processing enterprises, in conditions of shortage of raw materials, could not refuse to accept milk from households for processing and, thus, are trying to "perform" the requirements of the new legislation on the quality and safety of milk, through a "mix" of milk received from households and agricultural enterprises.

It is confirmed by the fact that in Ukraine sanitary control of milk quality is conducted only in 14.8% of households engaged in milk production (Kovalchuk, 2021). Therewith, milk quality control is performed only in 8.4% of households that cultivate 0.5 hectares of land or less, 17.1% of households – with an area of 0.51-1 hectares and 28.3% of households – with an area of land of more than 1 hectare.

Table 4. *Dynamics of the number and capacity of milk processing enterprises in Ukraine*

	1990	2000	2007	2010	2014	2019	2025 (forecast)	2019 to 1990,%
Number of enterprises, units	643	447	354	287	252	192	157	29.86
Total production capacity, million tonnes	18.6	13.9	13.46	12.7	12.0	9.8	8.1	52.69
Average capacity, thousand tonnes	28.9	31.1	38.02	44.2	47.6	51.04	51.6	176.6

The results of the research demonstrate that if the current adverse trends in the dynamics of milk production and supply for processing continue, 1-2 large milk processing enterprises will disappear in Ukraine every year. And it is confirmed by the results of the analysis of changes in the number of milk processing enterprises and their total processing capacity (Table 4). Thus, if at the end of 1990, there were 643 processing enterprises in the country, in 2020 there were only 192 (of which 178 were operating) or only 29.86% of their number in 1990 (Udomkun *et al*., 2020; Breus & Yevtushenko, 2022). However, notably, mainly old low-capacity enterprises were closed. The result of this feature was an almost twofold increase in the average production capacity of milk processing enterprises. However, these capacities, due to the lack of raw materials, are used on average by 30-40%.

The results of the analysis of the functioning enterprises demonstrate that the 80 most powerful milk processing enterprises, currently, produce 75-85% of domestic dairy products from whole milk. The owners of these enterprises invest heavily in the modernisation of production, improving the quality of dairy products, monitoring and promptly responding to changes in market conditions, and constantly improving and expanding the range of products to optimise the production process and increase production volumes and profits. The problem of adapting milk and dairy products production in Ukraine to European requirements, which became particularly urgent after the annexation of Crimea and the loss of the russian market, pushes them to do it. The desire to enter the markets of the EU, CIS, Asia and Africa stimulates the enterprises of the dairy subcomplex of the agro-industrial complex to increase the volume of production that is competitive in these markets.

Although, if considering the development of competitiveness of domestic dairy processing enterprises and their products in the world and domestic markets, then, admittedly, for a processor who wishes to export its products profitably, it would be economically feasible to have one modern enterprise with a capacity of at least 500 thousand tonnes of milk processing per year. However, the establishment of such an enterprise in Ukraine requires the availability of an appropriate raw material zone for it based on the establishment of 5-6 modern dairy farms with a population of 10 thousand cows each and their productivity at the level of 10 tonnes of milk per cow per year.

The results of the research allow identifying abnormal heat and the loss of a specific amount of fodder among the factors that influenced directly or indirectly the reduction in milk production during 2020. As a consequence, there was a significant increase in fodder prices (December 2020 to December 2019) for feed wheat by 57%, feed maize by 82%, sunflower meal by 126% and soybean meal by 74%. A significant problem in dairy farming is the insufficient amount of fodder to ensure balanced diets for cows. In the author's opinion, the growth of fodder prices will continue in the coming years as the global trend of rising prices for energy, fertilisers and agricultural products continues. From this, it can be concluded that further rise in grain prices will increase the price of mixed fodder, and therefore the production of meat and milk will remain low-profit or may even become unprofitable.

Therewith, the rise in fodder prices reflects on the cost of production of livestock products and increases prices. Thus, milk prices in 2020 were: extra – 12.15 UAH/kg, top – 11.7 UAH/kg, first – 11.08 UAH/kg. The weighted average price – 11.64 UAH/kg. The range of fluctuations in prices for medium and large batches of extra milk by region was: north and centre – 11.7-12.45 UAH/kg; south – 11.7-12.45 UAH/kg; east – 11.6-12.4 UAH/kg; west – 11.6-12.35 UAH/kg. The results of the analysis demonstrate that in Ukraine the prices for extra and premium milk are higher than in some EU countries. It results in the fact that domestic dairy products have a low level of competitiveness in foreign markets.

Ukraine has a huge potential in dairy production, and sustainable development of this industry is possible, but subject to the availability of cheap and long-term loans, appropriate professional education, and stable national policy on the conditions of functioning of the dairy subcomplex of the agro-industrial complex. Notably, in 2018, the state programme for fattening young cattle in private farms was launched

by the Resolution of the Cabinet of Ministers of Ukraine of February 7, 2018, No. 107 "On approval of the Procedure for using funds provided in the state budget to support the livestock industry". This resolution provided budgetary assistance to households on a non-refundable base for raising young animals to 13 months of age for 2500 UAH/head. However, in 2019, the population began to be massively denied subsidies, and in 2020 they were completely cancelled.

The development and stable functioning of the dairy farming and dairy processing industry require significant investments. Thus, to increase the number of cows to 2.1 million heads by 2030, and milk production – up to 11 million tonnes and, therewith, to process 9 million tonnes, it is necessary to invest UAH 9-11 billion annually in the industry. The state should actively participate in this, using the EU model as an example, where up to 50% of producers' costs are compensated by the state. For this purpose, with the restoration of the Ministry of Agrarian Policy, it is necessary to design a strategy for the development of dairy farming and dairy processing industry, which would include state support for breeding and genetic renewal of the herd, state participation in investing in the construction of new and reconstruction and modernisation of existing dairy complexes, development of cooperation of various forms, farming, development of infrastructure for cold logistics, etc. In reality, by abolishing the special VAT regime for agricultural producers in 2017, the government undertook to allocate at least 1% of the "agrarian" GDP for state support programs for the agro-industrial complex by 2021 – i.e. about UAH 7 billion. However, not a single year since this decision was made, the total amount of state support has not corresponded to the declared amounts, and only UAH 4.5 billion is planned for 2021.

As for the issues of increasing the production of quality and safe milk and its supply for processing, the future belongs to the cooperation of farms and households. By uniting, they can ensure the stability of production volumes, quality and safety of milk, and work with large processors. It is confirmed by the analysis of the experience of Poland, where there are about 200 thousand family farms with an average number of 10 cows. Thus, with a total number of cows of about 2 million and an average productivity of 6.5 tons per year, the country produces 13.5-14.6 million tons of milk per year and ranks 6th in Europe and 13th in the world. The price of Polish raw milk is 9-11% lower than the European average and 5% lower than the world average. The price of Polish raw milk is 9-11% lower than the European average and 5% lower than the world average.

Conclusions

The main factors of transformation of the dairy subcomplex of Ukraine include: a reduction in the number of cows, insufficient amount of quality raw milk and its non-compliance with EU regulations and standards, low technological level of milk production, insufficient control over the quality of raw materials, lack of modern equipment, high capital and labour intensity of production processes, rising prices for energy and other resources, reduced consumption of dairy products due to low purchasing power, increased competition in the world market.

Adverse factors that hinder the development and stable functioning of the subcomplex are:

- low level of investment attractiveness of the subcomplex due to the long payback period of investments and insufficient level of state support for its functioning and development;

- the necessity to allocate significant areas of agricultural land for fodder crops,

hayfields and pastures, which is quite problematic for livestock enterprises in the conditions of land market opening.

The problems of the functioning of the dairy processing subcomplex of the agro-industrial complex can be solved through the implementation of the "Concept of state support for livestock breeding for 2021-2023" and the "National Strategy for the development of the dairy industry 2021-2030", developed by the Ministry of Economy in dialogue with industry associations.

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Фактори трансформації молокопродуктового підкомплексу АПК України

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Аннотація. Одним із основних напрямів подолання існуючої проблеми забезпечення населення країни білками тваринного походження є, в тому числі, збільшення виробництва і споживання молока та молочних продуктів. Виходячи з цього, розгляд існуючих проблем функціонування молокопродуктового підкомплексу АПК країни є дуже актуальним. Мета дослідження є оцінка сучасного стану підкомплексу та розробка практичних рекомендацій щодо підвищення ефективності його функціонування. Виконані дослідження базувались на застосуванні методів: аналізу і синтезу, індукції та дедукції, факторного та економіко-статистичного порівняльного аналізу, аналітичних та логічних узагальнень тощо. На відміну від наявної позитивної тенденції зростання обсягів виробництва молока у світі, в молочному скотарстві України відбувається постійне скорочення поголів'я корів та обсягів виробництва молока. Тільки за останні 10 років поголів'я ВРХ в країні скоротилось на 1,952 млн. голів, у тому числі, корів на 0,958 млн. голів, а виробництво молока на і у 2020 р склало 9,263 млн т молока (на 17,64 % менше, ніж у 2010 р). Відбулася скорочення кількості молокопереробних підприємств. Так у 2020 р їх залишилося лише 192 (з яких працювало 178) або лише 29,86 % від їх кількості у 1990 р. Все це призвело до того, що фактичне споживання молока на душу населення у 2020 р склало всього 53,13 % від науково-обґрунтованих норм споживання молока та молочних продуктів. За результатами дослідження встановлено, що зниження поголів'я корів, не враховуючи зростання їх продуктивності у господарствах усіх категорій, призвело до зменшення обсягів виробництва молочної сировини. Результати досліджень дозволяють визначити основні чинники, які впливають на скорочення обсягів виробництва молоко та його похідних. Проаналізувавши стан та тенденції розвитку молочного скотарства можна стверджувати, що збільшення обсягів виробництва якісного та безпечного молока й поставку його на переробку потрібна кооперація фермерських господарств та господарств населення. Об'єднавшись, вони можуть забезпечити стабільність виробництва необхідних обсягів молока, відповідної якості та безпечності та забезпечити поставку значних обсягів сировини великим переробникам. Подальшого дослідження потребують можливі напрямки та інноваційні технології утримання тварин та виробництва і переробки молока

Ключові слова: молочне скотарство, молочна галузь, молочна сировина, переробка молока, ринок молочної продукції

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Influence of biochemical properties of raw materials on the change of quality of salted fish products

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Abstract. According to the state of development of the fishery industry of Ukraine and increasing requirements for the quality of food products, it is relevant to address issues of preventing losses of fish products from spoilage of microbial origin, protecting them from oxidation, ensuring proper quality, safety and competitiveness of finished products sold on the Ukrainian market**.** The purpose of the work is to study the influence of the biochemical properties of raw materials on the change in the quality of salted fish products. The research explores the influence of the biochemical properties of raw materials on the change of quality of salted fish products packed in a modified environment. The main reasons for the deterioration of the quality of salted fish products are described. Possible areas for increasing the stability of salted fish products during storage are presented. The level of activity of tissue proteolytic enzymes is one of the main factors that characterise the maturation rate of salted fish, and the mass fraction of fat can determine the degree of influence of carbon dioxide on muscle tissue during storage. Accordingly, the results of the study of the initial fish raw materials, namely the mass fraction of fat and enzymatic activity of muscle tissue are presented. It was established that fish raw materials had significant differences in both the mass fraction of fat and enzyme activity. The results of studies of the physical and chemical parameters of salted fish

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products packed in a modified environment are presented. Initial composition of the gas mixture: 40% CO_2 and 60% N_2. High-barrier bags were used for packaging. The results of the experimental studies demonstrated that in terms of changes in quality indicators, the packaging of salted fish in a modified environment is most effective for products from non-fat raw materials with low total acidity and proteolytic enzyme activity. The practical value of the scientific work is to develop promising areas for improving the sustainability of salted fish products by using modified environments. Despite a significant amount of scientific research in the field of packaging, systematic studies of such products have not been conducted, thus, the practical application of modified environments raises the greatest number of questions for manufacturers regarding the reliable sustainability of products

Keywords: fish raw materials, salted fish products, biochemical parameters, modified environment

Introduction

The deterioration of the quality of salted fish products can be considered based on several compositional and environmental factors (Ivaniuta *et al*., 2021; Mazur *et al*., 2013).

Environmental factors include temperature, presence of packaging and modified environment, including modified gas environment (O_2, CO_2, N_2) and vacuum. Compositional factors (Kolyanovska *et al*., 2019; Zheplinska *et al*., 2021) include salt concentration, preservative, number of microorganisms, pH, and water activity.

One of the promising areas for increasing the sustainability of salted fish products is using modified environments during packaging and storage. Despite a significant amount of scientific research in the field of packaging, systematic studies of such products have not been performed, thus the practical application of modified environments and the influence of biochemical properties of raw materials on the change in the quality of salted fish products is an urgent subject of scientific research.

Analysis of recent studies and publications. The following scientists made a significant contribution to the study of technological factors affecting the change in the quality of salted fish products during storage: V.I. Shenderiuk, V.P. Lisova *et al.* (Golembovskaya, 2019).

The packaging process is of great significance in the production of salted fish products, which significantly affects the preservation of quality and economic indicators of production. Research in the field of packaging in modified environments of fish products was performed by the following foreign scientists: S. Knoechel, N. Huss, L. Gram, P. Masniyom and others (Holembovska *et al*., 2021; Sukhenko *et al*., 2019).

In the works of Devlighere, it was demonstrated that the degree of inhibition of microorganisms growth in the atmosphere of MGE is determined by the concentration of solubility in the product of CO_2. The concentration of CO_2 in food depends on the fat and water content and the partial pressure of CO_2 in the atmosphere. However, at high concentrations of oxygen dioxide in the package, and higher water content in the product, the appearance of a sour taste in the surface layer of meat is possible (Eveleva & Cherpalova, 2019).

Numerous studies have demonstrated the efficiency of packaging fish products in a vacuum and modified atmosphere (Palamarchuk *et al*., 2020; da Silva *et al*. 2019; Lansing *et al*. 2018).

Studies by V.P. Lisova demonstrated that using synthetic films for packaging salted herring under a vacuum significantly delayed

the process of fat oxidation (Fernandez *et al.*, 2019; Zheplinska *et al.*, 2020).

Thus, the results of the review of scientific literature demonstrate the prospects of using a modified environment in the technology of production of salted fish products.

The purpose – explore the influence of biochemical properties of raw materials on the change in the quality of salted fish products packed in modified environments during storage.

Material and Methods

The following fish species were used for the study: Baltic cod (Gadus morhua callarias), Atlantic herring (Clupea harengus), Baltic herring (herring) (Clupea harengus membras), Baltic sprat (Sprattus sprattus balticus), pink salmon (Oncorhynchus gorbuscha), Atlantic mackerel (Scomber scombrus), Atlantic salmon (Salmo salar). To obtain a given mass fraction of salt (4.2-4.5%), mixed salting of fish divided into fillets (except sprat and herring) and carcasses (sprat, herring) was performed. The mass fraction of preservative in the products was 0.02%. A mixture of sodium benzoate and potassium sorbate in a ratio of 1:1 was used. After salting, the skin was removed from the fish (except for sprat and herring) and packed in the form of fillets in high-barrier bags. After packing, the bags were filled with a modified gas environment on a vacuum machine. Initial composition of the gas mixture: 40% CO_2 and 60% N_2. High-barrier bags were used for packaging.

The mass fraction of lipids by the Soxhlet method, which consists in weighing the fat after its solvent extraction from a dry sample in a Soxhlet apparatus, is based on the determination of the change in the mass of the sample after the extraction of fat with a solvent.

Water activity (aw) was determined on the LabMaster-aw device by the hygrometric electrolytic method. Active acidity (pH) was determined according to GOST 28972-91 (1991). Canned and processed fish and non-fish products.

The mass fraction of sodium chloride was determined by the argentometric method according to GOST 7636-85 (1985). Fish, marine mammals, marine invertebrates and their products.

The activity of proteolytic enzymes of muscle tissue was determined by the intensity of amine nitrogen accumulation (mg/100 g of tissue per min).

Results

The method of establishing an oxygen-free environment in the package with salted fish (vacuum or modified gas environment consisting of carbon dioxide and nitrogen) affects the biochemical processes that occur in the experimental salted fish during storage. Table 1 presents data on fat content and activity of tissue proteolytic enzymes in the feedstock.

Table 1. *Characteristics of raw materials*

Fish species	Mass fraction of fat, %	Enzymatic activity, μg of nitrogen per 1 g of muscle tissue, min
Mackerel	25.3 ± 0.12	0.23 ± 0.01
Salmon	14.2 ± 0.14	0.11 ± 0.02
Herring	12.3 ± 0.05	0.22 ± 0.03
Salaca	6.3 ± 0.04	0.08 ± 0.01
Sprat	4.9 ± 0.02	0.37 ± 0.02
Pink salmon	4.1 ± 0.06	0.07 ± 0.01
Cod	0.6 ± 0.04	0.06 ± 0.01

As Table 1 demonstrates, the fish raw materials used for the studies had significant differences in both the mass fraction of fat (0.6-25.23%) and enzyme activity (0.07-0.37 μg nitrogen/g/min). The highest activity was observed in muscle tissue enzymes of sprat, mackerel and herring, and the lowest – was in cod and pink salmon.

The physicochemical characteristics of fish after posting are presented in Table 2.

Despite the close values of the mass fraction of salt, the differences in water activity for the investigated fish species are quite significant, due to their different fat content and, consequently, different moisture content. It is essential to consider a wide range of active acidity (pH).

Table 2. *Physicochemical parameters of salted fish products*

Fish species	Mass fraction of sodium chloride, % in muscle tissue	Concentration of sodium chloride, % in the water phase	pH, unit			aw, unit
			0-day	40th day		
				v/p	MGE	
Salmon	4.3 ± 0.1	6.2 ± 0.1	6.20 ± 0.01	6.1	6.07	0.946 ± 0.003
Mackerel	4.2 ± 0.3	7.2 ± 0.3	6.18 ± 0.03	6.16	6.15	0.946 ± 0.002
Pink salmon	4.3 ± 0.2	5.4 ± 0.2	6.16 ± 0.02	6.1	6.15	0.959 ± 0.003
Herring	4.4 ± 0.3	6.1 ± 0.3	6.21 ± 0.01	6.2	6.26	0.953 ± 0.001
Salaca	4.2 ± 0.1	5.4 ± 0.1	6.60 ± 0.03	6.39	6.42	0.961 ± 0.002
Sprat	4.1 ± 0.2	5.3 ± 0.2	6.60 ± 0.01	6.34	6.36	0.963 ± 0.001
Cod	4.2 ± 0.2	5.5 ± 0.2	7.10 ± 0.02	7.02	7.01	0.969 ± 0.001

On the 40th day of storage, the pH values of muscle tissue of most types of products (except pink salmon and salmon) packed in modified media were lower, and the total acidity was higher than in samples in vacuum packaging. Such data along with the dynamics of oxygen changes in the package can explain the specific biochemical and microbiological processes of pink salmon and salmon. Perhaps the increased pH value of raw materials was one of the reasons for the earlier onset of organoleptic spoilage of salted fish in vacuum packaging.

Thus, considering the results of the conducted research, packaging of salted fish in MGE (CO_2 – 40%, N_2 – 60%) is the most effective in terms of changing the quality indicators for products from non-fat raw materials with low total acidity and low activity of proteolytic enzymes, which in this research includes herring and cod.

Conclusions

As a result of the research, the highest activity of muscle tissue enzymes was established in sprat (0.37), mackerel (0.23) and herring (0.22), the lowest – in cod (0.06) and pink salmon (0.06).

It was established that the lowest fat content was detected in cod (0.6), and the lowest – in mackerel (25.3).

It has been proved that packaging in modified media is most suitable for herring and cod, as they are the least fatty and have low indicators of total acidity of proteolytic enzyme activity.

Based on the results obtained, the ways of further research were determined: to explore the influence of the mass fraction of salt on the change in the quality of salted herring packed in modified environments during storage.

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Вплив біохімічних властивостей сировини на зміну якості малосоленої рибної продукції

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Анотація. Відповідно до стану розвитку рибного господарства України та підвищення вимог до якості харчової продукції актуальним є вирішення питань спрямованих на попередження втрат рибної продукції від псування мікробного походження, захисту їх від окислення, забезпечення належної якості, безпечності та конкурентоспроможності готової продукції, що реалізується на ринку України. Метою роботи є дослідження впливу біохімічних властивостей сировини на зміну якості малосоленої рибної продукції. У статті досліджено вплив біохімічних властивостей сировини на зміну якості малосоленої рибної продукції, упакованої в умовах модифікованого середовища. Охарактеризовано основні причини погіршення якості малосоленої рибної продукції. Наведено можливі напрями підвищення стійкості малосоленої рибної продукції під час зберігання. Рівень активності тканинних протеолітичних ферментів – це один з основних чинників, що характеризує швидкість дозрівання соленої риби, а масова частка жиру може визначати ступінь впливу вуглекислого газу на м'язову тканину в процесі зберігання. Відповідно, представлено результати дослідження вихідної рибної сировини, а саме масової частки жиру та ферментативної активності м'язової тканини. Встановлено, що рибна сировина мала значні відмінності, як за масовою часткою жиру, так і активністю ферментів. Представлено результати досліджень фізико-хімічних показників соленої рибної продукції, упакованої в умовах модифікованого середовища. Вихідний склад газової суміші: 40 % CO_2 і 60 % N_2. Для пакування використовувалися високобар'єрні пакети. Результати проведених експериментальних досліджень показали, що з погляду зміни якісних показників, пакування солоної риби в умовах модифікованого середовища є найефективнішим для продукції з нежирної сировини з низькою загальною кислотністю та активністю протеолітичних ферментів. Практична цінність наукової роботи полягає в розробці перспективних напрямків підвищення стійкості малосоленої рибної продукції за рухунок використання модифікованих середовищ. Незважаючи на значний обсяг наукових досліджень в області пакування систематичні дослідження такої продукції не проводилися, тому практичне застосування модифікованих середовищ викликає у виробників найбільшу кількість питань, що стосуються надійного забезпечення стійкості продукції

Ключові слова: рибна сировина, малосолена рибна продукція, біохімічні показники, модифіковане середовище

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Study of the efficiency of using beet syrup in products based on the principles of nutrition

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Abstract. The relevance of this research is to provide the population with food products that, when consumed regularly or excessively for a long time, have not caused any health problems. Thus, the purpose of the work was to use beet syrup and beets in the technology of kinds of ketchup and sauces based on the principles of nutrition. Standard research methods were used to achieve the results. The practical value of the scientific work is the development of food products for healthy nutrition, environmentally and medico-biologically safe, high nutritional value with reduced sugar, salt, high fibre and protein content, and low energy value. The research substantiates the usage of beet syrup and beet in ketchup technology, and the advantages of the developed recipes for human health. In addition, the physicochemical composition of beet syrup, which contains 93.5% of dry matter, the composition and content of beet syrup sugars (glucose, fructose, sucrose, maltose), the total sugar content is 48.8 g/100 g, which is 50.2 g/100 g less than that of regular sugar. The ratio of prescription ingredients established by experimental experiments on organoleptic indicators is substantiated. The water activity index was explored, which is 0.92 for sample No. 2, 0.93 for sample No. 1, and 0.935 for the control sample, which will positively affect their shelf life. Studies of the chemical composition demonstrated that the protein content in sample No. 1 increased by 33%, in sample No. 2 – by 56% compared to the control sample; sugar content decreased by 42.7% in sample No. 1 and by 50.6% in sample No. 2; vitamin C content increased, fibre content increased 3 times, the developed products are enriched with iron, phosphorus, potassium. The Nutri-score calculation demonstrated that the developed samples according to recipes No. 1 and No. 2 belong to categories A and B and are more balanced and useful for human health, which indicates the high nutritional value of the products. The energy value of the developed samples exceeds the control one. The energy value (kcal/100 g) of sample No. 1 is 100, sample No. 2 – 89.5, control sample – 104

Keywords: ketchups, sauces, healthy food, technology, sugars, nutritional value

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Introduction

The subject of a healthy lifestyle and healthy eating is developing rapidly. The diet of a modern person is designed to ensure that foods have low-fat content, reduced sugar content, and minimal salt content, are enriched with fibre, vitamins, and macro- and microelements, and have a reduced energy value.

