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ТВАРИННИЦТВО ТА ТЕХНОЛОГІЇ ХАРЧОВИХ ПРОДУКТІВ

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State and prospects of fish processing technologies

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Abstract. The fishing industry plays a significant role in ensuring food security and nutrition of the world's population. Therefore, analysing the trends in the flourishing of aquaculture and

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natural fisheries, the specifics of the use of raw materials for food, the degree of provision of the population with these products and new processing technologies is an urgent task to determine the priority areas for improving the nutritional and biological value of aquaculture products, taking into account modern nutrition recommendations. The purpose of the study was to investigate the current state of the fish industry, innovative areas of aquatic products manufacturing to identify promising areas of fish and seafood technology. The study was conducted using a comparative analysis of scientific works by domestic and foreign scientists published in the Scopus, Web of Science, Journal Citation Reports, Scimago Journal & Country Rank, and Google Scholar databases