Tomato ketchups and sauces are particularly popular among consumers, namely for cooking fast "street" food, and at home, catering establishments, and restaurants they are widely used.

Nowadays, before buying products, consumers first pay attention to the composition of the product, which provides information about its quality and safety.

The population of Ukraine began to actively explore food ingredients, their benefits and properties, more closely monitor the correct diet and care about their health. Therefore, the presence in food products of flavours, preservatives, artificial colours, substances with high-fat content, and carbohydrates does not attract a significant part of consumers. Despite the shortage of time of modern man, the search for products that belong to healthy food is a priority.

Nowadays, ketchup is one of the most popular sauces in the world. Ketchup, produced industrially, is a homogeneous sauce obtained either from pure, fresh, ripe tomatoes, from which the skin and pips have been removed or from tomato derivatives, including concentrates, with the addition of vinegar, sugar, salt, aromatic ingredients and their extracts, such as onions, spices and permitted additives (Villas-Boas & Zhao, 2020; Zheplinska *et al.*, 2020).

It is ingredients such as distilled vinegar, high fructose corn syrup, salt, onion powder, and artificial flavours, can cause some health problems if consumed in excess over a long period.

Classic ketchup contains almost 4 g (approximately 1 teaspoon) of free sugar, which is considered a significant amount that should be reduced. According to the current recommendations for daily sugar intake, adults should get less than 5 per cent of their daily calories from sugar, which is almost 25 g but the sugar in ketchup is often even worse than table sugar (sucrose) as it is in the form of fructose and this can cause weight gain and insulin resistance and result in obesity, diabetes, heart disease and weakened immune system, etc (WHO, 2015; Zolfaghari *et al.*, 2020).

1 tablespoon of ketchup contains 160 mg of sodium, which is 7% of the recommended daily value. This salt can cause conditions such as high blood pressure, mineral imbalances in the body and toxicity to body systems. Tomato ketchup does not contain protein, fibre, vitamins and minerals. Therefore, apart from its taste characteristics, this sauce has no health benefits (Nasir, Hussain and Jabbar, 2015; Świąder et al., 2018).

Tomatoes are rich in citric and malic acid. When too much of these acids accumulate in the stomach, the body will be flooded with compounds that cause heartburn or acid reflux. People suffering from gastroesophageal reflux disease are not recommended to eat more tomatoes than the recommended dose per week (Villas-Boas & Zhao, 2020; Saric *et al.*, 2016).

The classic recipe of ketchup has several drawbacks, which have an adverse effect on human health. Thus, the improvement of this recipe in social and technological terms should be based on the maximum satisfaction of consumers' demands and the production of

high-quality healthy sauce of a new generation, environmentally and biologically safe.

Beet syrup, as organic beet sugar, was developed in France and implemented in agro-industrial companies. Dark syrup with a good vegetable taste having a small caramel note is ideal for making sauces and marinades. It is characterised by significant nutritional value and the number of mineral elements. In addition, the syrup is used to sweeten dairy products, desserts, organic gingerbread, and organic beer. The technology proposed in this work is being tested for the first time in Ukraine (Kryzhova & Deyak, 2021; Topchiy *et al.*, 2020).

The purpose of the research – to improve the technology of ketchups and sauces by using beet syrup and beets based on the principles of nutrition.

Materials and Methods

The determination of organoleptic, physicochemical, functional-technological, and structural-mechanical parameters of ketchup and sauce was performed using standard research methods. The humidity content was determined by the arbitration method, the active acidity (pH) was determined using the Combo pH meter, the sugar content in beet syrup and ketchup was determined by the high-performance liquid chromatography (HPLC) method, the dry matter content was determined using the RHW25Brix/ATC refractometer, protein content was determined on the VELP Scientifica (Italy) by the Kjeldahl method, fat content was determined on the SOX 406 fat analyser (China) by the Soxhlet method, water activity was determined on the Rotronic HygroPalm (Switzerland), vitamin C was determined on the spectrophotometer by the method of high-performance liquid chromatography at a wavelength of 265 nm, fibre content – on the FIWE Raw Fiber Extractor (Italy) by the Weende method, based on the dissolution of components other than cellulose in sulfuric acid and potassium hydroxide, colour determination – on the Cm-5 spectrophotometer Konica Minolta Sensing Europe, determination of consistency – by rheometer MR301, energy value – by calculation, Nutri-score – by calculation method on the analysis of 100 g of product, considering the content of nutrients and ingredients to be preferred or restricted.

Results

The development of beetroot ketchup and sauce will eliminate the deficiency of vitamins, micro- and macroelements and other essential substances, and establish new healthy food products with reduced sugar and salt content.

Ketchup according to the classical technology belongs to the category “Extra” and is made from fresh tomatoes/tomato products, salt, sugar (or sweeteners/sugar substitutes), and aromatic components without the addition of fruit/vegetable ingredients, oil and preservatives.

The process of making beet ketchup does not differ from tomato ketchup in terms of manufacturing technology. However, its development considers the principles of nutrition: it contains a minimum amount of sugar, reduced salt content, and is enriched with nutrients.

Modern trends in the nutrition of a person seeking to have a healthy lifestyle and eat healthy food require the consumption of foods with reduced energy value, with a minimum amount of fat, sugar, salt, increased amount of protein, vitamins and minerals, fibre, which improve digestion, absorption and metabolism.

In the current economic and social situation, food companies are increasingly paying attention to using non-conventional sources of sugar, which is more beneficial for the health

of consumers. One such source is beet syrup – a by-product of beet processing into sugar.

It is a viscous, dark-coloured syrup consisting of fermented sugars (sucrose, glucose, fructose) and non-sugar substances originating from compounds that do not precipitate during the purification stage, and substances obtained as a result of chemical or enzymatic reactions during processing (Hobbs *et al.*, 2012; Filipčev *et al.*, 2010).

Beet syrup is characterised by a high dry matter content. The sugar-free part of beet syrup covers macronutrients and micronutrients such as potassium, sodium, calcium, magnesium, iron and copper and several important bioactive compounds (Gujral, Sharma & Singh, 2002; Liliana & Oana-Viorela, 2020).

Beet syrup contains a significant amount of potassium (about 3.6%). Minerals in the syrup are dissolved and, thus, can be easily absorbed in the body. It is a source of antioxidants and an ingredient in functional foods (Dyakonova & Stepanova, 2015).

One of the most valuable compounds in beet syrup is betaine. It promotes proper homocysteine metabolism and thus reduces the risk of several non-communicable diseases (Ljubiša *et al.*, 2016; Ponder and Hallmann, 2018).

Beet syrup has a caramel taste, caramel smell and bitterness compared to other sugars/sweeteners, less sweet than honey, sucrose, and inverted sugar. Only beetroot syrup contains vitamins and small amounts of minerals.

Beet syrup is an alternative to artificial colours, corn syrup, and sugar.

To achieve the purpose of the scientific work, the main ingredients of ketchup and syrup are tomatoes and beets, as a sweetener – beet syrup, to extend the shelf life – white vinegar, to enhance the aroma and taste of the product – salt, ginger and garlic.

Beetroot is an excellent source of vitamins A, K, C and E, and minerals, B vitamins, contain a group of highly bioactive pigments known as betalains, a source of phytochemicals, vitamin C and fibre, important minerals such as manganese and potassium.

Functional and technological properties of the product depend on the physical and chemical parameters of the syrup, for which the moisture content, dry matter and pH were determined (Table 1).

Table 1. *Physico-chemical parameters of beet syrup*

The test sample	Humidity content, %	Dry substances content, %	pH
Beet syrup	6.5	93.5	8-8.2

The obtained results of the dry matter content and the value of active acidity (pH) in beet syrup correspond to the provisions of the standard for it. The composition and sugar content in beet syrup was determined by high-performance liquid chromatography (HPLC) (Table 2).

Table 2. *Composition and sugar content of beet syrup, g/100 g*

Content	Fructose	Glucose	Sucrose	Maltose
	13.99	14.18	20.39	0.20

According to the research results, it was established that the main part of the sugar content is sucrose – 20.39 g/100 g. Glucose and fructose contain almost the same amount.

Studies have demonstrated that the total sugar content is 48.8 g/100 g, which is 50.2 g/100 g less than regular sugar.

Establishing new recipes for healthy food, the ketchup in the "Extra" category was taken as a control sample, the recipe of which included tomatoes, vinegar, water, salt, sugar, ginger, and garlic. The recipe of the developed sample No. 1 included the same ingredients, but sugar was replaced with beet syrup, sample No. 2 was made with a complete replacement of tomato with beet, and sugar with beet syrup.

The ratio of recipe components for the explored samples 1 and 2 was chosen according to organoleptic parameters. Particular attention was devoted to the texture of ketchup. According to the consistency of the control sample, the added amount of tomatoes/beets, water and beet syrup in the test samples was adjusted. The developed samples differed significantly from the control sample in colour by using beets and beet syrup, which significantly changed it.

As a result, the established ratio of ingredients for the developed recipes was derived by experimental experiments and demonstrated the best combination with all other components of the recipe and the high consumer properties of the finished ketchup and sauce.

Sample No. 1 according to the results of organoleptic indicators had a higher score than sample No. 2. Both samples acquired a darker colour due to the addition of beet syrup, and when using beet as the main raw material in sample number 2, it had a dark red colour and differed in its taste characteristics, but the sweet-sour taste inherent in the control sample was preserved in both samples. All three samples had the same consistency – a thick, homogeneous mass.

It is known that there is a correlation between the moisture content of food and its storage: more bound water is less able to support the processes that spoil food, namely the growth of microorganisms and hydrolytic chemical reactions. Other factors can have a stronger impact on product spoilage. It is such an indicator of water activity that can be measured and used to assess the condition of water in food and its influence on chemical changes.

The explored water activity parameters of the samples are presented in Figure 1.

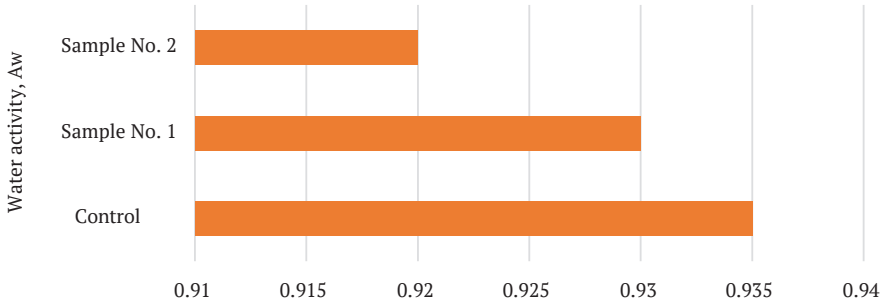

Figure 1. Water activity index of the tested samples

Studies have demonstrated that the water activity index in sample No. 2 is lower than in other samples, which gives grounds to assert that the sauce is more resistant to the development of adverse chemical reactions in the product and will positively affect its shelf life.

Chemical composition and functional and technological indicators are significant for determining the value and quality of the product (Fig. 2, 3).

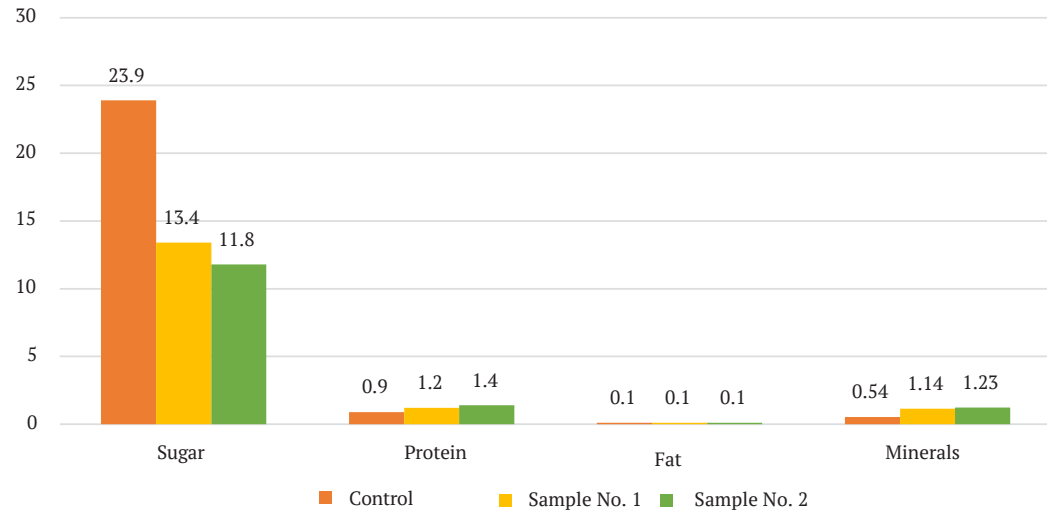

Figure 2. Chemical composition of the tested samples, g/100 g

Studies of the chemical composition demonstrated that the content of protein and minerals in samples No. 1 and No. 2 is higher compared to the control sample, which confirms the correctness of the selected recipe ingredients and their ratio: the protein content in sample No. 1 increased by 33% and in sample No. 2 by 56% compared to the control. And most significantly, the purpose of the work to reduce the sugar content in the developed samples by 42.7% in sample No. 1 and 50.6% in sample No. 2 was achieved.

To confirm other positive characteristics of the developed products, the content of vitamin C and fibre was explored (Table 3).

Table 3. *Vitamins and minerals, 100 g of product*

Content	Control	Sample No. 1	Sample No. 2	Recommended daily amount
Chrome	0.02	0.02	0.08	0.12
Mangan	0.00003	0.00003	0.00018	0.0003
Vitamin C, mg	0.006	0.007	0.008	0.012
Fibre, g	0.48	0.55	1.5	3.0

According to the recommended daily amounts of vitamins and minerals, their amount is significant in the chemical composition of ketchup and sauce. For quick recognition, at a glance, of the quality of food products, in European countries (France, Belgium, Spain, Germany), the front side of the package is marked with a colour scale and a letter.

Using such labelling on food packaging helps consumers easily switch to a healthier diet.

The formula for calculating the Nutri-score, based on the analysis of 100 g of product,

considers the nutrients for limited consumption (the number of sugars, saturated fats, salt, low energy value) and useful substances (the amount of protein, fibre, vegetables, fruits, nuts, rapeseed, nut, olive oil). This additional labelling identifies the nutritional value of the product on a scale from A to E. In this case, the healthiest products are rated in categories A and B (dark green), and the least healthy products belong to categories D and E (dark red). Products included in category C (light orange) have average nutritional value.

To classify the tested samples into five categories of food quality, indicated on a colour scale from dark green to dark red, together with the letter from A to E, Nutri-score was calculated (Table 4).

Table 4. *Nutri-score for the tested samples*

Sample	Negative points	Positive points	Evaluation	Colour	Letter
Control	6	1	5	Light orange	C
Sample No. 1	3	1	2	Green	B
Sample No. 2	3	4	-1	Dark green	**A**

According to the results obtained, it can be concluded that the Nutri-score of the tested samples, in which beet syrup and beet were added, is higher than the Nutri-score of ketchup, where the main raw materials are tomatoes and sugar.

According to the calculated Nutri-score, the formulations for samples No. 1 and No. 2 are more balanced and beneficial for human health, as they belong to categories A and B. These two categories indicate a high nutritional value of the product and a significant amount of nutrients such as fibre and protein.

As for the control sample, it belongs to category C, such a product should be consumed in moderation due to a significant amount of salt, sugar and insufficient protein and fibre.

In addition, the energy value of the developed samples was calculated, which is, kcal/100 g of product: for sample No. 1 – 100, for sample No. 2 – 89.5, for the control sample – 104, which confirms the advantage of the developed samples over the control sample.

Conclusions

According to the literature review, such ingredients as beet syrup and beetroot were chosen in the technology of ketchups for healthy eating.

1. Optimisation of the recipe allowed the development of experimental samples of beet ketchup and sauce with the addition of beet syrup in different amounts and the complete replacement of tomatoes with beets.

2. Studies have established that the developed samples are enriched with protein, fibre, phosphorus, potassium, iron and vitamin C, and have a lower sugar and salt content, which indicates a higher nutritional value compared to the control sample of classic ketchup. In addition, using beet syrup and beetroot provided a higher Nutri-score of the product, the formulations for samples No. 1 and No. 2 belong to the category Nutri-score A and B. These two categories indicate a high nutritional value of the product and a significant amount of nutrients such as fibre and proteins.

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Дослідження ефективності використання бурякового сиропу у продуктах на основі принципів нутриціології

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Анотація. Актуальність даного дослідження полягає в тому, щоб забезпечити населення харчовими продуктами, які при звичайному або надмірному споживанні протягом тривалого часу не викликали жодних проблем зі здоров'ям. Саме тому метою роботи було використання в технології кетчупів та соусів бурякового сиропу та буряків на основі принципів нутриціології. Для досягнення результатів використовували стандартні методи досліджень. Практична цінність наукової роботи полягає в розробленні харчових продуктів здорового харчування, безпечних екологічно і в медико-біологічному відношенні, високої харчової цінності зі зниженим вмістом цукру, солі, підвищеним вмістом клітковини та білка, невисокої енергетичної цінності. У роботі обґрунтовано використання бурякового сиропу та буряку в технології кетчупів, переваги розроблених рецептур для здоров'я людей. Також наведено фізико-хімічний склад бурякового сиропу, який містить 93,5 % сухих речовин, склад та вміст цукрів бурякового сиропу (глюкози, фруктози, сахарози, мальтози), загальний вміст цукрів становить 48,8 г/100 г, що менше на 50,2 г/100 г від звичайного цукру. Обґрунтовано співвідношення рецептурних інгредієнтів, встановлене експериментальними дослідами за органолептичними показниками. Досліджено показник активності води, який становить для зразка №2 – 0,92, для зразка №1 – 0,93, для контрольного зразка – 0,935, що позитивно впливатиме на терміни їхньої придатності. Дослідження хімічного складу показали, що вміст білка в зразку №1 підвищився на 33 %, у зразку №2 – на 56 % порівнюючи з контрольним зразком; вміст цукру знизився на 42,7 % у зразку №1 та на 50,6 % у зразку №2; підвищився вміст вітаміну С, у 3 рази підвищився вміст клітковини, розроблені продукти збагачено залізом, фосфором, калієм. Розрахунок Nutri-score показав, що розроблені зразки за рецептурами №1 та №2 належать до категорії А та В і є більш збалансованими та корисними для здоров'я людини, що свідчить про високу харчову цінність продуктів. За енергетичною цінністю розроблені зразки переважають контрольний. Енергетична цінність (ккал/100 г) зразка №1 становить 100, зразка №2 – 89,5, контрольного зразка – 104

Ключові слова: кетчупи, соуси, здорове харчування, технологія, цукри, харчова цінність

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Substantiation of amplitude-frequency characteristics and design parameters of the vibration exciter of the separator of volume vibrations

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Abstract. Evaluation of the influence of amplitude-frequency and power parameters of external technological action on bulk products in the process of separation of the impact, the way of low-frequency oscillations of the working bodies of the separator and the angle of inclination of the container during processing determines the main indicators of technical and economic efficiency of the explored process, which is the relevance of the research. The purpose of the study is to substantiate the operating parameters of the explored separator of volume vibrations by determining the patterns of change in the kinematic and power characteristics of the vibration drive. To determine the rational parameters of the vibration screening process, the equations of motion of the working bodies in the form of a conical sieve surface were obtained using the method of Lagrange equations of the 2nd kind. Using the solution of the Cauchy problem for linear inhomogeneous differential equations, the solution of the latter was obtained. Using the Math CAD mathematical environment, the dependences of the amplitude of oscillations, vibration velocity and vibration acceleration, and the intensity of oscillatory motion were obtained, which allowed performing a mathematical analysis of the power and energy characteristics of the vibration drive of the explored separator. The main effects of the developed design of the vibrating separator are an increase in the driving force of the process of separation of bulk solids in this work, which was achieved by providing the working cylindrically-conical

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container with vibratory motion; improvement of the conditions for the passage of product particles through the perforations, which was achieved by providing the sieve surface with volumetric vibrations; reduction of energy consumption and improvement of the operating conditions of the supporting units during the operation of the designed vibrating screen, which was achieved by installing additional elastic elements between the separator body The inclined arrangement of the conical sieve surface allows for spatial gyratory or circular translational motion, which allows implementing of the advantages of bulk separation of bulk solids. The results of the analytical study allowed substantiation of the optimal angle of inclination of the working sieve surface. Based on the analysis, the design parameters of the vibration exciter were substantiated and specified and the design of this technical system was presented. The practical value of the conducted research can be attributed to using the designed kinematic combined vibration exciter of volumetric oscillations in the separator, which allows reducing the weight of the oscillating parts of the drive and, accordingly, the energy consumption for the separation process

Keywords: vibration separation, conical sieve surface, vibrating screen, volumetric oscillations, amplitude-frequency characteristics, energy consumption for the drive, vibration velocity, vibration acceleration, mechanical combined vibration drive, feed mixture, low-frequency oscillations

Introduction

Using low-frequency oscillations to intensify the separation processes in the processing agricultural and food industries becomes effective during the processing of solid bulk heterogeneous systems at minimum humidity, which eliminates the influence of adhesive and sorption factors. Such conditions determine the effective implementation of the processes of vibration separation of grain mixtures and seed material.

The main distinguishing feature of mechanical vibrations as one of the types of mechanical impacts is the ability to transfer the energy of high specific power to the processed products. Therewith, the possibility of adjusting the parameters of vibration in a wide range allows extending its effect to both significant volumes of products and its local layers (Palamarchuk *et al.*, 2020a; Wei *et al.*, 2020); the possibility of combining the process of material transportation with its technological processing, and for products that vary significantly in their physical and mechanical properties; simplicity of machine design; no restrictions on the granulometric composition of the material; possibilities of complex mechanisation and automation of several production processes; intensification of technological processes by establishing a vibrating fluidised layer during technological processing (Palamarchuk *et al.*, 2020a). These processes are accompanied by a rapid increase in the surface of the interaction of components or phases, an increase in the rate of convective diffusion, and a decrease in viscosity, which determines the effects of their intensification and ensuring the completeness of the flow. Thus, vibration can be considered as a universal form of mechanical impact on processed materials and is widely used in the implementation of separation of bulk technological masses, which is one of the most common processes of food production, in particular, primary processing of agricultural raw materials and products.

The course of change of these processes, in turn, is determined by both the features of the physical and mechanical structure of the material, and the laws of low-frequency technological action, namely the amplitude-frequency and force impact, the way of oscillations of the working body, the angle of its inclination to the horizon. The influence of these factors on oscillatory systems is understudied, and the design of the corresponding experiments does not reach sufficient accuracy, which substantiates the *relevance* of this scientific work and has broad prospects for development.

A large galaxy of scientists and engineers provided the development of areas of application of vibration impact in the processes of separation of solid bulk heterogeneous systems.

In particular, I.I. Blekhman solved the problem of the motion of a material point and particles with a flat and rounded shape on a rough surface that performs periodic oscillations, and determined the optimal law of oscillations, substantiating the effective coefficient of friction during vibration transportation. Goncharevich I.F. (Palamarchuk, Tsurkan, & Kostenko, 2016) developed the classification, theory, methods of calculation and basics of design of vibrating transport and technological machines, established the basics of theory and methods for determining the optimal modes of vibration transportation of bulk solids, considering the dynamic loads of the machine. V.S Bykov. (Palamarchuk, Tsurkan, & Kostenko, 2016) established the dependences between the structural and kinematic parameters of the separation process on flat oscillating sieves, substantiating the effective modes of implementation of the working processes of modern grain cleaning machines. Based on studies of the vibration movement of finely dispersed bulk products by V.V. Gortynsky (Bal-Prylypko, Palamarchuk, & Nikolaenko, 2019), the theoretical foundations of the layer-by-layer movement of masses on a vibrating surface were developed, the movement of bulk bodies in a vessel with circular and translational oscillations was explored, and recommendations for the process of vibratory separation of bulk mixtures were substantiated. The research on the mechanics of bulk material movement on the working body of vibrating machines allowed B.I. Kryukov to determine the resistance caused by aerodynamic forces, the nature of the movement of individual particles, and the forces of their mutual friction and collisions; to approximate the influence of these factors by linear functions of the absolute and relative velocities of the product layer. P.M. Vasylenko (Palamarchuk *et al.*, 2020b) determined the value of the critical speed of sieving particles through the holes of the sieve, at an angle of inclination of the latter not exceeding 10° in particle decent area, considering air resistance. The most complete theoretical studies of the operation of a flat sieve that performs longitudinal oscillatory movements were performed in the fundamental works of I.E. Kozhukhovskyi and P.M. Zaika (Palamarchuk *et al.*, 2020a), in which the dependences of the quality of separation of a flat sieve on such parameters as the angle of inclination of the sieve to the horizon, the oscillation angle, the shape and location of the holes, the sieve dimensions, their specific loading, moisture content and contamination of the grain material were obtained. P.M. Zaika (Palamarchuk *et al.*, 2020a; Palamarchuk *et al.*, 2022) for the first time recorded a system of differential equations of spatial motion of the working body of a vibrating machine with several mechanical vibrators, the axes of which are arbitrarily oriented in space; which allowed

solving the problem of moving agricultural materials as discrete solids on the working surfaces of separators; to cover the mechanism of self-sorting processes, rumbling, to solve the problems of clogging and cleaning the holes of sieves. M.V. Bakum explored the possibility of sifting and post-cleaning grain material on serial grain cleaning machines and grain cleaning machines with high-frequency modes of movement of working bodies. A.V. Zilbernagel developed a method for calculating the limiting velocity of the relative movement of grain depending on the angle of the elongated sieve opening under the condition of particle passage through the opening. O.V. Chernyakov based on modelling the movement of grain material on the sieve established that biharmonic vibrations of the sieve are one of the effective ways to improve the technological process of grain separation. B.I. Kotov and S.P. Stepanenko confirmed that a promising area for further productivity increase, with a standardised quality of grain cleaning on vibrating sieve separators, is the intensification of loosening of the grain layer by braking elements-rippers, in particular when using gravitational-inertial, centrifugal, vibration-centrifugal executive bodies. L.M. Tishchenko (Rogovskii *et al*., 2020; Cherntongchai *et al*., 2019) has developed methods for calculating the intensification of vibrating centrifugal separation processes in terms of technical indicators of productivity and quality. The study of the process of vibro-pneumatic centrifugal separation of seed mixtures by V.V. Bredikhin allowed obtaining analytical dependences of the separation time and the speed of movement of the mixture layer on the main operating and design parameters of the process. O.M. Vasylkovsky received a model of the process of separation of the grain mixture on the inertial straight-through separator, which allowed establishing that the completeness of the separation of the grain mixture and the specific productivity of the separator simultaneously increase with the increase in the speed of movement of the material on the sieve, the maximum value of which is limited by the conditions of possible degradation of the grain in interaction with the rotor blades. O.B. Kozya established that the quality of the process of separation of seed materials on non-perforated friction oscillating surface significantly depends on the structural and kinematic parameters of the vibrating grain cleaning machine: amplitude, frequency and angle of oscillation, and angles of inclination of the working body to the horizon in the longitudinal and transverse ways (Bazaluk *et al*., 2022; Barrero, Taiebat & Dafalias, 2020).

According to the results of the analysis, it can be concluded that the problem of exploring the influence of mechanical drive bodies of separators on the dynamics of their work and energy consumption has not been practically performed.

The purpose of the study is to determine the mode parameters of the drive of volumetric oscillations of the conical working body of the separator of coarse grain products through the theoretical analysis of the amplitude-frequency and energy characteristics of this process. To achieve this purpose, the following main *objectives* of the scientific work were defined: to analyse the current state of analytical studies of the processes of vibration separation of bulk solids, to determine the patterns of change in the main parameters of vibration and to substantiate the design scheme of the separator being explored.

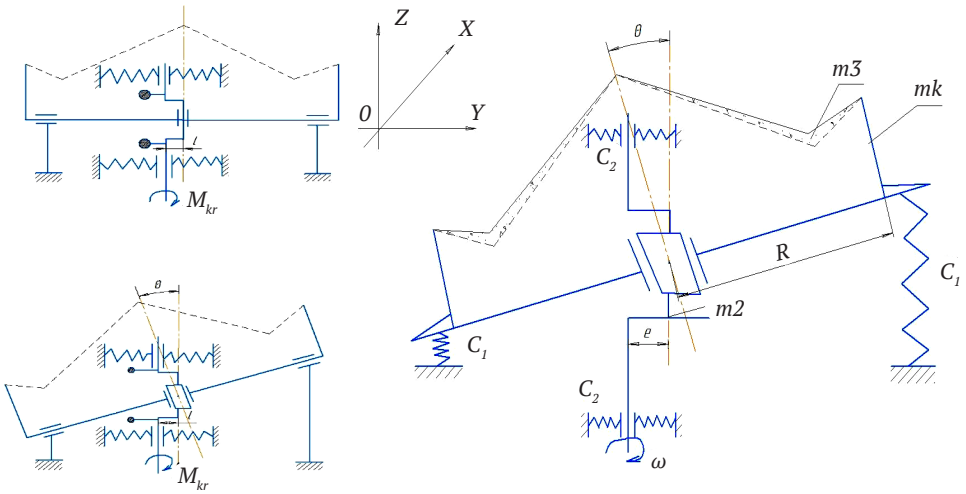
Materials and Methods

To perform the above objectives, a prototype model of the vibrating screen was developed,

and a set of special devices was manufactured that provide a measurement of amplitude-frequency and energy characteristics and automatic control of the drive shaft rotation speed of the vibrating exciter. During the analytical studies, the Lagrange method was used to compile the equations of motion of the actuators, and the Delambert method to determine the main power and energy characteristics of the oscillating system. Processing of the obtained dependencies was performed in the mathematical environment of MathCAD.

Results and Discussion

The explored process of separation of a bulk heterogeneous system as a driving force contains centrifugal alternating force and moment load on the technological environment, for the establishment of which the development of a vibration exciter of spatial oscillations was provided to set the sieve surface in motion. The developed mechanism rationally fits into the design of a vibrating screen with a conical sieve and can be used to generate both plane and spatial vibrations (Palamarchuk *et al.*, 2020c, Deng et al., 2019). This drive is characterised by kinematic vibration excitation and the presence of spring-bearing units. The vertical arrangement of the drive shaft of this vibrating exciter with the horizontal arrangement of the bearing surface of the conical screen (Fig. 1, a) allows for establishing a gyratory, i.e. gradual movement of the working bodies of the machine in the horizontal plane. To increase the speed of movement of the loading mass, it is advisable to perform the sieve surface inclined (Fig.1, a,b), for which a sleeve with an inclined outer surface was used. Fixing the support sleeve on the drive shaft of the vibrating exciter and the presence of a spring-loaded sieve platform results in the gyratory spatial movement of the working bodies of the vibrating screen (Fig. 1, a). The elastic elements of the support nodes partially eliminate parasitic vibrations that can be transmitted to the structure.



a) b)

Figure 1. Schematic diagram of the developed vibrating screen with the drive of volumetric vibrations at the straight and inclined arrangement of the working sieve surface: M_{kr} – torque on the drive shaft; ω – angular speed of rotation of the drive shaft; C_1 and C_2 – stiffnesses of elastic elements, respectively, of the conical working body and the drive shaft; θ – the angle of inclination of the sleeve for adjusting the inclination of the sieve surface

Using the Lagrangian method, the basic equations of motion of the working container were obtained (Palamarchuk *et al.*, 2019, Zhu *et al.*, 2019, Ashtiani, Salarikia and Golzarian, 2017) and their solution using Cauchy solutions:

$$x = e^{-0.5\alpha_x t}\left[\frac{F_m(\omega_2^2-k_x^2)}{(k_x^2-\omega_2^2)^2+\alpha_x^2\omega_2^2}\cos\rho_x t + \left(\frac{\vartheta_{x_0}}{\rho_x} - \frac{0.5F_m\alpha_x\rho_x^{-1}(k_x^2+\omega_2^2)}{(k_x^2-\omega_2^2)^2+\alpha_x^2\omega_2^2}\right)\sin\rho_x t + \frac{F_m(\alpha_x\omega_2\sin\omega_2 t+(k_x^2-\omega_2^2)\cos\omega_2 t)}{(k_x^2-\omega_2^2)^2+\alpha_x^2\omega_2^2}\right. \quad (1)$$

$$y = e^{-0.5\alpha_y t}\left(\frac{F_m\alpha_y\omega_2\cos\rho_y t}{(k_y^2-\omega_2^2)^2+\alpha_y^2\omega_2^2} + \left(\frac{\vartheta_{y_0}}{\rho_y} + \frac{F_m\omega_2\rho_y^{-1}(0.5\alpha_y^2-k_y^2+\omega_2^2)}{(k_y^2-\omega_2^2)^2+\alpha_y\omega_2^2}\right)\sin\rho_y t\right) + \frac{F_m\left((k_y^2-\omega_2^2)\sin\omega_2 t-\alpha_y\omega_2\cos\omega_2 t\right)}{(k_y^2-\omega_2^2)^2+\alpha_y^2\omega_2^2} \quad (2)$$

where ω_2 is the angular velocity of the drive shaft of the vibration exciter; $k_x^2 = \frac{C_x}{m_0}$ and $k_y^2 = \frac{C_y}{m_0}$ – the natural frequencies of the system; $\alpha_x = 2\sqrt{k_x^2-\omega_2^2}$ and $\alpha_y = 2\sqrt{1485-\omega_2^2}$ – the dissipation coefficients of the system in the corresponding areas; $F_m = \frac{m_1}{m_0}e\omega_2^2$ – the specific modulus of the forcing force; $\rho_x = \sqrt{k_x^2-0.25\alpha_x^2}$ and $\rho_y = \sqrt{k_y^2-0.25\alpha_y^2}$ – the reduced frequencies of the system.

The following indicators were used as criteria for evaluating the developed vibration drive: the amplitude of oscillations of the working container for the nominal mode A; angular velocity of the drive shaft ω; power consumption for the drive of the oscillating system for the nominal mode N and its minimum value N_{min}; vibration velocity $\upsilon=A\cdot\omega$ and vibration acceleration, $a=A\cdot\omega^2$ of oscillatory motion; vibration intensity $I=a\cdot\upsilon=A^2\cdot\omega^3$.

Using the composite equations of motion of the executive bodies of the vibrating screen and their mathematical analysis, graphical dependences for the kinematic and energy parameters of the investigated vibrating drive of the separator for 50 positions of the support sleeve were obtained in the mathematical environment MathCAD, the average values of which are presented in Figures 2, 3, 4.

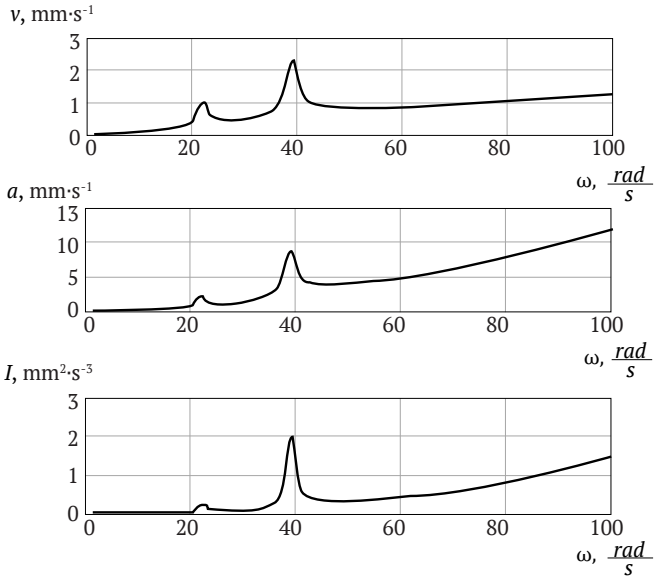


Figure 2. Dependences of the average values of the kinematic characteristics of the screen vibrating exciter on the angular velocity of the drive shaft: v – vibration velocity; a – vibration acceleration; $I = a\cdot v$ – vibration intensity

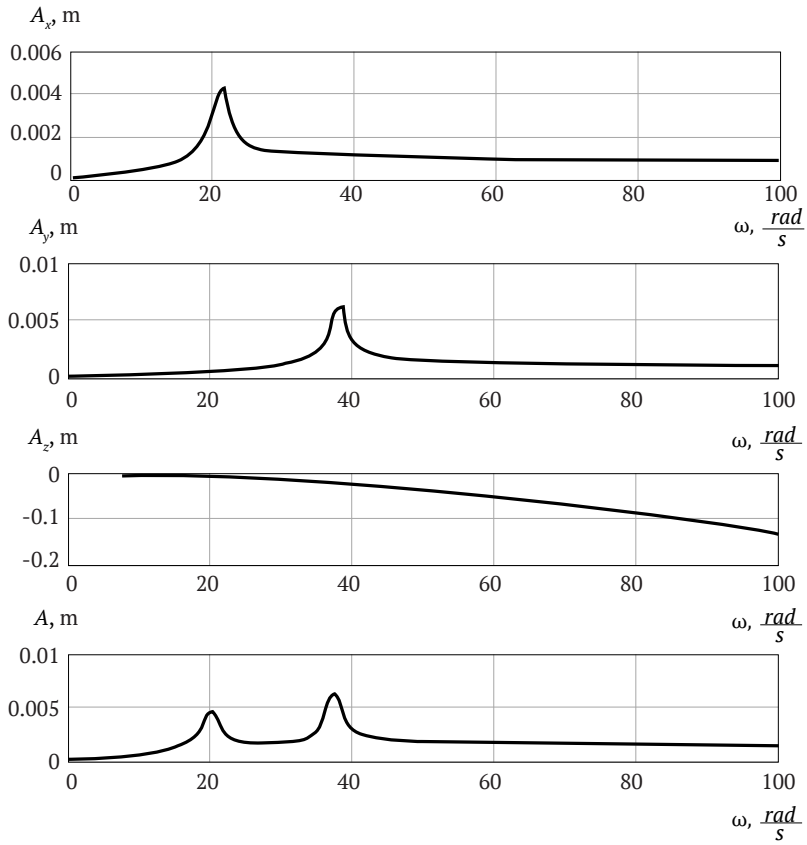


Figure 3. Dependence of the average values of the components of the vibration amplitude on the angular speed of the drive shaft

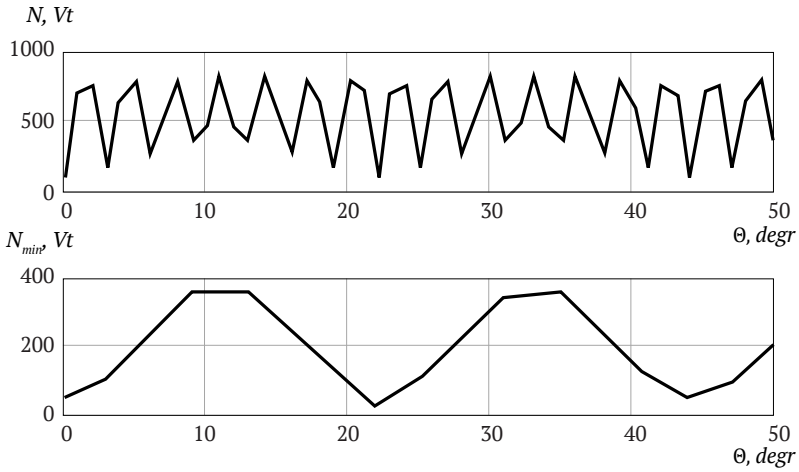


Figure 4. Dependence of average values of power consumption for the vibration separation process on the angular speed of the drive shaft: N – power on the drive shaft; N_{min} – minimum power value on the drive shaft; Θ – the angle between the drive shaft axis and the OZ axis

Exploring the changes in power on the drive shaft depending on the angle of rotation of the support sleeve, a sinusoidal nature of the change in this value was noted (Fig. 3). It allowed determining the peaks of minimum energy consumption for specific angles of rotation of the sleeve. The double peaks of the kinematic characteristics indicate the presence of two elastic couplings in the system.

As can be seen from Fig. 4, the envelope of minimum power values on the drive shaft changes according to a sinusoidal law with a period of change in the angle between the axes of the working container and the drive shaft equal to $\Theta_{min} = 22°$. Such a sufficiently large value of this design parameter is not appropriate for technological and structural reasons. Therefore, when choosing the optimal angle Θ, the dependence can be used

$$\Theta_{min} = 360 - z_{max}\,\Theta \qquad (3)$$

where z_{max} – the maximum integer to obtain a positive value in equation (3): it is obvious that for $z_{max} = 16$; $\Theta_{min} = 14°$

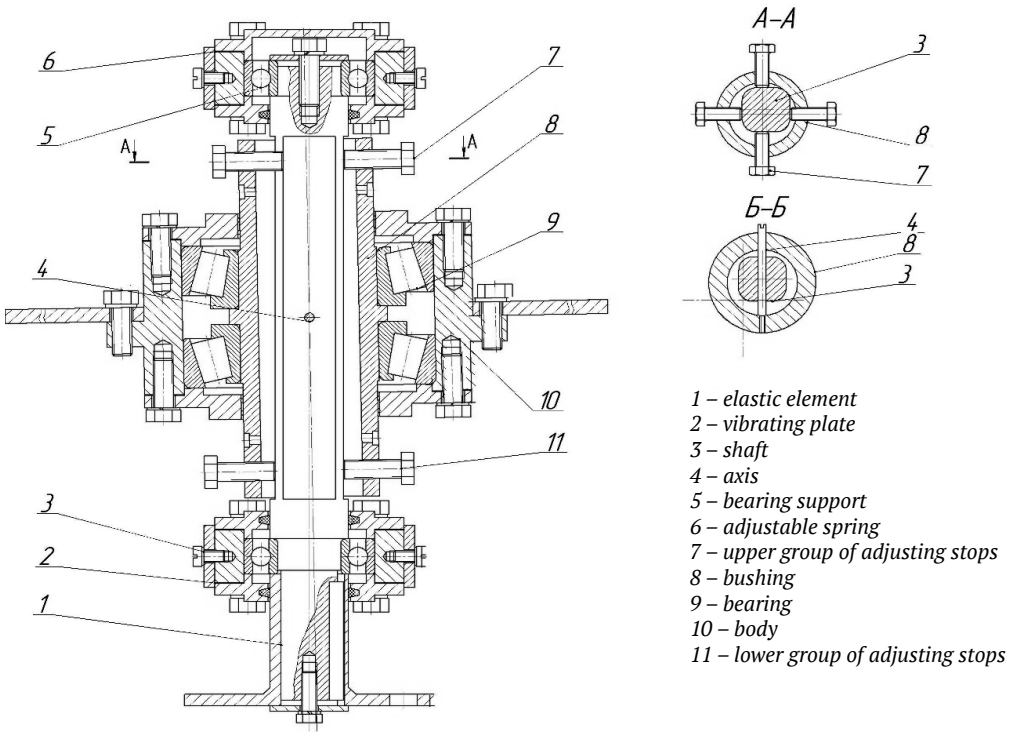


Figure 5. Structural diagram of the vibration exciter with the guide sleeve of the explored sieve separator

Based on the theoretical studies, the design of the gyratory vibration drive of spatial oscillations was developed (Fig. 5), which presents the main structural components of the developed vibration exciter, in particular, the mechanism for adjusting the inclination of the working surface of the support sleeve.

Conclusions

1. Using the Lagrange equation of the second kind, the dependences for the main independent movements of the executive bodies of the explored vibrating screen were compiled, and their solution was obtained using the Cauchy method, which allowed determining the patterns of change.

2. Based on the obtained equations of motion of the executive bodies of the vibrating screen, the dependences of the main kinematic and energy parameters of the explored vibration excitation scheme of the separator were obtained.

3. The modes of minimum power consumption on the drive shaft alternate approximately every 22° of rotation of the working surface of the support sleeve to the vertical; the optimal angle between the axes of the working container and the drive shaft for the technological and structural features for the explored machine is 14°, which allowed clarifying the design scheme of the vibrating exciter of the developed screen.

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Обгрунтування амплітудно-частотних характеристик та конструктивних параметрів віброзбуджувача сепаратора об'ємних коливань

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Анотація. Оцінка впливу амплітудно-частотних та силових параметрів зовнішньої технологічної дії на сипку продукцію у процесі її сепарації впливу, напрямку низькочастотних коливань робочих органів сепаратора та кута нахилу контейнера у процесі обробки визначає основні показники техніко-економічної ефективності досліджуваного процесу, що становить актуальність проведених досліджень. Метою дослідження є обгрунтування режимних параметрів досліджуваного сепаратора об'ємних коливань за рахунок визначення закономірностей зміни кінематичних та силових характеристик віброприводу. Для визначення раціональних параметрів процесу вібраційного грохочіння були отримані рівняння руху робочих органів у вигляді конічної ситової поверхні використовуючи метод рівнянь Лагранжа 2 роду. Застосовуючи рішення задачі Коші для лінійних неоднорідних диференціальних рівнянь було отримано розв'язок останніх. Використовуючи математичне середовище Math CAD, були отримані залежності амплітуди коливань, віброшвидкості та віброприскорення, інтенсивності коливального руху дали змогу здійснити математичний аналіз силових та енергетичних характеристик віброприводу досліджуваного сепаратора. Основними ефектами розробленої конструкції вібраційного сепаратору є збільшення рушійної сили процесу сепарації сипкої маси в цій роботі, що досягли через надання робочому циліндрично-конічному контейнеру вібраційного руху; поліпшення умов проходження часток продукції через перфорації, що досягли завдяки наданню ситовій поверхні об'ємних коливань; зменшення енерговитрат та поліпшення умов роботи опорних вузлів під час експлуатації проектованого віброгрохоту, що досягли внаслідок встановлення додаткових пружних елементів між корпусом сепаратора та підшипниковими вузлами вертикального приводного валу віброзбуджувача. Похиле розташування конічної ситової поверхні дає змогу здійснювати просторовий гіраційний або коловий поступальний рух, що дає можливість реалізувати переваги об'ємного розділення сипких мас. Результати

проведеного аналітичного дослідження дали можливість обґрунтувати оптимальний кут нахилу робочої ситової поверхні. На основі проведеного аналізу були обґрунтовані та уточнені конструктивні параметри віброзбуджувача та представлена конструкція цієї технічної системи. До практичної цінності проведених досліджень можна віднести застосування у сепараторі проектованого кінематичного комбінованого віброзбуджувача об'ємних коливань, що дозволяє зменшити масу коливних частин приводу та відповідно енерговитрати на процес сепарації

Ключові слова: вібраційна сепарація, конічна ситова поверхня, віброгрохот, об'ємні коливання, амплітудно-частотні характеристики, енерговитрати на привод, віброшвидкість, віброприскорення, механічний комбінований вібропривод, кормова суміш, низькочастотні коливання

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Dynamics of interfacial interaction between components during mixing

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Abstract. The effect of mechanical action on the mixing and whipping of a mixture of components contributes to the establishment of a three-dimensional sponge-mesh continuous structure of the gluten framework, as it determines the elastic and elastic properties of the medium and is relevant in the dispersion of gas in a liquid. The purpose of the work was to establish the relationship between the gas retention capacity of the medium and the energy consumed for the hydration of the components. The experiments performed the task of determining the gas retention capacity of the medium with variable parameters of the height of the liquid phase from the intensity of mixing, the time of the transient processes of the formation of the full volume of the gas-liquid medium, the time of the transient process of the dispersed gas phase. The difference in levels before the gas phase generation and the stirring mode determines the value of gas retention capacity. Therefore, it was concluded that it is expedient to completely destabilise the steady-state regimes by changing the modes of action of the working body in the flow system. An additional impact on the system is the change of hydrodynamic regimes due to the unstable dynamics of the dispersed gas phase generation. The generation of this phase means the presence of energy costs for the interfacial surface establishment, which must be considered in the overall energy balance. In addition, a part of the gas phase, which existed and continues to exist in the new regime after mixing, enters the

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transient regime. Therefore, the most effective mixing occurs in case of compliance with the shifted mode of dosing components in a suspended state and the mechanical impact of the working body. Considering the tasks and conditions for mixing the dough, the requirements for the design of the mixer are determined, and it is established that the supply of components should last at least 45 seconds. During this period, there is hydration and a reduction in energy consumption. Such an approach intensifies mass transfer and biochemical processes under conditions of thermodynamic equilibrium with appropriate desorption bonds of the dissolved part of the gas phase and liquid, which covers a new method of mixing and allows further use in the design calculations of working chambers

Keywords: mixing, solid, liquid and gaseous phase, change of concentrations, thermodynamics, hydration, stripping

Introduction

The initial conditions of the mixing process are compliance with the recipe of the components. Mixing and whipping of semi-finished products for bakery and confectionery products have their defined stages (Chernenkova *et al.*, 2019; Stadnyk *et al.*, 2021a). The processes of mixing, whipping and foaming are essentially the same and consist in dispersing gas in a liquid. Such a system mainly contains gas bubbles in the whipped mass. They are separated by a thin film of liquid. Schematically, the foam structure can be represented as a packing of gas bubbles with thin films of the main highly dispersed filler (Stadnyk *et al.*, 2021b).

The biopolymers involved in the establishment of such systems include proteins, starches, pentosans, and shell parts. In the process of mixing the components of the emulsion (brew), complex colloidal, physicochemical and biochemical transformations occur under the influence of water and enzyme systems. Colloidal processes are the most active. As a result of water absorption, proteins, starches and pentosans increase in volume, and sugars, minerals, water-soluble substances and vitamins are transferred to the solution. In the wheat dough establishment, the primary role belongs to proteins, which absorb double the amount of water compared to their weight. Osmotically bound moisture in them is 75%, and absorption bound – 25%. It is due to osmotically bound moisture that the protein molecule loosens and increases in volume (Danyliuk *et al.*, 2017).

During the mixing and beating of the mixture of components, swollen, water-insoluble protein substances (gluten proteins) increase in volume due to mechanical action and form a three-dimensional sponge-mesh continuous structure (Lisovska *et al.*, 2017). It is called the gluten framework. It is this that determines the elastic and resilient properties of the material. The framework consists of starch grains, insoluble pentosans, and particles of grain shells. The hydration processes of the environment components occur at different speeds and depend on the water temperature. The maximum swelling of proteins occurs at a temperature of 30°C with water absorption of 2.0...2.5 g/g. At higher temperatures, the swelling of proteins is limited. Water absorption of starch is 0.3...0.4 g/g of water per dry matter. Pentosans absorb water osmotically and form viscous solutions, resulting in a significant increase in moisture absorption

capacity and consistency (Stadnyk *et al.*, 2019; Nakov & Ivanova, 2020).

It is considered that the absorbed and bound water between the components is distributed as follows, in %: whole starch grains – 26.4; damaged starch grains – 19.1; gluten proteins – 31.2; pentosans – 23.4 (Kolyanovska *et al.*, 2019).

There are three phases produced by mixing flour with water: solid, liquid and gaseous. *The solid phase* is established by insoluble proteins that establish the gluten framework and ensure its stretchability and elasticity. *The liquid phase* is a viscous solution consisting of adsorbed flour and water components. *The gaseous phase* is established as a result of the saturation of the dough with air balls during mixing and partially by adding air with flour, water, eggs, milk protein, sodium caseinate, etc. It is considered that the gas phase is close to 10% in the total volume of the medium (Mushtruk *et al.*, 2020).

Research analysis

A significant amount of substances in the environment, changes in concentrations, interactions between them and microorganisms, the presence of stimulants, etc. result in relative instability of the system. Under such conditions, there are areas in which the impact of individual factors is assessed. However, adverse effects should be programmed, for example, by osmotic pressures, impacts of factors, deterioration of product quality, etc. While the effect of temperature can be traced, there is no definitive opinion on physical pressure (Palamarchuk *et al.*, 2020; Sukhenko *et al.*, 2019). However, the provisions of thermodynamics closely relate the parameters of pressure and temperature, for example, in the gas laws, the Mendeleev-Clyperon equation, Henry's law, etc. From the standpoint of technical availability, adiabatic or polytropic processes are of interest in influencing fermentable masses (Osipenko *et al.*, 2019; Savenkova *et al.*, 2019). Due to the compression of the establishing mixture on the surface of the chamber, the temperature of the gas phase partially increases. Evidently, before the system is compressed, the temperatures of the gas phase and the vapour coincide. However, after compression, the ratio of temperatures is obtained:

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \quad (1)$$

in the adiabatic process and polytropic process,

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{m-1}{m}} \quad (2)$$

where T_1 and T_2 are the initial and final temperatures of the gas phase, respectively; P_1 and P_2 – respectively, the initial and final pressure; k and m – adiabatic and polytropic indices.

The energy input into the system under such conditions [6] is equal to:

$$E = \frac{MR}{k-1}(T_2 - T_1), \quad (3)$$

where M – mass of the compressed gas; R – the universal gas constant.

The energy introduced in this way must be redistributed between the dispersed gas phase and the vapour, where the overall temperature of the system increases.

According to Henry's law, an increase in partial (and in this case total) pressure increases the solubility of the gas in the liquid phase of the medium, and an increase in temperature decreases the solubility:

$$c_н = kp, \quad (4)$$

where k – Henry's constant.

This indicator considers how the proportionality factor affects the temperature and physical and chemical properties of the system components. Increasing temperature decreases solubility $c_н$ (Fig. 1).

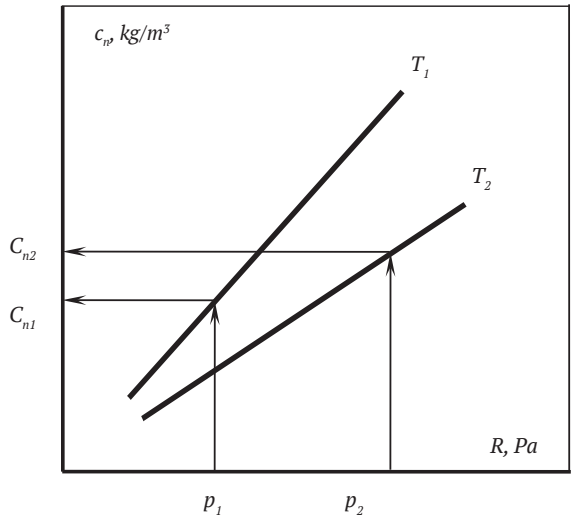

Figure 1. Diagram of the dependence between the parameters C_n and R according to Henry's law

On the graph, isotherms T_1 and T_2 indicate that there are theoretically possible variants in which solubility increases, decreases or remains constant with changes in pressure. Therewith, the temperature of the medium according to the Van Hoff law affects the osmotic pressure of the solution:

$$\pi = CRT, \quad (5)$$

where π – osmotic pressure of the solution, kPa; C – its molar volume concentration (molarity), kmol/l; R=8.314 J/(mol·K) – universal gas constant.

The molarity of a solution *C* is the ratio of the amount of dissolved substance *n* to the volume of the solution *V* (l):

$$C = \frac{n}{V}, \quad (6)$$

and the amount of substance is equal to its mass *m* divided by the molar mass *M*. Therefore it follows:

$$C = \frac{m}{MV} \quad (7)$$

and the Van Hoff equation:

$$\pi V = \frac{mRT}{M};$$

$$\pi = \frac{mRT}{MV} \quad (8)$$

From the last condition it follows that in addition to the influence of the temperature *T* of the medium, which can be selected in a sufficiently noticeable range, a significant impact on the osmotic pressure is achieved due to the destruction of sugars and other organic polymers in the process of fermentation, whipping, since the final results of the transformations are alcohol and carbon dioxide and air.

Thus, the secondary consequence of pressure changes in the system is the change in the temperature of the dispersed gas phase, the introduction of additional energy into the system, and the change in osmotic pressure. The primary consequence of the pressure change in the medium is the active mixing of the mixture of components. Its course occurs

under conditions of volumetric stress due to compression or expansion of the gas phase. Therewith, it is significant that under such conditions there is an interaction between local zones, the centres of which are gas caverns. The emergence of the latter in the physical essence corresponds to the phenomenon of breaking the continuity of the medium based on the transformation of the chemical energy of the compounds of the medium into the mechanical potential and, therewith, the kinetic energy of change of shape and size.

The transient process of active gas generation affects the growth of the overall dimensions of the massive medium and its volume. However, the speed of such changes is quite limited. Changes in the volume of the medium occur in a potential field of gravitational forces, which are overcome by the driving factor of the potential energy of the generated gas phase under the intensive establishment of alternating pulses of the acting forces (Shishkin *et al.*, 2020; Pyvovarov *et al.*, 2021).

The course of such processes can be quite fleeting. Therewith, the two processes are combined, since the fermentation of sugars in the medium is added to the pulse mixing. The consequence of this combination is the intensification of mass exchange and biochemical processes. Others will be manifestations of energy impulses in conditions of sharp pressure drops. The difference in pressures means the transition of the system to new parameters of thermodynamic equilibrium with a rapid increase in the gas retention capacity of the system through the expansion of the gas phase with a corresponding increase in its amount. This fact is caused by the desorption of the dissolved part of the gas phase. Evidently, such a transition process concerns both the gas phase and the liquid phase, since the increase in the volume of the gas phase determines the increase in the volume of the gas-liquid mixture and the movement of the liquid phase. The dynamics of the latter is accompanied by the emergence of inertia forces and, accordingly, an increase in pressure in terms of its general and programmed reduction.

The movement of the liquid phase as a result of the establishment of the dispersed gas phase is performed by the vertical working chamber. The established gas-liquid system in dynamics with elastic solid systems with distributed masses results in a conclusion about their equivalence and the possibility of applying Rayleigh's principle for determining the reduced mass of the liquid phase. The availability of data on the masses of the system being studied and force actions on it means the possibility of using the Lagrange-Delambert principle in its modelling. The definition of the driving factor is associated with the dynamics of changes in speed and pressure. Their reactions to the pulsed energy disturbance will coincide since the generators of mechanical impact for pressure reduction are the gas phase itself.

The purpose of the research is to establish the correlation between the gas retention capacity of the medium and the energy spent on the hydration of the components.

Materials and Methods

The research was performed to determine the gas retention capacity of the medium with variable parameters of the height of the liquid phase $h_{p.ф}$. from the intensity of mixing, the time of the transient processes of the development of the total volume of the gas-liquid medium, the time of the transient process of the dispersed gas phase.

The difference in levels before the gas phase is established and in the mixing (aeration) mode

determines the value of gas retention capacity. The beginning and end of the transition processes (obtaining a homogeneous mass) were recorded visually. The change in the height of the liquid phase was accompanied by a similar cycle of changes in the exposure parameters.

Results

The change Δh in the height of the swollen gas-liquid layer compared to the height of the liquid layer meant that it allowed determining the value of gas retention capacity:

$$u_{e.p.c.} = \Delta h f, \quad (9)$$

where f – cross-sectional area of the working chamber. For the inner diameter of the chamber d=0.15 m have f=0.0177 m^2.

The results of measurements of primary data are presented in Table 1.

Table 1. *Results of determination of hydrodynamic parameters of the system with air*

Height of liquid phase $h_{p.ф.}$ = 0.2 m						
Rotameter reading countdown	0.0	10.0	15.0	18.0	20.0	27.0
Mix height, m	0.14	0.15	0.17	0.18	0.19	0.195
Retention capacity, m^3	0.000708	0.000885	0.001239	0.001416	0.001593	0.001682

The analysis of the obtained data leads to the expected conclusion about the growth of gas retention capacity in the system with intensive mixing of components, which affects the increase of gas flow on aeration and height of the liquid phase. Therewith, the effect of the transient process is recorded, according to which the stabilisation of the gas phase velocity occurs at a height of 0.15...0.2 m above the plane of its injection into the liquid. A graphical interpretation of the results of tabular data is presented in Fig. 2.

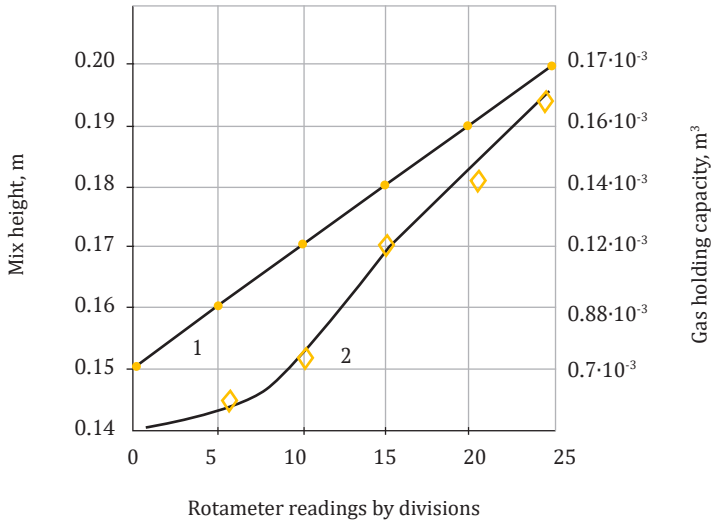

Figure 2. Dependence of the height of the liquid-air mixture (1) and its gas retention capacity (2) on the rotameter readings at a liquid layer height of 0.2 m

Transient processes in mixing systems can occur in modes of a sharp increase in gas retention capacity or a decrease in planned conditions.

Transient processes in the conditions of introduction of liquid flows include those that correspond to the appearance of a dispersed gas phase in the full volume of the medium. Therewith, at the moment of establishment and exit of the gas phase from the medium, the level of gas retention capacity is the highest with subsequent active decrease and transition to the steady state. To explain such a course of processes can be explained by the establishment of circulation circuits in the working chamber at this moment and the increase due to this absolute velocity of the gas phase.

In addition, the transition process corresponds to the termination of the intensive action of the working body on the gas phase generation. If it is performed by a sharp decrease in the flow, it results in the mass floating of the dispersed gas phase.

The observed difference in the velocity of air masses is explained by the physical properties of the gas and the interaction of its dispersed masses with the liquid. Evidently, at the stages of the surfacing of the arrays, there is a restructuring of circulation flows in the remnants of the gas-liquid phase and, therewith, the entire system, which is represented by a combination of liquid and gas-liquid phases (Fig. 3).

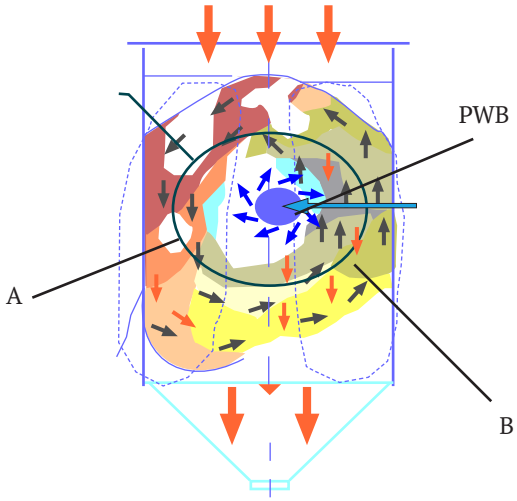

Figure 3. Scheme of movement of mixed components in the working chamber: A – circulation circuit of movement of components; B – the action of forces on components; PWB – plate working body

In such an interaction, the liquid phase moves and the energy potential decreases. Due to the transience of this stage, note its relatively small impact on the technological process and the lack of external energy flow, since the course of events occurs due to the potential and kinetic energy of the system at the beginning of the stage.

In connection with the latter and the part of the experiments that concerned the determination of gas retention capacity, it was concluded that it is advisable to completely

destabilise the steady-state regimes by changing the modes of action of the working body in the flow system.

Notably, this component of A_{hyd} hydration has not been previously explored. Its value was accepted in the appropriate parameters. Therefore, in this case, the energy spent on hydration of the components will be considered by the system of equations:

$$\begin{cases} \Delta U = A_{газ} + q \\ Q_{гід} = \frac{BC_T \Delta t_{гід}}{M} \end{cases} \quad (10)$$

where ΔU – change in internal energy; Q_{hyd} – the amount of heat provided by hydration J; Δt_{hyd} – temperature increase due to hydration; q – the amount of heat provided to the system, J; A_{gen} – work performed by the system, J; M – amount of flour in dough, kg; B – the amount of processing dough, kg; C_T – specific heat capacity of dough, kJ/kg.

During the whipping of the mixture, where there is no work for plasticisation, it was assumed:

$$A_{gen} = Q_{hyd}. \quad (11)$$

Considering that the author of the mixing process [9] believes that:

$$C_T = \frac{C_M M + W}{B} \quad (12)$$

where C_M is the specific heat capacity of flour, kJ/kg; W – amount of water (substitutes) according to the dough recipe, kg; M – amount of flour, kg; B – the amount of processing dough, kg.

Then:

$$\begin{cases} A_{гід} = \frac{BC_T \cdot \Delta t_{гід}}{M} \\ A_{гід} = \Delta U - g \end{cases} \quad (13)$$

Change of internal energy :

$$\Delta U = \frac{(C_м M + W) \cdot \Delta t_{гід}}{M} \quad (14)$$

Solution (10) :

$$A_{ГД} = \frac{\Delta t}{M}(CM + B) \quad (15)$$

From the analysis of the above about the energy, which can be transferred in various forms through the working body to the medium, the general modes of the cycle of energy changes in the growth of the gas dispersed mass, i.e., the component of the mixing stage, are taken. Maximum crushing of gas bubbles in the generating mixture at a uniform level of activity of the surface of the plate working body contributes to the emergence of thin-walled fine uniform porosity of products. The crushing of gas bubbles is one of the main factors affecting the shape stability of the semi-finished product. It is further transformed into other qualitative indicators. Therewith, it is necessary to ensure minimal energy consumption to establish a homogeneous mixture with a fairly uniform distribution of the concentration of solid components (flour) in the liquid phase throughout the mixed volume.

The achieved uniform state of the mixture is unstable. Aeration of the mixture increases the speed of metabolic processes, which generally affects its oxygen saturation. The saturation of the mixture with oxygen results in an intensive oxidation catalysis process. Some of the bubbles are in the form of an emulsion of gas in the liquid phase of the mixture, and the other is in the swollen proteins of the mixture in the form of gas bubbles. Increasing the absorption of water volume activates the action of enzymes, which generally determines the processes of swelling and peptisation of proteins and dilution of the mixture.

Considering this, the change in the volume of the establishing system during mixing in the form of porosity (volume of the gas phase) was predicted. From the energy balance equation, the work spent on heating the structural components and the interacting working body with them was determined [1]:

$$A_э = \frac{t_2 - t_1}{n\tau}(m_m c_m - m_м c_м) \quad (16)$$

Considering the Mendeleev-Clyperon law for an ideal gas [8] and the equations of the theory [1] and the defined hydrothermal reaction, the following is obtained:

$$\begin{cases} \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \\ A_{заг} = A_3 + A_{гід} = \frac{t_2 - t_1}{n\tau}(m_m c_m - m_м c_м) + \frac{\Delta t}{M}(C_б M + B) \end{cases} \quad (17)$$

Assuming that T_2=t_2-t_1, the system of equations was transformed, and the volume of the gas phase V_2 was determined.

An additional impact on the system is the change of hydrodynamic regimes due to the unstable dynamics of the dispersed gas phase generation. The surface of the gas-liquid flow is determined through a combination of physical and chemical properties of the medium and the speed of flow of the surface of the working body. The established gas-liquid circuits are frequently chaotic, which results in disturbances of thermal circulation. Therewith, the levels of such violations can be quite deep with changes in areas in the contours of the working chamber.

Thus, hydrodynamic modes in the working chamber are determined by three reasons. The first of them concerns the generated flows of surface contours during the interaction in suspension of the dosing yeast suspension and dosing flour. The second – is the establishment of flows of surface contours under the rotational action of the plate working body. The third reason concerns the establishment of flows with the participation of the gas phase and gravitational action on the flows that rapidly drain down the walls of the cylindrical working chamber.

Evidently, each of these reasons is characterised by its driving factors. For the first and second factors, there is a difference in the movement of the medium and temperatures. In the third case, the driving factor is the presence of the dispersed gas phase, and the rate of establishment of the latter is significant, which in turn depends on the speed of whipping and the establishment of the foam frame. A specific level of generalisation in the latter case can be represented by the retention capacity of the medium in the gas phase. The gas retention capacity of the medium depends on the change in the height of the liquid phase in the working chamber of the machine, the intensity of aeration, the time of the transient processes of the establishment of the full volume of the gas-liquid medium, the time of the transient process of the dispersed gas phase. Gas characteristics are presented in Table 2.

Table 2. *Physical parameters of air*

Gas	Molecular weight	Specific mass, kg/m³	Gas steel, J/(kg·K)
Air	28.96	1.293	287

The change Δh in the height of the swollen gas-liquid layer compared to the height of the liquid layer meant that it allowed determining the value of gas retention capacity:

$$u_{г.р.с.} = \Delta h f. \quad (18)$$

where f – cross-sectional area of the working chamber.

Accordingly, the volume of the expanded

gas-liquid layer for each zone of the working chamber will be:

$$V = \pi \int_{h_1}^{h_2} y^2 dx \qquad (19)$$

where y – radius of the cylindrical chamber, mm; x – chamber height, mm.

Considering that the level of the central part of the dough is on average 20...30 mm higher than that of the walls of the working chamber and considering the conical part of it, the volume of the generated mixture before unloading will be determined:

$$V_{заг} = \pi \int_{h_1}^{h} [y_1 + (x - h_1)tg\alpha]^2 dx = \frac{\pi}{3tg\alpha}\{[y_1 + (h - h_1)tg\alpha]^3\}. \qquad (20)$$

The rate of generation of the gas phase is determined by the process technology and each cross-section of the cylindrical working chamber of the machine can detect signs of a dispersed gas phase. The control system of thermodynamic parameters provides for the achievement of maximum pressure P_1=P_{max}, and from the moment it is reached, it is supposed to decrease to a specific value of P_2. Therewith: ΔP=P_1-P_2.

It is essential that the change in pressure ΔP does not vary with the coordinate of the selected point in the working chamber. The volume of the generated medium depends on the size of the retention capacity and the location of the corresponding layers. Evidently, the generated phase is in the form of arrays of dispersed bubbles, the total volume of which is calculated using the Mendeleev-Clyperon equation:

$$V_{num.} = \frac{m_{O_2}}{P_{(к)}} RT. \qquad (21)$$

The specific mass of O_2 is known (Table 2) and the final pressure $P_{(к)}$ corresponding to the chosen coordinate h is known, then:

$$P_{(к)} = P_0 + mgh. \qquad (22)$$

Therefore, the specific volume of the generated whipping mass according to the recipe with the corresponding air saturation will be:

$$V_{num.} = \frac{m_{O_2}}{P_0 + mgh} RT, \qquad (23)$$

where R and T are respectively the universal gas phase and the absolute temperature of the medium.

This generation of the dispersed gas phase means the presence of energy costs for the establishment of the interfacial surface, which should be considered in the overall energy balance. Therewith, it is necessary to name one more feature. A part of the gas phase, which existed and continues to exist in the new regime after mixing, enters the transient regime. Existence is inevitable as the new bubble nucleated in the medium is instantly acted upon by the Archimedean force regardless of the state of the liquid phase. In this regard, the relative movement of the gas phase begins with increasing speed to the value at which the resistance force of the medium becomes equal to the Archimedean force. Therefore, it is necessary to perform a technological operation with the generated environment for a specific period (10...20 seconds) – unloading of the semi-finished product.

Conclusions

The volume of the mixture changes the most at the end of the mixing stage at the maximum mass (according to the recipe), i.e. in the generated mixture and the percentage of the gas phase is 13.6%. Therefore, powdered solids and liquids are most effectively mixed on the

surface of the phase contact, while it is necessary to observe the shifted mode of dosing the components in suspension and the mechanical impact of the working body. Considering the tasks and conditions for mixing the dough, the requirements for the design of the mixer are determined, therewith, it is established that the supply of components should last at least 45 seconds. During this period, there is hydration and a reduction in energy consumption.

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Динаміка міжфазової взаємодії між компонентами при перемішуванні

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Анотація. Вплив механічної дії на змішування та збивання суміші компонентів сприяє утворенню тривимірної губчасто-сітчастої неперервної структури клейковинного каркасу, бо саме він визначає еластичні та пружні властивості середовища і є актуальним у диспергуванні газу в рідині. Метою роботи було встановлення взаємозв'язку газоутримувальної здатності середовища та енергії, затрачуваної на гідратацію компонентів. Дослідами виконувалося завдання визначення газоутримувальної здатності середовища зі змінними параметрами висоти рідинної фази від інтенсивності змішування, часу перебігу перехідних процесів формування повного об'єму газорідинного середовища, часу перехідного процесу виходу диспергованої газової фази. Різниця рівнів до утворення газової фази й у режимі перемішування визначає значення газоутримувальної здатності. Тому прийшли до висновку про доцільність повної дестабілізації усталених режимів завдяки зміні режимів дії робочого органа в системі потоків. Додатковим впливом на систему є зміна гідродинамічних режимів у зв'язку з несталою динамікою утворення диспергованої газової фази. Генерування цієї фази означає присутність енергетичних витрат на утворення міжфазної поверхні, що повинно враховуватися в загальному енергетичному балансі. Також частина газової фази, що існувала і продовжує існувати в новому режимі після змішування, потрапляє в режим перехідного процесу. Тому найефективніше замішування відбувається в разі дотримання зміщеного режиму дозування компонентів у зваженому стані та механічного впливу робочого органу. З огляду на поставлені завдання і умови проведення змішування опари, визначені вимоги до конструкції змішувача, а також встановлено, що подача компонентів має тривати не менше 45 с. За цей період відбувається гідратація та зменшення споживання енергоресурсів. Такий підхід інтенсифікує масообмінні і біохімічні процеси в умовах термодинамічної рівноваги при відповідних зв'язках десорбції розчиненої частини газової фази та рідини, що розкриває новий спосіб перемішування та дозволяє в подальшому використовувати при конструктивних розрахунках робочих камер

Ключові слова: перемішування, тверда, рідка і газоподібна фаза, зміна концентрацій, термодинаміка, гідратація, опара

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Honey as a component of marinade for semi-finished meat products

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Abstract. The specific features of the biochemical composition and properties of raw meat determine the necessity of finding new technologies for its processing to obtain new products with high consumer properties. The actual area of technology development is the enrichment of raw meat with useful components with functional and technological properties that have high biological value: api products and products of plant origin.The purpose of the work was to develop a marinade with the addition of honey and to explore its effect on the semi-finished meat product, depending on the duration of marinating. Selection of samples for investigations and their preparation for analysis was performed according to GOST 4288-76 "Culinary and semi-finished products of minced meat. Acceptance rules and test methods", organoleptic examinations were performed according to DSTU 4426:2005**,** moisture content determination – GOST 9793-74 "Meat products. Methods for determination of moisture", the amount of fat – for GOST 23042-86 "Meat and meat products, "Methods for determination of fat", the amount of protein – GOST 25011-81 "Meat and meat products. Methods for determination of protein", determination of ash content – GOST 31727-2012 "Meat and meat products. Determination of mass fraction of total ash", determination of pH – GOST 26188-84 "Products of fruits and vegetables processing, canned meat and meat. Determination of pH", and determination of fibre-forming and fibre-retaining properties were performed through sample preparation and determination of fibre content. According to the scheme of the experiment, the research technology was determined. The research results of the initial raw meat, honey and marinated semi-finished product are presented in the study. It was established that the decrease in the pH of the marinated semi-finished product during the 24-hour exposure period ensures the stability of the meat to storage, as most bacteria develop at high pH values, while on acidic nutrient media below 6.2, their development is slowed down. Long marinating allows obtaining meat with increased moisture binding and moisture retention capacity and improved consistency and juiciness. The task of establishing new products requires new approaches and techniques of technology. Using apiproducts that have antioxidant properties will

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allow refraining from using preservatives and stabilisers of chemical origin. Thus, honey can be used in the composition of marinated meat products. The introduction of active components of honey into the marinade will extend the shelf life and adjust the organoleptic properties. In addition, during heat treatment, the meat marinated with honey marinade acquires new taste qualities, and the appearance becomes brighter due to the caramelisation of honey

Keywords: safety, components, method and duration of pickling, organoleptic and physicochemical parameters, natural antioxidants

Introduction

Providing the country's population with quality and safe products is of particular relevance in modern environmental realities and for strengthening immunity. In performing this task, an important role is played by the successful development of agriculture and high-quality production of meat raw materials and its further industrial processing. The actual area of technology development is the enrichment of raw meat with useful components with functional and technological properties that have high biological value: api products and products of plant origin (Zharinov *et al.*, 2016).

The current consumption of meat products requires a variety of new assortment of semi-finished products, which is explained by the fact that the priority is determined by the speed of cooking, availability and shelf life of food, and the usefulness and availability of antioxidant properties of food products (Gotsik & Bandurenko, 2012; Wie'k A. *et al.*, 2020).

The deterioration of the environmental situation, deformation of the diet and excessive consumption of products with carcinogenic substances pose a significant threat to the health of the population of Ukraine. Therefore, improving the range of food products, in particular, portioned semi-finished products with high nutritional and biological value is quite relevant.

To diversify the range of meat products, and to provide them with new nutritional and taste qualities, various processing processes are used, which result in new types of meat products (Kim *et al.*, 2010; Semenchenko, Nefedova & Savinova, 2013).

Currently, scientists have established a large number of technologies for the preparation of semi-finished meat products, using different types of marinades, since marinated semi-finished products have a longer shelf life and high yield after heat treatment (Balyabina *et al.,* 2016; Merenkova & Lukin, 2016). In addition, marinated meat becomes more tender and juicy, which facilitates the digestion and absorption of the maximum amount of nutrients contained in it by the body (Jinap *et al.*, 2015; Shamsudin *et al.*, 2020). Thus, in studies (Tänavots *et al.*, 2018) it was established that after the stage of marinating pork in the honey-mustard marinade with its subsequent cooking, the product became softer and more tender compared to the product cooked in vinegar-containing (white wine) marinade. In addition, the semi-finished product marinated in the honey-mustard marinade was characterised by a high yield of the finished product.

The main types of additives in marinades are: vinegar, wine materials, citrus juices, soy sauce, mayonnaise. Each of these components has its drawbacks. For example, vinegar helps to soften the structure of muscle fibres of the meat, but there is a decrease in the brightness of the taste of the finished product, with the appearance of a slightly sour taste (Seong *et al.*, 2012; Serdaroğlu *et al.*, 2007; Żochowska-Kujawska *et al.*, 2012). Marinade based on soy sauce has a spicy but quite salty and very spicy taste; allergic reactions are possible.

Mayonnaise significantly increases the nutritional and energy value of the semi-finished product (Toleubekova *et al.*, 2020). Marinades made with non-conventional products can be spicy, savoury, sour, sour-sweet, sweet, exotic, fruity and flavoured with spices. Marinades with the addition of honey are particularly bright.

In previous studies (Alzahrani *et al.*, 2012; Yücel *et al.*, 2005) of the physicochemical and organoleptic properties of meat products and semi-finished products, it was proved that the combination of meat and honey has an interesting and promising nature of research. After all, using bee products in the marinade provides the meat with new technological and taste properties.

Honey is most widely used in the production of lactic acid products: yoghurts, and curd desserts. In addition, using of beekeeping products found itself in the production of salted fish and caviar products, as an alternative to synthetic preservatives, the foundation for the production of environmentally friendly, organic products.

According to the literature on physicochemical and quality indicators, honey has therapeutic value due to the nature of carbohydrates and the content of pollen grains. It promotes the normalisation of metabolism and the strengthening of immunity. Useful substances contained in it contribute to normalising the acidity of gastric juice and improving digestion. Honey has a positive effect on the nervous system and improves the quality of sleep. For diabetics and those with high blood cholesterol, honey successfully replaces sugar. Regular consumption of honey significantly improves performance, thus, it should be consumed by patients, athletes and anyone who works physically (Iliaab *et al.*, 2021).

Literature data suggest that honey, used alone or as an auxiliary ingredient, may be a potential natural antioxidant (Ahmed *et al.*, 2019). Thus, the development of new recipes for marinades with the addition of honey and their use in the production technology of semi-finished meat products will allow both to diversify the taste of conventional products and to increase their nutritional value.

It is proven that numerous natural products, in particular honey, reduce the oxidation process of meat. Such antioxidant activity can reduce potential carcinogenic substances. Antimicrobial activity can inhibit the establishment of biogenic amines produced during microbial growth (Lee *et al.*, 2020).

The development of heterocyclic amines, in particular, in chicken meat, was explored by Jinap *et al.* During their research, it was determined that using tamarind in marinades with honey reduces the content of heterocyclic amines.

Regarding the requirements of national and international standards for honey quality and safety, in addition to compliance with organoleptic and physicochemical parameters, the content of antibiotic residues should be monitored (Kumar *et al.*, 2020; Khamid, Pushkar & Hurko, 2020).

The study (Benzik *et al.*, 2020) was designed to explore the impact of the pickling process on the quality of the newly designed food product. The influence of marinating and the duration of heat treatment on the quality of product samples was explored. According to the results of the experiments, the optimal composition of the marinade is proposed.

Quality meat products with high biological value will be quite competitive, which is an integral part of the development and prosperity of any enterprise in the food industry and catering.

The purpose of the study was to develop a marinade with the addition of honey and to explore its effect on the semi-finished meat product depending on the duration of marinating (2 and 24 hours).

Material and Methods

The research was conducted in the laboratory of the Department of Meat, Fish and Seafood Technology of the National University of Life and Environmental Sciences of Ukraine.

Beef hips and marinades based on different types of honey were chosen for the study: goldenrod – crystallised and dense, and citrus – transparent with a liquid consistency. According to organoleptic indicators, the varieties of honey corresponded to the requirements of DSTU 4497:2005 "Natural honey. Specifications", according to the type of plants from which they were collected, had the aroma and taste inherent in this variety and did not contain mechanical impurities and signs of fermentation. According to the scheme of the experiment, the following technology was performed: the meat semi-finished product was pre-incubated in a marinade of oil, honey, salt, pepper and a mixture of herbs for 2 and 24 hours, followed by baking at a temperature of 180°C. There were 5 experimental samples and 1 control in which honey was used in the following proportions (Table 1):

Table 1. *The ratio of honey in the marinade*

Sample number	Honey type	%
c	-	-
1s	Citrus	10
2s	Citrus	20
3s	From goldenrod	10
4s	From goldenrod	20
5s	Citrus + from goldenrod	20 (10 each)

Sampling for organoleptic and physicochemical studies and their preparation for analysis was performed according to GOST 4288-76 "Culinary products and semi-finished products from minced meat. Acceptance rules and test methods".

- organoleptic studies were performed according to DSTU 4426:2005;

- determination of moisture content – GOST 9793-74 "Meat products. Methods of moisture determination";

- fat content – according to GOST 23042-86 "Meat and meat products Methods of determination of fat";

- protein content – GOST 25011-81 "Meat and meat products. Methods of protein determination";

- determination of ash content – GOST 31727-2012 "Meat and meat products. Method the mass fraction of total ash";

- pH – GOST 26188-84 "Fruit and vegetable products, tinned meat and canned meat. Determination of pH";

- determination of moisture-binding and moisture-holding capacity was performed by pressing the samples and the release of free moisture, further calculated using the appropriate formulas.

$$MBC = \frac{(A-B\times 8{,}4)}{A} \times 100$$

where, MBC- moisture binding capacity, %; A – total moisture content in bulk, %; 8.4 – constant, which means the amount of moisture retained by 1 cm^3 filter paper; B – wet spot area, cm^2.

Moisture-holding capacity (%):

$$MHC = \frac{(A-B\times 8{,}4)}{M} \times 100$$

where, MHC – moisture holding capacity of meat, %; A – total moisture in the meat sample, mg; 8.4 – constant, which means the amount of moisture retained by 1 cm^3 filter paper; B – wet spot area, cm^2;

Results

In the course of the research, it was established that the physical and chemical parameters of the initial meat raw materials corresponded to the requirements of the state standard (Table 2). The results of the physicochemical parameters of honey research are presented in Table 3. Analysing the data obtained, it was established that the physicochemical parameters of honey corresponded to the requirements of the highest grade of DSTU.

Table 2. *Physicochemical parameters of beef meat*

Indicator	Experimental sample	According to DSTU 4426:2005
Active acidity, pH	6.00±0.03	5.6-6.5
Mass fraction of moisture, %	69.8±0.2	67.7-70.5
Mass fraction of ash, %	0.91±0.10	1.0
Mass fraction of protein,%	17.5±0.1	18.9
Mass fraction of fat,%	11.2±0.3	12.4
Moisture-holding capacity, %	65.31±0.05	65-67

Table 3. *Main physical and chemical parameters of honey quality*

Indicator	DSTU (Top quality)	Goldenrod honey	Citrus honey
Pollen analysis result	presence of pollen grains	Present	Present
Species composition of pollen grains, % not less	10.0	35.6	41.2
Mass fraction of water, %, no more than	18.5	16.3	17.1
Mass fraction of reducing sugars, %, not less than	80.0	88.4	81.7
Mass fraction of sucrose, %, not more than	3.5	3.5	3.0
Diastasis number, Gote units (Schade units for EU countries), not less than	15.0	16.3	4.1
Hydroxymethylfurfural content, mg/kg, not more than	10.0	7.2	7.4
Acidity, milliequivalents of sodium hydroxide per 1 kg, not more than	40.0	39.1	34.5
Electrical conductivity, mS/cm	0.2-0.1	0.1	0.09
Proline content, mg/kg	300	299	298

In addition, the diastase number of citrus honey, according to the state standard, this figure should not be less than 15 units of Gothe, while according to Directive 2001/110/EC (Council Directive 2001/110/EC, 2001) for citrus honey should be at least 3.0 units Gothe. Whereas the sample of citrus honey in terms of diastase number was 4.1 units of Gothe.

Thus, having examined the organoleptic and physicochemical characteristics of beef and honey varieties used for marinating, it can be concluded that all the requirements of the raw materials corresponded to the quality indicators.

Analysing the methods of marinating meat, for 2 and 24 hours, the observed decrease in the pH of the marinated semi-finished product during the ageing period up to 24 hours indicates the stability of the meat to storage, as most bacteria develop at high pH values, while on acidic nutrient media below 6.2, their development slows down (Fig. 1). The obtained results are confirmed by scientific research of foreign scientists (Yusop *et al.*, 2010)

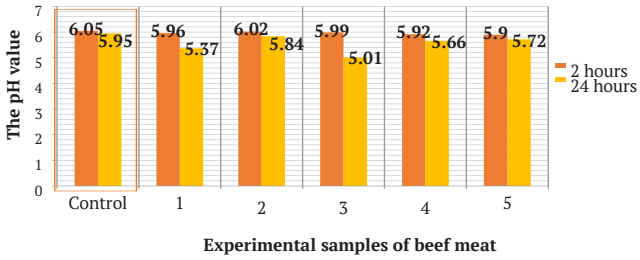

Figure 1. Effect of ageing time on pH change in samples of beef meat

According to the results of determining the physicochemical parameters (Tables 4, 5), it was established that the addition of honey to the marinade increases the protein content in the samples being studied, best of all in samples No. 2 by 0.16 and No. 5 by 0.23 for storage for 2 hours and, respectively, by 0.66% and 0.69% after storage for 24 hours, compared to the control sample. Indicators such as the mass fraction of ash did not vary significantly in all the experimental samples, but the fat content, on the contrary, did not significantly, but increased in all samples, due to sunflower oil, which was part of the marinade.

Table 4. *Physicochemical parameters of portioned semi-finished products in the marinade for 2 hours, %*

Indicator	Characteristic					
	Control	No.1	No.2	No.3	No.4	No.5
Mass fraction of moisture	69.14	70.58	69.84	68.95	68.49	68.05
Mass fraction of fat	12.65	11.31	11.83	12.72	13.25	13.74
Mass fraction of protein	17.30	17.43	17.46	17.45	17.39	17.53
Mass fraction of ash	0.91	0, 88	0.87	0.88	0.87	0.88
Mass fraction of table salt	1.63	1, 61	1.66	1.65	1.62	1.64

Table 5. *Physicochemical parameters of portioned semi-finished products in the marinade for 24 hours, %*

Indicator	Characteristic					
	Control	No.1	No.2	No.3	No.4	No.5
Mass fraction of moisture	69.02	69.61	69.04	67.70	67.32	67.81
Mass fraction of fat	12.72	11.95	12.08	13.49	13.94	14.27
Mass fraction of protein	17.35	17.56	18.01	17.93	17.86	18.04
Mass fraction of ash	0.91	0.88	0.87	0.88	0.88	0.88
Mass fraction of table salt	1.69	1.73	1.81	1.80	1.88	1.78

Thus, the process of marinating increases the hydration and solubility of muscle tissue proteins, due to the accumulation of free myosin (the most moisture-binding protein of meat).

According to the research results of the moisture retention capacity of the marinated semi-finished product during 24 hours of exposure, it was established that this indicator is 1.09 times higher than the samples marinated for 2 hours. Therewith, the moisture binding capacity was 1.6 times higher. As a result, meat with increased moisture binding and moisture holding capacity acquired improved consistency and juiciness. In addition, these results are confirmed by the research of other scientists (Aktaş *et al.*, 2003).

In addition, as a result of the research, it was established that the moisture-binding capacity of beef meat without the addition of honey (control sample) was 49.86%, which is 1.15 times less than the average value of other samples after 24 hours of exposure to the marinade. When marinated for 2 hours, the control sample (without the addition of honey) was 1.64 times less in terms of the value of the MBC compared to the samples marinated with the addition of honey. Thus, with the addition of honey, the moisture binding and moisture holding capacity increases compared to the control, which provides the finished product with taste, smell and colour.

Several physical and chemical changes occur in marinated semi-finished meat products during refrigeration storage: hydrolytic and oxidative changes of oil. The products of these reactions become integral components of meat. Due to the heating of semi-finished products, secondary lipid oxidation products can be generated, which poses

a serious health hazard (Wie˛k *et al*., 2020). It is essential to compose the marinade ingredients in such a way as to minimise these processes.

During the manufacture of semi-finished pork products, the effect of the mustard-honey marinade was determined in comparison with marinades containing apple cider vinegar, white wine vinegar and kefir. The mustard-honey marinade retained the original pH during the ageing period compared to raw meat samples. A significant decrease in pH value in samples treated with apple and white wine marinade ($P<0.05$). The lowest losses during heat treatment were in the samples of mustard-honey marinade. In addition, semi-finished pork products where mustard-honey marinade was used were softer after cooking (Tänavots *et al*., 2018).

The study (Meretukova and Abregova, 2021) determined the effect of marinating and cooking with sous-vide technology, compared to conventional methods, on the quality characteristics of the finished product and shelf life. Pickling, in particular, in vacuum packaging and the proposed method of heat treatment can significantly increase the shelf life of the semi-finished product and improve its taste while maintaining microbiological purity.

To accelerate and improve the absorption of the marinade in semi-finished meat products, in particular pork chops, high-pressure treatment is used. In addition, from a microbiological standpoint, high-pressure treatment, namely at 300, 400 or 500 MPa, extended the shelf life by 16, 22 and 29 days, respectively. The results demonstrated that high-pressure treatment ⩾400MPa increased ($P<0.05$) marinade absorption, which enhanced the organoleptic performance of marinated semi-finished products (O'Neill *et al*., 2019).

Conclusions

The expediency and efficiency of using natural honey in the technology of marinating semi-finished meat products have been theoretically substantiated and experimentally confirmed. It was confirmed that the samples of honey and meat raw materials chosen for the research comply with the requirements of the current regulatory documents.

It was established that when the meat is marinated for 2 hours, the pH value does not change, and after 24 hours it decreases by only 0.13-0.63 units, depending on the type of honey used.

It was established that for marinating for 24 hours, the value of the MHC was 1.09 times higher than the samples marinating for 2 hours on average, while the MBC was 1.6 times higher. As a result, meat with increased moisture binding and moisture holding capacity acquired improved consistency and juiciness.

Based on the results obtained, the area of further research was established, namely, to establish the basic indicators of organoleptic characteristics of the finished product, to determine the complex indicator of the quality of the finished product after baking, and to determine the nutritional and biological value of the products.

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Мед, як складова маринаду для м'ясних напівфабрикатів

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Анотація. Особливості біохімічного складу та властивостей м'ясної сировини зумовлюють необхідність пошуку нових технологій її перероблення для отримання нових продуктів із високими споживчими властивостями. Актуальним напрямом розвитку технології є збагачення м'ясної сировини корисними компонентами з функціонально-технологічними властивостями, що володіють високою біологічною цінністю: апіпродукти та продукти рослинного походження. Метою роботи було розробити маринад з додаванням меду та дослідити його вплив на м'ясний напівфабрикат, в залежності від тривалості маринування. Відбір проб для досліджень та їхнього підготовлення до аналізу здійснювали за ГОСТ 4288-76 «Изделия кулинарные и полуфабрикаты из рубленого мяса. Правила приемки и методы испытаний», органолептичні дослідження проводили за ДСТУ 4426:2005, визначення вмісту вологи – ГОСТ 9793-74 «Продукты мясные. Методы определения влаги», вміст жиру – за ГОСТ 23042-86 «Мясо и мясные продукты Методы определения жира», вміст білків – ГОСТ 25011-81 «Мясо и мясные продукты. Методы определения белка», визначення вмісту золи – ГОСТ 31727-2012 « Мясо и мясные продукты. Метод определения массовой доли общей золы», визначення pH – ГОСТ 26188-84 «Продукты переработки плодов и овощей, консервы мясные и мясорастительные. Определение pH», визначення вологозв'язуючої та вологоутримуючої здатності проводили через пресування зразків та виділення вільної вологи. Відповідно до схеми експерименту визначили технологію за якою відбувалося дослідження. У статті представлено результати дослідження вихідної м'ясної сировини, меду та маринованого напівфабрикату. Встановлено, що зниження pH маринованого напівфабрикату в період 24-годинної витримки забезпечує стійкість м'яса до зберігання, тому що більшість бактерій розвиваються за високих значень pH, тоді, як на кислих поживних середовищах нижче 6,2 їхній розвиток уповільнюється. Тривале маринування дає змогу отримати м'ясо з підвищеною вологозв'язуючою та вологоутримуючою здатністю й поліпшеною консистенцією та соковитістю. Завдання створення нових продуктів потребує нових підходів і прийомів технологій. Використання апіпродуктів, які мають антиокислювальну властивість, дасть змогу утриматися від використання консервантів і стабілізаторів хімічного походження. Через це, мед може бути використаний у складі м'ясних маринованих продуктів. Внесення активних компонентів меду до складу маринаду дасть змогу подовжити термін придатності та відкоригувати органолептичні властивості. Також під час термічного оброблення м'ясо, замариноване медовим маринадом, набуває нових смакових якостей, зовнішній вигляд стає більш яскравим через карамелізацію меду

Ключові слова: безпечність, компоненти, спосіб та тривалість маринування, органолептичні та фізико-хімічні показники, природні антиоксиданти

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Fatty acids content in milk of cows under the influence of β-carotene

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Abstract. For the enrichment of milk with vitamin A and β-carotene, vitaton is used, which contains up to 10% of trans-β-carotene, which can be converted into vitamin A, and demonstrate antioxidant, immunostimulating and anticarcinogenic effects in the body. Previous studies have demonstrated that in sanitary terms, the biomass of the fungus *Bl. trispora* is safe for animals and can be used in animal husbandry to prevent diseases of the mammary gland, and digestive organs, increase reproductive function and obtain healthy viable offspring. The research was conducted on cows of the Ukrainian black-and-white dairy breed in the conditions of LLC "Kuibysheve", Poltava region. The purpose of the research was to determine the content of fatty acids in milk fat of lactating cows, as with the introduction of vitatons, lipids, higher saturated and unsaturated fatty acids, vitamins E and B, which to some extent can affect the processes of synthesis of milk components in the mammary gland. Determination of lipid content and their fractions in milk fat was performed on a gas chromatograph-mass spectrometer Agilent Technologies. Established that the introduction of vitaton in the diet for cows increases the fat content in milk by an average of 0.26% and enhances the synthesis of phospholipids in the mammary gland by 1.8 times. The ratio of unsaturated to saturated free fatty acids in the milk fat of cows of the experimental group did not vary from the control, which indicates a positive effect of β-carotene on the intensity of milk fat biosynthesis in the secretory epithelium of the mammary gland of cows. Vitaton stimulated the establishment and inclusion of two unsaturated fatty acids, namely nonadecanoic and α-linolenic acids in the composition of milk fat against the background of the disappearance of the arachidonic acid peak on the chromatogram. It is established that the samples of milk fat from cows of the control group contained arachidonic acid, which was absent in the milk of cows of the experimental group, which is probably due to the inclusion of these higher fatty acids and their isomers, which are part of vitaton, in the composition

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of milk fat, and the effect of β-carotene on the synthesis of milk lipids. The results of the research are essential for the production of biologically complete milk and its products, which will have antioxidant properties and will be enriched with vitamin A and β-carotene

Keywords: lactating cows, milk, butter, milk lipids, vitaton, fatty acids

Introduction

The production of high-quality and biologically complete livestock products is impossible without using several biologically active substances in animals, namely: macro- and microelements, immunostimulants, hepatoprotectors, antioxidants, dyes, flavouring, aromatic additives, vitamins and vitamin-like substances, including carotenoids. Their widespread use in the practice of livestock production is primarily associated with the prevention of diseases, stimulation of growth, development and productivity of animals, and improvement of the quality and biological value of livestock products (Ul Haq *et al.*, 2014; Lopes *et al.*, 2016; Wang & Bu, 2015; Hassan Rafiee *et al.*, 2016; Sukhikh *et al.*, 2019).

The transition of livestock production to industrial technologies requires a complete revision of the concept of providing animals with biologically active substances, including β-carotene, which is associated with the dry type of feeding of many species of farm animals, and hence the emergence of some problems in the preparation, storage and introduction of juicy fodders as a source of carotenoids into complete fodder (Shevchenko *et al.*, 2018; Abd El-Salam & El-Shibiny, 2020; Đorđević, Nenad *et al.*)

Currently, more than 600 carotenoids are known, and their structure, chemical properties and physical characteristics have been explored, which allows them to be used as antioxidants, stimulants of animal growth and development, photo- and radioprotectors, immunostimulants, precursors of vitamin A, dyes for livestock products, etc. Scientists have explored the species composition of carotenoids in many plants, fungi, bacteria and algae, and explored their effect on the clinical condition, productivity, metabolism, reproductive capacity and quality of animal products (Shevchenko *et al.*, 2018; Lutfiye Yilmaz-Ersan *et al.*, 2018).

At present, the problem of providing the demand of animals with carotenoids remains unresolved, since there is no single concept for determining the efficiency of using both a mixture of carotenoids and their representatives, which have different effects on the body of animals, including provitamin.

The transition of livestock to industrial technologies requires a complete revision of the concept of providing animals with biologically active substances, including β-carotene, which is associated with the dry type of feeding of many types of farm animals, and hence the emergence of some problems in the preparation, storage and introduction of juicy fodder as a source of carotenoids into the composition of complete fodder.

According to the latest data, it is known that the content of β-carotene in blood plasma and colostrum of cows does not always indicate a sufficient supply of their body vitamin A, while the concentration of vitamin A in colostrum is one of the most objective indicators in the diagnosis of A-hypovitaminosis of cows (Sakhniuk, 1997).

The content of carotenoids and vitamin A in cows' milk depends on the season of the year.

Thus, in the winter-stall period of keeping cows in milk, the lowest concentration of β-carotene and vitamin A is observed. During the transfer of animals to pastures, the level of β-carotene first increases, and later – the content of vitamin A in milk. In addition, the breed of cows has a significant impact on the accumulation of carotenoids in milk. Thus, the milk of cows of Shvitz, Simmental, Chervonogorbatov and Red Steppe breeds contains an average of 180 – 190 μg/kg of carotene, in the milk of cows of the Brown Latvian breed – up to 240 μg/kg of carotene, while the milk of cows of other breeds is much poorer in this biologically active compound (Carrara *et al.*, 2021).

The level of vitamin A and β-carotene in colostrum and milk of cows is largely determined by the composition of the diet and lactation period. Thus, the colostrum of the first milk yield contains 134.0 μg/l of vitamin A and 396.0 μg/l of β-carotene, the milk of the sixth milk yield – 80.0 and 60.0 μg/l, and the tenth milk yield – 27.0 and 25 μg/l, respectively. The transition of carotenoids into milk provides the intensity of its colour and largely depends on the breed characteristics of cows. A study of the colour of cow milk and its β-carotene content demonstrated that milk obtained from purebred Friesian cows contained less β-carotene than that from non-purebred cows (Strickland *et al.*, 2021).

The accumulation of carotenoids in cattle fat is influenced by age and feeding level. Thus, the accumulation of carotenoids in fat is less intense in free-feeding bulls at the age of one and two years than in restricted feeding (Boom & Sheath, 1997; Retrini *et al.*, 2022).

One of the ways to increase the level of carotenoids and retinol in milk is the development and implementation of biologically active fodder supplements for cows. Several studies by leading scientists of the CIS countries, the USA and Japan are devoted to this issue. Thus, feeding dry cows with β-carotene of microbial origin at a dose of 15 g per head per day increased the level of vitamin A in the milk of the first milk yield by 33.8%, and carotene – by 26.8% compared to animals that did not receive this supplement. The same dependence persisted on the fifth to the seventh day of lactation (Vargas-Bello-Pérez *et al.*, 2020).

Partial replacement of silage β-carotene with β-carotene of microbial origin improves the saturation of colostrum and milk of Holstein cows both with carotene and vitamin A and with protein (Ulytko *et al.*, 1997). In addition, several studies have confirmed the superiority of carotene of microbial origin over the carotene of corn silage, alfalfa and coniferous flour. Therewith, it was established that the level of vitamin A in the colostrum of cows fed with microbial β-carotene was the highest, which exceeded the value in animals fed with silage by 1.71 and 1.57 times, respectively. In the milk of cows of this group, a similar pattern of β-carotene accumulation was observed (Ulytko & Dushkyn, 2002).

Replacement of 32-43% of silage carotene in cow diets with carotene of microbial origin allowed for increasing milk productivity of cows by 9.7-14.0% and contributed to an increase in milk fat content, particularly during the winter-stall period (Alekseeva *et al.*, 2001; Yemets & Mamenko, 2020). Using lipocarotene (an oil extract of the biomass of the fungus Bl. trispora) in the feeding of cows at a dose of 20 ml per head per day contributed to an increase in productivity by 0.5 kg of milk per day, fat content in milk – by 0.2% (Kartamysheva & Khmelkov, 2006; Yakubchak *et al.*, 2018).

The transformation product of β-carotene – vitamin A significantly affects the quality of cows' milk. Thus, the inclusion of vitamin A

in the composition of fodder for cows in a dose increased by 10 and 25% compared to the demand, contributing to an increase in average daily milk yield by 6.3-10.3%. The milk of cows that consumed fodder with a high content of vitamin A contained more fat (by 0.29-0.50%) and protein (by 0.12-0.18%). Therewith, it was more thermostable and withstood exposure to 80% alcohol concentration against 72% in the control (Belykova *et al*., 2005).

There is an opposite standpoint on the accumulation of carotenoids in animal products. Thus, using pasture cattle in Zealand causes the problem of increased carotenoid content in carcass fat and milk fat, which, from the standpoint of experts, worsens the marketability of meat and dairy products. To solve this problem, the Zealand scientists developed a lifetime test for determining the degree of yellowness of fat in cattle carcasses, which is based on the determination of the ratio of cholesteryl and plasma carotenoids (Knight *et al*., 2001). In addition, the yellowness of fat correlates with the content of saturated and monounsaturated fatty acids. The authors conclude that the advantages of yellow fat meat over white fat meat are insignificant (Knight & Death, 1997).

On the other hand, the increase in the content of carotenoids and vitamin A in milk and its processed products is of interest to specialists in terms of creating mass and specific food products enriched with vitamins, particularly antioxidants. According to the All-russian Health Organisation, milk and dairy products in the human diet constitute at least 50%, and they occupy the same place in the diets of the population of Ukraine and other countries of the world. XXV and XXVI International Dairy Congresses (1998, 2002) were dedicated to the establishment and development of functional dairy products (Vasheka & Rashevska, 2005; Galstian & Avetysian, 2005; Zielinska *et al*., 2019).

Thus, notably, the problem of their establishment is solved mainly by using the introduction of oil extracts and cryopowders of biologically active substances into finished products (Hryhoreva, 2003).

As for β-carotene, it is added to milk in the form of 1% concentrate based on 30% paste based on CPMC. Thus, its concentration in the finished product is 50 mg/kg, which does not affect the viability of lactic acid bacteria such as bifidobacteria, bacillus and Str. termophylus provides further processing of milk (Narushyn, 2004; Katserykova *et al*., 2000), improves organoleptic properties and prolongs the shelf life of this product (Polianskyi *et al*., 2001).

Thus, β-carotene is introduced into the composition of dairy products such as butter, which contains 0.03% of this biologically active substance in the finished product. However, there is another standpoint on the direct introduction of β-carotene preparations of microbial origin into food products. There is evidence of the intake of foreign metabolic products of fungi producing carotenoids into the human body, which can cause various disorders in body tissues and cause side effects (Mahintha, 2022; Ulfman, 2022).

Thus, using β-carotene in cows feeding solves both the issues of prevention of diseases of the mammary gland and digestive organs, reproduction and obtaining healthy viable offspring and production of biologically complete milk and its products. However, the problem of obtaining milk with a high content of β-carotene and vitamin A remains unresolved due to the lack of scientifically sound recommendations on using new sources of natural β-carotene (especially microbial synthesis) in cow feeding, in-depth studies on quality, and biological integrity and sanitary safety of the products.

The purpose of the research. The purpose of the research was to determine the content of fatty acids in milk fat of cows with the addition of vitaton with β-carotene content of 5% to their diet.

Materials and Methods

In the experiment, the efficiency of using β-carotene of the fungus Bl. trispora in cows was determined to improve the quality of milk at different types of feeding. For this purpose, two groups of cows of the Ukrainian black-and-white dairy breed were established: control and experimental in LLC "Kuibysheve", Poltava region. The cows of the experimental group (189 cows) were fed vitaton with β-carotene content of 5% in addition to the fodder of the main diet. The dose of vitaton for lactating cows was 2 kg/t of fodder. The experiment lasted 120 days. Animals of the control group (216 cows) were fed fodder of the main diet. Average daily milk samples were collected monthly to determine the quality and production of butter in which the content of carotenoids, vitamin A and fatty acids was determined.

Determination of lipid content and their fractions in milk fat was performed by chromatographic separation in thin layers of silica gel (Silufol, Czech Republic) using a system of solvents hexane:diethyl ether:acetic acid in a ratio of 76:23:1. The content of individual lipid fractions was determined using a densitometer after staining chromatograms with 5-10% phosphoric-molybdenum acid solution in ethanol. Chromatograms were developed for 4-5 min at 90-110°C (Veselskyi *et al.*, 2001).

The fatty acid content of butter was determined after saponification and extraction with hexane. The obtained methyl esters were analysed on a gas chromatograph-mass spectrometer Agilent Technologies 6890N/5973 N, chromatographic column DB-5MS; L=30 m; Id=0.25 mm, catalogue No. 122-5532 Agilent Technologies, F: lm=0.25 mm, carrier gas – helium (DSTU ISO 5508:1990, 2003). The research results were processed statistically (Kokunyn, 1975).

Results and Discussion

Dairy productivity and milk quality of cows are determined primarily by the clinical condition of animals, the intensity of metabolic processes in the tissues of the body and the mammary gland, which are closely related to the level of supply of nutrients and biologically active substances, including vitamin A and its precursor β-carotene. The introduction of vitaton as a source of β-carotene into the composition of lactating cows' fodder provides for the intake of lipids, higher saturated and unsaturated fatty acids, and vitamins of groups E and B, which to some extent can affect the processes of synthesis of milk components in the mammary gland of cows.

Assimilation and transport of β-carotene and retinol in the digestive apparatus of animals are closely related to lipid metabolism, namely with the absorption of higher fatty acids into the blood and lymph and their participation in the synthesis of milk fat, as evidenced by an increase in milk fat content by an average of 0.26% compared to the control (Table 1).

Table 1. *Physicochemical properties of cow milk, %, M±m, n=6*

Indicator	Group	
	Control	Experimental
Fat	4.21±0.04	4.47±0.06*
SMMG	8.52±0.07	8.58±0.10
Density, g/cm^3	1.027±0.0002	1.027±0.0005

Table 1. Continued

Indicator	Group	
	Control	Experimental
Protein	3.07±0.03	3.10±0.03

The increase in fat content in the milk of cows of the experimental group with vitaton supplementation is consistent with an increase in the synthesis of phospholipids in the mammary gland by 1.8 times compared to the control (Table 2). The data obtained are consistent with the results of previous studies, namely, the increased content of phospholipids in the colostrum of the first milk of cows when feeding them vitaton during the dry period.

The content of free and esterified cholesteryl in the milk of cows fed with vitaton was at the level of animals of the control group, which indicates the absence of adverse effects of β-carotene on the processes of transport and absorption of cholesteryl in the tissues of cows.

Table 2. *Composition and lipid content of cow milk, mg/100 ml, M±m, n=4-5*

Indicator	Group	
	Control	Experimental
Phospholipids	28.07±1.50	50.15±6.57*
Free cholesteryl	24.78±3.33	31.76±4.55
Esterified cholesteryl	22.68±1.77	23.48±1.64
Higher fatty acids (short-chain)	18.68±2.24	25.52±4.44
Higher fatty acids (long-chain)	25.36±1.74	30.52±3.95
Diglycerides, g/l	11.05±0.66	12.86±0.58
Triglycerides, g/l	24.13±0.67	27.22±2.23

The content of di- and triglycerides in the milk of cows using vitaton in the first 30 days of lactation did not differ significantly from the same indicators of milk obtained from cows of the control group.

Feeding vitaton to lactating cows did not affect the total content of higher fatty acids, both short- and long-chain, in milk compared to the control, which is consistent with the data of free fatty acids analysis by gas chromatography-mass spectrometry (Table 3).

Therewith, the total content of saturated acids: caprylic, caproic, lauric, myristic, pentadecanoic, palmitic, margarine, stearic, and unsaturated acids: oleic, palmito-oleic and linoleic in milk fat obtained from the milk of cows of the experimental group with vitaton feeding was at the level of animals of the control group.

Notably, the ratio of the total content of saturated to unsaturated fatty acids in the milk of cows under the action of vitaton was at the level of animals of the control group, which indicates the absence of influence of the components of the biologically active additive on the processes of milk fat synthesis.

Table 3. *Total fatty acid content in butter (fat content 78%), mg/kg, M±m, n=3*

Fatty acid	Group	
	Control	Experimental
Caprylic	1845.28±224.75	1504.97±149.55

Table 3. Continued

Fatty acid	Group	
	Control	Experimental
Capric	12451.41±713.90	7112.15±758.82
Lauric	8213.44±384.68	11602.94±871.35
Tridecylic	205.51±39.13	782.62±39.62
Myristic	78457.44±5593.35	70969.54±9592.81
Pentadecylic	5830.38±611.55	4032.86±322.87
Palmitic	311282.37±32074.00	270485.75±5959.82
Margaric	4329.72±747.52	3180.64±349.63
Stearic	104944.42±17887.20	81676.94±2940.12
Nonadecylic	-	565.57±76.21
Arachidic	960.80±135.54	784.35±43.82
Oleic	238021.59±36561.72	207070.65±5801.40
Palmitoleic	7527.23±586.73	6345.99±218.76
Linoleic	21429.86±2321.98	14166.37±754.52
α-Linolenic	-	803.61±112.53
Arachidonic	1032.35±125.73	-
Total acid content	795775.06±10280.48	680172.18±16993.12
including the content of saturated acids	528452.26±50105.91	452321.31±10233.01
unsaturated acids	267322.80±5300.48	227850.87±6760.26
Ratio of unsaturated to saturated acids	1:2	1:2
Share of saturated acids in their total content, %	66.4	66.5

The level of free fatty acids in the milk of cows fed with vitaton was at the level of similar indicators of the control group, which is consistent with the total level and content of conjugated fatty acids in milk fat (Tables 4, 5).

Table 4. *Content of free fatty acids in butter (fat content 78%), mg/kg, M±m, n=3*

Fatty acid	Group	
	Control	Experimental
Caprylic	416.76±24.80	402.40±27.41
Capric	1110.66±58.84	1281.93±42.37
Lauric	1704.59±83.29	1682.09±117.56
Myristic	7813.09±380.00	8932.66±547.31
Pentadecylic	941.89±143.86	586.14±36.15
Palmitic	29593.35±2628.12	22020.50±1589.69
Margaric	603.75±127.76	473.37±17.47
Stearic	8682.99±462.70	8663.43±513.82
Oleic	22518.57±2253.62	16358.52±1185.70

Table 4. Continued

Fatty acid	Group	
	Control	Experimental
Palmitoleic	1446.82±282.09	1001.71±145.82
Linoleic	3764.94±352.26	2032.11±244.65
Total acid content	76209.21±6158.21	56228.79±3999.42
including the content of saturated acids	50216.12±4713,99	37847.70±2689.85
unsaturated acids	25993.06±3452.37	18381.09±1311.09
Ratio of unsaturated to saturated acids	1:1.9	1:2
Share of saturated acids in their total content, %	65.9	67.3

As it can be seen from the data obtained, the main proportion of free fatty acids in milk fat of cows with vitaton feeding is oleic and palmitic, which respectively 29 and 39% of the total free fatty acids, which were at the level of similar indicators in the control.

The ratio of unsaturated to saturated free fatty acids in the milk fat of cows of the experimental group did not vary from the control, which indicates a positive effect of β-carotene on the intensity of milk fat biosynthesis in the secretory epithelium of the mammary gland of cows.

Table 5. *Content of conjugated fatty acids in butter (fat content 78%), mg/kg, M±m, n=3*

Fatty acid	Group	
	Control	Experimental
Caprylic	1567.45±428.06	1236.70±167.61
Capric	11340.88±765.72	5830.21±105.42
Lauric	6508.86±322.18	9920.85±168.11
Tridecylic	205.51±39.13	782.62±39.62
Myristic	70644.35±9443.61	65014.43±8204.58
Pentadecylic	5202.45±128.93	3642.09±409.50
Palmitic	281685.69±28216.69	248465.26±5680.12
Margaric	3927.22±102.88	2707.30±166.71
Stearic	96261.44±1853.98	75901.31±2853.90
Nonadecylic	-	565.57±56.73
Arachidic	960.80±35.54	784.35±43.82
Oleic	215503,04±3538,89	190712.09±5509.38
Palmitoleic	6562.69±251.15	5678.18±208.70
Linoleic	18919,90±1193.85	12811.62±724.11
α-Linolenic	-	803.61±76.53
Arachidonic	1032.35±109.99	-
Total acid content	719565.91±10325.12	623943.40±16264.88
including the content of saturated acids	478236.13±55346.21	414473.63±9823.51
unsaturated acids	241329.74±4988.02	209469.80±6449.43

Therewith, notably, during the feeding of vitaton in the milk of cows of the experimental group, two unsaturated acids appeared, namely nonadecanoic and α-linolenic acids, which were identified as conjugated compounds, probably di- or triglycerides, while in the samples of milk fat from cows of the control group contained arachidonic acid, which was absent in the milk of cows of the experimental group. It is probably connected with the inclusion of these higher fatty acids and their isomers, which are part of vitaton, in the composition of milk fat, and the influence of β-carotene on the synthesis of milk lipids.

Conclusions

Thus, it can be concluded that the biomass of the fungus *Bl.trispora* strain TKST (vitaton) is an effective source of β-carotene for animals, as it contains a high concentration of active substances (10-12% in terms of dry matter) and a complex of biologically active substances that promote the absorption and transformation of carotenoids in the body of animals.

It was established that feeding lactating cows with vitaton as a source of natural β-carotene does not significantly affect the content and ratio of free fatty acids in milk fat, but promotes the inclusion of nonadecanoic and α-linolenic fatty acids instead of arachidonic fatty acids in the conjugated form in milk lipids.

Further research in this area will allow obtaining of dairy products with antioxidant properties, which will be enriched with vitamin A and β-carotene. And considering the properties of vitaton and the introduction of trans-β-carotene of Bl. trispora fungus into animal fodder can significantly affect the processes of gene transcription and regulation of reproductive capacity, homeostasis of the antioxidant defence system, tissue regeneration and immune protection, and improve the biological integrity of products, which will preserve the health of animals, extend their productive life, obtain healthy viable offspring and increase the efficiency of livestock production.

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Вміст жирних кислот в молоці корів за дії β-каротину

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Анотація. Для збагачення молока вітаміном А та β-каротином, використовують вітатон, який містить до 10 % транс-β-каротину, здатного перетворюватись у вітамін А, а також проявляти антиоксидантну, імуностимулюючу і антиканцерогенну дію в організмі. Дослідженнями, які були проведені нами раніше, встановлено, що в санітарному відношенні біомаса гриба *Bl. trispora* є безпечною для тварин і може використовуватися у тваринництві для профілактики захворювань молочної залози, органів травлення, підвищення відтворної функції та одержання здорового життєздатного потомства. Дослідження було проведено на коровах української чорно-рябої молочної породи в умовах СТОВ «Куйбишеве» Полтавської області. Метою досліджень було встановити вміст жирних кислот у молочному жирі лактуючих корів, тому що, при введенні вітатону, до організму тварин надходять також ліпіди, вищі насичені та ненасичені жирні кислоти, вітаміни групи Е та В, що певною мірою може впливати на процеси синтезу компонентів молока в молочній залозі. Визначення вмісту ліпідів та їх фракцій у молочному жирі проводили на газовому хромато-мас-спекрометрі Agilent Technologies. Встановлено, що введення вітатону до складу раціону для корів сприяє збільшенню вмісту жиру в молоці в середньому на 0,26 % та посиленню синтезу фосфоліпідів у молочній залозі в 1,8 раза. Співвідношення ненасичених до насичених вільних жирних кислот у молочному жирі корів дослідної групи не відрізнялося контролю, що свідчить про позитивний вплив β-каротину на інтенсивність біосинтезу молочного жиру у секреторному епітелії молочної залози корів. Вітатон стимулював утворення та включення до складу молочного жиру двох ненасичених жирних кислот, а саме нонадеканової та α-ліноленової на фоні зникнення на хроматограмі піку арахідонової кислоти. Встановлено, що у зразках молочного жиру в корів контрольної групи містилася арахідонова кислота, яка була відсутня в молоці корів дослідної групи, що, ймовірно, пов’язано з включенням цих вищих жирних кислот та їх ізомерів, що входять до складу вітатону, до складу молочного жиру, а також впливом β-каротину на синтез ліпідів молока. Результати дослідження важливі для виробництва біологічно повноцінного молока і продуктів його переробки, що матимуть антиоксидантні властивості і будуть збагачені вітаміном А та β-каротином

Ключові слова: лактуючі корови, молоко, масло вершкове, ліпіди молока, вітатон, жирні кислоти

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Biological efficiency of rainbow trout meat lipids depending on the levels of amino acids in fodder

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Abstract. In trout farms of Ukraine, when using compound fodder for their production, the question arises of clarifying the requirement of rainbow trout in energy, protein and amino acids to achieve the maximum realisation of its biological productivity potential. Accordingly, the research explored the effect of using complete fodder with various levels of lysine and methionine on the biological efficiency of rainbow trout meat lipids. The purpose of the experiment was to determine the effect of different levels of amino acid nutrition of commercial rainbow trout on the fatty acid composition of meat lipids and their biological efficiency. For this purpose, five experimental groups were established by the method of analogues. The experiment lasted 210 days and was divided into two periods: equalising (10 days) and main (200 days). During the equalisation period, the feeding diet was the same for the fish of the control and experimental groups. During the main period, the level of lysine and methionine in the experimental fodders for different experimental groups of trout ranged from 2.5 to 2.9% and from 0.8 to 1.0%, respectively. Feeding of rainbow trout during the study period was performed 4-6 times a day, during the daytime at regular intervals. The required amount of fodder was calculated according to the individual weight of the fish and the temperature of the environment during feeding. Cultivation of marketable two-year-olds was performed in ponds with an area of 100 m^2 at a planting density of 50 specimens/m^2 and a water level of 1 m. The total number of trout in the experimental studies was 25 thousand specimens. It is established that the main share of fatty acids of lipids of rainbow trout meat is saturated fatty acids and monounsaturated fatty acids. As a result of the research, it was determined that using feed with increased levels of lysine and methionine for fish of the 4th experimental group was accompanied by an increase in the content of the sum of saturated fatty acids in meat by 5.84% compared to the control. With the growth of amino acid nutrition of the fodder, there is an increase

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in the content of linoleic acid in trout m′eat by 0.19-0.24% compared to the control. The practical value of the scientific work is to substantiate approaches to the technological bases of increasing the efficiency of using fodder nutrients in trout farming to ensure high fish productivity, which is of great economic importance

Keywords: rainbow trout, fish feeding, mixed fodder, lysine, methionine, meat, lipids, fatty acid composition

Introduction

Fish flesh is one of the most vital foodstuffs for humans and a source of complete proteins, fat, minerals, and vitamins. Its quality and nutritional value depend on both genotypic and phenotypic factors with the latter presupposing rational and balanced fish feeding [1;2;3].

Using complete compound feeds with different lysine and methionine levels directly affects the bioefficacy of rainbow trout flesh lipids [4;5]. Consequently, it is essential to explore the influence of different amino acid nutrition types of commercial rainbow trout on the flesh bioefficacy indicators in modern industrial conditions of cold-water fish farms in Ukraine.

Materials and Methods

Experimental studies were conducted on two-year-old rainbow trout *Oncorhynchus mykiss* in the Shypot fish farm of Perechyn district in Zakarpattia region. The scientific and economic experiment was designed to determine the effect of different types of amino acid nutrition of commercial rainbow trout on the biological efficiency of meat lipids and its fatty acid composition. For this purpose, were formed five experimental groups by the method of analogues (Table 1).

Table 1. *The design of scientific and economic experiment*

Fish group	Stocking density at the beginning of the experiment, specimen/m²	Mean body weight at the beginning of the experiment, g	Experimental periods			
			Equalising (10 days)		Main (200 days)	
			Content per 1 kg of compound fodder, %			
			Lysine	Methionine	Lysine	Methionine
1– control	50	53.9±3.17	2.7	0.9	2.7	0.90
2 – experimental	50	53.4±2.86			2.5	0.80
3 – experimental	50	54.2±3.74			2.6	0.85
4 – experimental	50	52.7±3.29			2.8	0.95
5 – experimental	50	54.0±3.06			2.9	1.00

During the equalising period of equalisation, the experimental fish consumed fodders equal to the control group with the same content of lysine and methionine. During the main period, fish of all experimental groups received a similar ration except for lysine and methionine levels. The abovementioned amino acids were added in varying proportions as provided by the experimental design. The nutritional value of the experimental grower compound feeds is presented in Table 2.

Table 2. *Chemical composition of compound fodder*

Indicator	Group				
	1st	2nd	3rd	4th	5th
Metabolic energy, MJ/kg	17.00	17.00	17.00	17.00	17.00
Crude protein, %	48.00	48.00	48.00	48.00	48.00
Crude fat, %	18.00	18.00	18.00	18.00	18.00
Crude fibre, %	2.40	2.40	2.40	2.40	2.40
Calcium, %	1.80	1.80	1.80	1.80	1.80
Total phosphorus, %	1.20	1.20	1.20	1.20	1.20
Lysine, %	2.70	2.50	2.60	2.80	2.90
Methionine, %	0.90	0.80	0.85	0.95	1.00
Vitamin A, thousand IU	10	10	10	10	10
Vitamin D_3, thousand IU	3	3	3	3	3
Vitamin E, mg/kg	200	200	200	200	200

During the study, rainbow trout were fed 4-6 times a day, in the daytime and at regular intervals. The required amount of compound feeds was calculated based on the indices of individual fish weight and ambient temperature at the time of feeding.

Commercial two-year-olds were reared in ponds with an area of 100 m^2 at a stocking density of 50 specimens/m^2, and a water level of 1 m. The total number of trout in experimental studies was 25 thousand specimens. Conditions for keeping experimental fish correspond the regulatory requirements in salmon farming [6;7].

The mass fraction of lipids was determined by the Soxhlet extraction method in accordance with DSTU 8717 [8]. The fat was weighed after its solvent extraction from a dry sample using a Soxhlet apparatus based on the determination of the sample mass change after the solvent extraction rendering.

The fatty acid content was determined using the chromatographic technique on a Kupol 55 chromatograph. The peaks in the chromatogram were identified by calculating the "carbon numbers" and by using chemically pure standard solutions and fatty acid methyl esters. The content of individual fatty acids based on the results of gas chromatographic analysis, i.e. chromatograms, was calculated according to the formula including correction factors for each of such acids. The above correction factors were defined as the ratio of the peak areas (namely peak heights) of heptadecanoic acid (internal standard) and tested acids at a concentration of 1:1 and isothermal operation of the gas-liquid chromatograph.

The mass fraction of polyunsaturated fatty acids (PUFA) was determined by the chromatographic technique on an HRGC 5300 chromatograph; lipids were extracted by the Folch and Bligh-Dyer extraction method; lipid efficiency ratio was determined by the calculation method; lipid biological significance coefficient (BSC) was calculated as the ratio of the sum of eicosapentaenoic and docosahexaenoic PUFAs to the mass fraction of fat in the product [9;10;11].

The research results were processed by the variation statistics [12;13;14] technique using the STATISTICA 7.0 software, and MS Excel with the built-in statistical functions.

Research and Discussion

The research results have identified that different levels of limiting amino acids in compound fodders for commercial rainbow trout entail some changes in the fatty acid composition of the flesh (Table 3).

As can be seen from the above data, the bulk of fatty acids in rainbow trout flesh lipids are saturated fatty acids, mainly palmitic and nonadecanoic acids and monounsaturated acids where oleic acid predominates.

Linolenic and linoleic acids occupy a unique position among PUFA since they are essential for human nutrition and the treatment and prevention of many diseases.

Experimental studies indicate that different types of rainbow trout amino acid nutrition do not significantly affect the fatty acid composition of flesh lipids [15;16]. Thus, using compound fodders with an increased level of lysine and methionine for fish of the fourth experimental group throughout rearing entailed an increase in saturated fatty acids in the flesh by 5.84% versus control. It is explained by an increased content of palmitic (by 5.42%), stearic (by 0.59%), and arachidic (by 0.21%) acids in the flesh versus control.

The value of nonadecanoic acid concurrently decreased. Thus, the content of the indicated acid in the fourth group trout flesh was 0.45% lower versus control.

Table 3. *Fatty acid composition of commercial rainbow trout flesh lipids (n=5)*

Fatty acids	Fatty acid code	Groups				
		1st	2nd	3rd	4th	5th
Saturated fatty acids (SAFA)		44.73	46.80	49.55	50.57	48.60
myristic	14:0	2.31±0.78	2.18±0.68	2.42±0.95	2.38±0.87	2.36±0.36
palmitic	16:0	19.08±1.24	21.6±2.84	23.1±2.04	24.5±1.02*	23.4±1.27*
stearic	18:0	3.15±0.63	3.12±0.41	3.55±0.74	3.74±0.68	3.66±0.47
arachidic	20:0	0.88±0.08	0.81±0.06	0.93±0.09	1.09±0.08	1.06±0.06
nonadecanoic	19:0	19.31±2.13	19.09±2.31	19.55±2.14	18.86±2.58	18.12±2.69
Monounsaturated fatty acids (MUFA)		35.52	37.70	36.98	36.82	36.66
palmitoleic	16:1	6.12±0.96	7.08±0.87	7.83±0.94	6.31±0.81	6.10±0.79
ω_9 oleic	18:1	14.08±1.44	14.93±1.24	14.62±2.12	15.10±2.39	15.31±2.69
ω_9 elaidic	18:1	1.21±0.09	1.38±0.06	1.44±0.02*	1.28±0.04	1.32±0.06
gadoleic	20:1	14.11±1.69	14.31±3.01	13.09±1.97	14.13±2.14	13.93±2.33
Polyunsaturated fatty acids (PUFA)		3.33	3.45	3.62	3.75	3.65
linoleic ω_3	18:2	1.74±0.09	1.78±0.12	1.78±0.11	1.93±0.09	1.98±0.05*
linolenic ω_6	18:3	0.83±0.04	0.88±0.09	0.93±0.06	0.94±0.07	0.84±0.05
eicosadienoic	20:2	0.76±0.02	0.79±0.06	0.91±0.06*	0.88±0.04*	0.83±0.07
Not identified		16.42	12.05	9.85	8.86	11.09

*Note: *p < 0.05 compared to the 1st group*

A similar pattern was inherent with MUFA. In particular, an increase in the content of limiting amino acids in diets for commercial rainbow trout resulted in an increase in the content of MUFA in meat by 1.14-2.18% relative to control analogues. It was explained by an increase in the content of oleic and elaidic acids.

In addition, it was discovered that using compound fodders with high levels of amino acid nutrition when feeding rainbow trout of the 4th and 5th experimental groups entailed a decrease in the MUFA content in the flesh, namely palmitoleic and elaidic acids, compared to the indicators of the 2nd group specimens.

Additionally, there were significant differences between two-year-old trout of different groups in terms of PUFA content in the flesh such as linoleic and linolenic amino acids. Thus,

an increase in the amino acid nutritional value of the compound fodders evoked an increase in the content of linoleic acid in the trout flesh by 0.19-0.24% versus control.

Overall, the highest content of fatty acids in the flesh inhered in commercial trout of the 4th experimental group fed with compound fodders with a lysine and methionine content of 2.8% and 0.95%, respectively.

Fish lipids are basic labile components affecting the nutritional and biological value of fish products. Fish oil is mainly distinguished by the predominance of unsaturated fatty acids (up to 84%), including fatty acids. Based on this, it was important to explore the biological efficiency of lipids of meat of two-year-old rainbow trout depending on the growing conditions (Table 4).

Table 4. *Bioefficacy indicators of flesh lipids in two-year-old rainbow trout (n=5)*

Group	Ratio of fatty acid types			
	SAFA:MUFA:PUFA	PUFA:SAFA	C 18:2:C:18:1	ω_6: ω_3
Ideal lipid	1:1:1	0.2:0.4	>0.25	10:1
1st	1:0.79:0.07	0.07:1	1:8.09	1:2.10
2nd	1:0.81:0.07	0.07:1	1:8.39	1:2.03
3rd	1:0.75:0.07	0.07:1	1:8.21	1:1.91
4th	1:0.73:0.07	0.07:1	1:7.82	1:2.05
5th	1:0.75:0.08	0.08:1	1:7.73	1:2.36

The experimental data obtained indicate that the growth of rainbow trout on fodder with different amino acid compositions contributed to the increase of biological efficiency of meat.

The C18:2:C18:3 ratio of fatty acids has proved to be consistent with the literature reports and is indicative of a high bioefficacy of rainbow trout flesh lipids. The ratio of the these fatty acids in flesh with predominantly ω_3 valuable fatty acids is of considerable interest.

The calculations demonstrate that the increase in the number of limiting amino acids (lysine and methionine) in grower compound fodders for commercial trout (3rd and 4th groups) has been accompanied by the accumulation of ω_3, ω_6 valuable fatty acids in the flesh.

Conclusions

1. The conducted research demonstrates the influence of different levels of amino acid nutrition of commercial rainbow trout on the fatty acid composition of flesh lipids and their bioefficacy.

2. It has been established that an increase in the content of limiting amino acids in the diets for commercial rainbow trout results in an increase in monounsaturated fatty acids in the flesh by 1.14-2.18% compared to the control.

3. The obtained results suggest that the highest content of fatty acids can be found in the flesh of commercial trout of the 4th experimental group fed with compound fodders containing 2.8% lysine and 0.95% methionine.

4. It has been proved that an increase in the amino acid nutritional value of compound feeds results in an increase in the content of linoleic acid in trout flesh by 0.19-0.24% compared to the control.

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Біологічна ефективність ліпідів м'яса райдужної форелі залежно від рівнів амінокислот у комбікормах

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Анотація. У форелевих господарствах України за використання комбікормів власного виробництва постає питання щодо з'ясування потреби райдужної форелі в енергії, протеїні та амінокислотах з метою досягнення максимальної реалізації її біологічного потенціалу продуктивності. Відповідно, у статті досліджено вплив використання повнораціонних комбікормів із різними рівнями лізину й метіоніну на показники біологічної ефективності ліпідів м'яса райдужної форелі. Метою досліду передбачалося встановити вплив різних рівнів амінокислотного живлення товарної райдужної форелі на жирнокислотний склад ліпідів м'яса та їхню біологічну ефективність. Для цього за методом аналогів було сформовано п'ять піддослідних груп. Дослід тривав 210 діб та поділявся на два періоди: зрівняльний (10 діб) та основний (200 діб). У зрівняльний період раціон годівлі був однаковим для риб контрольної та експериментальних груп. В основний період рівень лізину й метіоніну в експериментальних комбікормах для різних піддослідних груп форелі коливався відповідно від 2,5 до 2,9 % і від 0,8 до 1,0 %. Годівлю райдужної форелі в період досліджень проводили 4-6 раз на добу, у денний час через рівні проміжки. Необхідну кількість корму розраховували відповідно до показників індивідуальної маси риб та температури середовища на момент годівлі. Вирощування товарних дволіток проводили в ставках площею 100 м^2 за щільності посадки 50 екземплярів/м^2, та рівня води в них 1 м. Загальна кількість особин форелі в експериментальних дослідженнях становила 25 тис. екземплярів. Встановлено, що основну частку жирних кислот ліпідів м›яса райдужної форелі складають насичені жирні кислоти та мононенасичені. У результаті досліджень виявлено, що використання комбікормів із підвищеним рівнем лізину та метіоніну для риб 4 дослідної групи супроводжувалося збільшенням вмісту суми насичених жирних кислот у м'ясі на 5,84 % порівнюючи з контролем. За зростання амінокислотної поживності комбікорму спостерігається збільшення у м'ясі форелі вмісту лінолевої кислоти на 0,19-0,24 % порівнюючи з контролем. Практична цінність наукової роботи полягає в обґрунтованні підходів до технологічних основ підвищення ефективності використання поживних речовин комбікормів у форелівництві з метою забезпечення високої рибопродуктивності, що мають важливе народногосподарське значення

Ключові слова: райдужна форель, годівля риб, комбікорми, лізин, метіонін, м'ясо, ліпіди, жирнокислотний склад

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Characteristics of biochemical parameters of sperm production of carp sire when using hulled oats in feeding during the pre-spawning period

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Abstract. The restoration of freshwater aquatic life and the cultivation of highly productive sires is a key stage in the process of restoring a new generation of fish, thus, the task of increasing fertility is always relevant for the fishing industry of Ukraine. The purpose of the study is to conduct an in-depth analysis of the physiological characteristics of ejaculates of respiratory and reproductive capacity, to explore the activity of enzymes of the respiratory chain of mitochondria, to determine the percentage of sperm survival when using pre-cleaned oats, as the main component in the diet of carp during the pre-spawning period In the study, males of the Nyvka interbreed type of Ukrainian scaly carp breed were used, which were kept during the pre-spawning period in pond conditions of the State Enterprise "State Farm "Nyvka" IRG NAAS. Individuals were divided into 3 groups. The first group (Experiment I) was fed 100% hulled oats, the second (Experiment II) – 30% and the control group of fish (Control) was fed a grain mixture. The quality of male carp sexual products was assessed by determining the effect of adding hulled oats to their diet during the pre-spawning period. Indicators of sperm motility and fertilizing ability, the content of γ-, β- and α-globulins, albumin, prealbumin and physiological characteristics of ejaculates of respiratory and reducing capacity, the activity of enzymes of the respiratory chain of mitochondria (COX and SDH) were explored. Considering the increase in the productivity of fish sperm, in particular, the increase in the number of sperm with rectilinear motion, the decrease in the number of lifeless sperm and changes in the protein formula of germ cells, it was established that it is advisable to add hulled

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oats to the main diet in the amount of 30%. According to the results of the conducted research, it was established that the addition of hulled oats to the fodder during the pre-spawning period has a positive effect on the quantitative and qualitative indicators of male carp sexual products, the results of the research can be useful for both students and workers of the fish processing industry of Ukraine

Keywords: male carp, sperm, rectilinear translational motion, succinate dehydrogenase, cytochrome oxidase, γ-, β- and α-globulins, prealbumin

Introduction

Selection of sires with high-quality sperm production, and fertilising ability of sperm is important in the breeding and breeding business (Ostapiv, 2008), as the main function of the reproductive system in fish is the production of sexual products while preserving the genetic material for the next generation. Thus, one of the main factors that in the future affect the viability and plasticity of fish planting material is the quality of germ cells. Therefore, the best quality sperm is one of the conditions under which the fertilisation process occurs with the subsequent development of the embryo (Yaremchuk *et al.*, 2015) . The duration of the period of preservation of sperm motility and fertilising ability is variable in different fish species and depends on the environmental conditions, feeding, keeping technology and individual characteristics of the sires. All this should be considered since some external factors have a significant impact on the body, i.e. they can accelerate, inhibit or completely stop the development (spermatogenesis) of germ cells.

It should be noted that sperm membranes are susceptible to peroxide damage by excess reactive oxygen species (ROS). The efficiency of the enzymatic antioxidant defence system, the key enzymes of which are superoxide dismutase, catalase and glutathione peroxidase, is important for maintaining the structural integrity, sperm survival and preventing the processes of lipid peroxidation (LPO). Therefore, it is important to explore the activity of succinate dehydrogenase and cytochrome oxidase as the primary link in the oxygen process.

Development and maintenance of carp breeding stock are one of the main and most crucial processes in breeding and breeding work, as the efficiency of the farm in the pre-spawning period is determined by the quality of the breeders and is crucial for obtaining results at the end of the growing season. Feeding carp fry in the pre-spawning period with artificial fodder, which fully provides the physiological requirements of fish at this stage of ontogeny, immediately affects the quality of sexual products and the success of the spawning campaign in general. Since, in the current conditions, the technological aspects of carp reproduction are fully developed, during the work in hatcheries, attention is devoted to the selection of elite sires and determination of the quality of their sexual products (Martínez Páramo *et al.*, 2014), (Yurchak *et al.*, 2018). Approximately, the quality of sperm is determined by a five-point scale of G.M. Persov. When assessing the quality of sperm, in addition to visual features (volume, colour, odour, consistency), the motility, concentration, survival, protein component and oxidative functions of sperm are explored (Makarenko *et al.*, 2022). Notably, motility is one of the most important characteristics associated

with the fertilising ability of sperm, indicating their viability and structural integrity. Thus, motility studies are an integral part of semen analysis (Iaremchuk *et al.*, 2012).

Succinate dehydrogenase (SDH) is one of the important oxidative enzymes of CTA and the first link in the chain of electron transfer through ubiquinone and cytochrome system to oxygen. The features of SDH are its location on the inner surface of mitochondria and the independence of the enzyme activity from the ratio of oxidised and reduced forms of NAD/NADH (Fauvel *et al.*, 2010). Cytochrome oxidase (COX) is an enzyme of the final link of electron and proton transport in the respiratory chain to oxygen (Makarenko *et al.*, 2021). COX, together with SDH, characterises the mitochondrial component of oxygen consumption, providing ROS resynthesis, thus, their activity affects metabolism in sperm (Kalachniuk, 2013). By exploring the biochemical parameters of sperm production, some scientists have established a link between the activity of oxidative enzymes and the fertilising ability of sperm, more pronounced with the activity of succinate dehydrogenase (SDH). A close connection between the activity of many enzymes of dehydrogenases and cytochrome oxidase (COX) of sperm with indicators of its quality and fertilising ability has been identified, which served as the basis for using the activity of these enzymes as an indicator of sperm quality (Kosenko *et al.*, 2007), (Ruiz-Pesini *et al.*, 1998) Studies have proved the connection between the activity of SDH of bulls' sperm and fertility, namely, there was a decrease in the fertility of bulls' sperm with a decrease in the activity of the enzyme in the ejaculate (Barbagallo *et al.*, 2020), (Linkevich *et al.*, 2014).

Thus, the results of a comprehensive assessment of male carp sperm production will provide a complete description of the reproductive system of male carp and will allow recommend using hulled oats in feeding during the pre-spawning period.

The purpose of the study – to explore the physiological characteristics of ejaculates respiratory and recovery capacity, the activity of enzymes of the mitochondrial respiratory chain (COX and SDH), sperm survival, motility and fertilization capacity, the content of γ-, β- and α-globulins, albumin, pre-albumin for using hulled oats in carp feeding during the pre-spawning period.

Materials and methods

The object of the research was different-aged individuals of Nyvkivsky scaly and small-scaled carp. For the research, sperm was collected during the spawning campaign of 2012 from males of Nyvkivsky scaly and small-scaled carp, which were grown in pond conditions under semi-intensive technology.

The semen was diluted with phosphate-salt buffer (NaCl – 0.8 g, KCl – 0.02 g, Na_2HPO_4 – 0.11 g, KH_2PO_4 – 0.02 g, $MgCl_2$ – 0.01 g, H_2O up to 100 ml).

Using the SpermVision program, which is installed based on the microscope, the analysis of sperm parameters was performed – their total activity, the percentage of sperm with rectilinear and translational movement and the percentage of lifeless sperm. The kinetic parameters of sperm were determined by using the computer system CASA (Computer Assisted Sperm Analysis) – Sperm Vision with the establishment of sperm movement parameters: velocity of curvilinear motion (*VCL*); velocity of sperm head advancement along the average trajectory (*VAP*); velocity of straight-line motion of the sperm head along the straight segment between the starting and ending points of the trajectory (*VSL*), degree of linearity

(*LIN=VSL/VCL*), degree of straightness of sperm motion (*STR=VSL/VAP*) and degree of deviation (*WOB=VAP/VCL*). Determined: sperm survival (h) at 22-24°C until the progressive movement stopped, the activity of succinate dehydrogenase (*SDH*; units/h × 0.1 ml of sperm) and cytochrome oxidase (*COX*, units/h × 0.1 ml of sperm), oxygen consumption – polarographically (ng-atom O/min × 0.1 ml of sperm) at 38.5°C in phosphate-salt buffer (*PSB*; NaCl – 0.8 g, KCl – 0.02 g, Na_2HPO_4 – 0.11 g, KH_2PO_4 – 0.02 g, $MgCl_2$ – 0.01 g, H_2O to 100 ml) (Dudchak & Sharan, 2010).

The fractional composition of soluble proteins was explored by vertical electrophoresis in 7.5% polyacrylamide gel (PAAG) plates (Fang *et al*, 2020). Samples for electrophoresis were prepared: in 7.5% PAGE: 0.1 ml of sperm was diluted 1:12 with electrode buffer (pH 8.5), 0.1 ml of the sample was mixed with the same amount of 40% sucrose, 0.02 ml (~150-200 µg of protein) was added to the wells of the concentrating gel. Marker dye – 0.01% bromphenol blue solution was added to the electrode buffer before sample dilution. After electrophoresis, the gels were fixed and simultaneously stained in 12.5% trichloroacetic acid with 0.25% aqueous Coomassie R 250 solution.

Digital statistical analysis of the material was performed using the computer program Microsoft EXCEL. The arithmetic mean (*M*), mean square error (*m*) and probability of differences (*P*) between the explored arithmetic means were determined.

Results

According to the methodology, in spring the main herd of breeders was boned and transplanted to the pre-spawning ponds. In the process of boniting the following types of measurements were used: fish weight, body length (industrialand total), body height, body girth, and head length.

Based on the data obtained, the statistical indicators and the main indices of body composition were calculated – body fatness index (B_F), relative weight index (*W/l*), index of high-spine (*l/H*), and girth index (*l/O*). All experimental groups of males were clinically healthy, in growth and development corresponded to the "elite" class and were used for spawning. The main characteristics are presented in Table 1.

Table 1. *Indicators of exterior of males of Nyvkivsky scaly and small-scaled carp used in the research*

Indicators Experiment I (*n* = 4)		Experimental group		
		Experiment II (*n* = 4)	Control (*n* = 4)	Control (n = 4)
Average weight (*W*), kg	*M*±m	5.35±0.28	5.42±0.35	5.74±0.20
	σ	601.12	515.22	288.10
	C_v, %	9.88	10.02	5.02
Total length (*L*), cm	*M*±m	56.32±4.31	54.45±2.80	59.22±0.98
	σ	6.61	7.01	1.99
	C_v, %	10.25	9.89	2.98
Industrial length (*l*), cm	*M*±m	51.78±3.80	54.06±3.99	54.80±1.12
	σ	5.87	4.99	1.64
	C_v, %	11.40	13.52	3.00

Table 1. Continued

Indicators Experiment I (n = 4)		Experimental group		
		Experiment II (n = 4)	Control (n = 4)	Control (n = 4)
Body height (H), cm	M±m	21±04±0.70	21.04±0.56	21.20±0.64
	σ	1.21	1.18	0.84
	C_v, %	5.30	4.98	3.95
Body girth (O), cm	M±m	49.03±1.86	48.48±2.65	50.0±1.20
	σ	2.11	2.23	1.58
	C_v, %	4.56	4.88	3.16
Body fatness index (B_p)	M±m	3.72±0.26	3.90±0.44	3.49±0.16
	σ	0.39	0.77	0.20
	C_v, %	21.80	22.15	5.74
Relative weight index (W/l), g/cm	M±m	105±2.05	102±1.87	104.72±2.72
	σ	2.26	3.01	3.26
	C_v, %	2.13	2.08	3.12
High-spine index (l/H)	M±m	2.45±0.25	2.51±0.15	2.59±0.07
	σ	0.18	0.22	0.08
	C_v, %	9.01	8.56	3.23
Girth index (l/O)	M±m	1.16±0.10	1.18±0.08	1.10±0.02
	σ	0.10	0.12	0.03
	C_v, %	6.98	7.21	2.83
Head index (l/C)	M±m	3.87±0.23	4.01±0.15	3.98±0.13
	σ	0.18	0.16	0.20
	C_v, %	5.33	5.39	0.20

It was established that all experimental groups of males had high rates of total sperm activity, the average value of which exceeded 92%. Therewith, the highest rate was recorded in the experimental animals of the second group – 94.2%, which is 1.32% higher than that of the control group. Individuals from this experimental group had the highest value of sperm content with rectilinear motion – 74.73% and the lowest value of sperm content with arena motion – 19.41%, but the indicators of this experimental group in terms of arena motion had the highest amplitude of fluctuations – 23.61% against 11.43% in experiment I and 11.2% – in control. Therewith, in individuals from experimental group I, the lowest value of dead sperm was observed – 5.77%, with the maximum variation – 37.21%. Somewhat higher values – 5.87% had individuals from the second experimental group, but the variability index decreased by 9.65%. The highest number of lifeless sperm – 7.0% was recorded among the indicators of sperm production in individuals from the control group, with a variability of 10.79% (Table 2).

Table 2. *Physiological parameters of carp sperm (n = 4, M± m)*

Experimental options	Total activity (%)	The content of sperm with rectilinear progressive movement (%)	Percentage of sperm with arena movement (%)	Percentage of lifeless sperm (%)
Experiment I	93.75±0.43 0.83	73.37±2.61 6.16	20.87±1.38 11.43	5.77±1.24 37.21
Experiment II	94.2±0.99 1.81	74.73±2.31 5.37	19.41±2.64 23.61	5.87±0.93 27.56
Control	92.97±0.38 0.72	72.63±1.28 3.06	20.37±1.32 11.20	7.0±0.44 10.79

After dilution of sperm, the survival of sperm at a temperature of 22-24°C on average exceeded 63.0 hours. The highest rate (66.37 h) was recorded in experiment II, and the lowest value and the highest rate of variability for this indicator were sperm samples obtained from individuals from the control group – 63.1 h and 7.87%, respectively. In this experimental group, the highest was the index of motility of non-diluted sperm, at a temperature of 22-24°C, it was 100.4 h and exceeded the index of experimental group I and control group by 2.63 and 3.31%, but the indicators in this group were the most variable, in particular, the variability index was almost 5% against 3.64 and 3.12 in experimental group I and control, respectively (Table 3).

Table 3. *Sperm survival and oxidative enzyme activity of carp sperm, (n = 4; M ± m)*

Experimental option	Survival of diluted sperm at 22-24°C, h	Preservation of motility of non-diluted sperm at 22-24°C, h	Enzyme activity, units/h × 0.1 ml of sperm	
			SDH	*COX*
Experiment I	63.6±0.53 1.45	97.83±2.06 3.64	16.8±0.71 7.31	27.47±2.68 16.88
Experiment II	66.37±1.20 3.14	100.4±2.72 4.70	19.95±2.98 25.87	32.7±2.34 12.39
Control	63.10±2.86 7.84	97.07±1.75 3.12	17.9±1.02 9.88	26.83±1.30 8.39

It is known that the intensity of substrate used by individual links of the respiratory chain is a marker of physiological parameters and characterises the fertilising ability of germ cells [17]. From the analysis of the activity of oxidative enzymes of male carp sex products, it was established that the samples of the experimental groups, compared to the control, had higher values, which indicates the ability of germ cells to use substrates of the environment to provide energy requirements through the resynthesis of ROS in the respiratory chain of mitochondria by adding hulled oats to the main diet.

This analysis demonstrated a significant variability of redox processes in male carp ejaculates. The highest activity of sperm enzymes was noted in the samples of the II experimental group. Thus, the average value of the *SDH* was 16.0 units/h × 0.1 ml of sperm, with a minimum value of 16.8 recorded in the I experimental group, and the maximum value – 19.85 units/h × 0.1 ml of sperm – in the II experimental group. Despite the highest rate,

the maximum value of variation was recorded in this group – 25.87%, compared to 7.31 and 9.88% in the experimental groups. The activity of the *COX* during the research demonstrated similar dynamics. With lower variability, compared to *SDH*, the maximum values were characterised by the samples of the II experimental group. The index of this group exceeded the index of the control group by 17.9%, and by 15.9% – of the I experimental group (Table 3).

Therewith, the quality of sperm depends both on the activity of enzymes and on the content of proteins and their fractions involved in protein metabolism. The analysis identified that the addition of hulled oats to the diet increases the content of protein fractions in semen. In particular, depending on the share of hulled oats in the main diet, the albumin content varied from 7.07 in the control to 9.80% (experiment with 30% content). A similar upward trend was recorded among the values of γ-globulins (46.7-50.97%). Among the group of α-globulins, there is a tendency to decrease this indicator, depending on the content of the fodder supplement. Among the results of this group, there were significant differences among the values of the coefficient of variation. Thus, in the control group, it ranged from 1.39 to 4.96%, in experimental I – from 7.14 to 19.89, and in experimental II – from 4.56 to 21.88%. Instead, the trend in the distribution of soluble sperm protein fractions, depending on the feeding of hulled oats, could not be traced among the values of β-globulins and prealbumin. Thus, the maximum value of these indicators was respectively 7.47 and 24.64% in the control, the minimum value for the content of β-globulins (5.33%) – in experiment I, for the content of prealbumin (22.01%) – in experiment II (Table 4).

Table 4. *Content of soluble protein fractions of carp sperm, % (n = 4, M ± m)*

Experimental option	γ-globulins	β-globulins	α_3-globulins	α_2-globulins	α_1-globulins	Albumin	Prealbumins
Experiment I	49.27±1.76 6.19	5.33±0.50 16.38	4.60±0.42 15.68	3.57±0.41 19.89	4.20±0.17 7.14	8.83±0.65 12.72	24.2±1.22 8.77
Experiment II	50.97±1.11 3.77	7.35±0.69 16.35	3.57±0.27 13.25	3.10±0.08 4.56	3.20±0.40 21.88	9.80±0.57 10.10	22.01±1.59 12.44
Control	46.70±1.14 4.24	7.47±0.43 9.87	5.70±0.16 4.96	4.17±0.03 1.39	4.25±0.04 1.66	7.07±0.75 18.47	24.64±0.97 6.81

The obtained data confirm that proteins in the fish body are in a dynamic state, which is provided by the processes of constant synthesis and decay. The latter are genetically determined and depend on the conditions of detention. In contrast to mammals, in fish, the share of amino acids only in the substrate of energy metabolism can be 50-90%.

Conclusions

It was established that additional feeding of hulled oats in the amount of 30% is effective. In particular, the addition of this proportion to the basic diet increases the total sperm activity by 1.32% and the rectilinear motion by 2.9% compared to the control. Thus, considering the increase in sperm productivity, which is

manifested in their higher activity, their ability to fertilise increases accordingly. In addition, there is an increase in the activity of enzymes of the respiratory chain - succinate dehydrogenase and cytochrome oxidase, which indicates an increase in the ability of germ cells to use substrates of the environment to meet energy needs through the resynthesis of ROS in the respiratory chain of mitochondria. In addition, the lack of a distinct trend in the distribution of the total protein content and their fractional composition in the testes of carp, depending on the proportion of hulled oats in the main diet, can be explained by the action of many environmental factors, and depend on the season, age and physiological state of the body.

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Характеристика біохімічних показників спермопродукції плідників коропа за використання в годівлі голозерного вівса впродовж переднерестового періоду

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Анотація. Відновлення популяції прісноводних гідробіонтів та вирощування високопродуктивних плідників є ключовим етапом процесу відновлення нового покоління риб, тому задача підвищення рівня запліднюваності завжди актуальна для риболовецької галузі України. Мета дослідження – провести поглиблений аналіз фізіологічних характеристик еякулятів дихальної та репродуктивної здатності, дослідити активності ензимів дихального ланцюга мітохондрій, встановити відсоток виживання сперматозоїдів при застосуванні попередньо очищеного вівса, як основного компоненту в раціоні коропа впродовж переднерестового періоду У дослідженнях використовували самців нивківського внутрішньопородного типу української лускатої породи коропа, яких утримували впродовж переднерестового періоду в ставових умовах «ДП «ДГ Нивка» ІРГ НААН. Особин було поділено на 3 групи. Першій групі (Дослід І) згодовували 100 % голозерного вівса, другій (Дослід ІІ) – 30 %, контрольній групі риб (Контроль) згодовували зернову суміш. Проведено оцінку якості статевих продуктів самців коропа способом визначення впливу додавання до їхнього раціону голозерного вівса впродовж переднерестового періоду. Досліджено показники рухливості та запліднювальної здатності сперми, вміст γ-, β- і α- глобулінів, альбуміну, преальбуміну та фізіологічні характеристики еякулятів дихальної й відновної здатності, активності ензимів дихального ланцюга мітохондрій (ЦХО та СДГ). З огляду на підвищення продуктивності сперміїв риб, зокрема збільшення кількості сперміїв з прямолінійно-поступальним рухом, зниження кількості неживих сперміїв та зміни білкової формули статевих клітин установлено, що доцільним є додавання голозерного вівса до основного раціону в кількості 30 %. Згідно з результатами проведених досліджень встановлено, що додавання до складу кормів голозерного вівса впродовж переднерестового періоду позитивно впливає на кількісні та якісні показники статевих продуктів самців коропа, результати досліджень можуть бути корисними, як для студентів так і для працівників рибопереробної галузі України

Ключові слова: самці коропа, сперматозоїди, прямолінійно-поступальний рух, сукцинатдегідрогеназа, цитохромоксидаза, γ-, β- і α- глобуліни, преальбумін

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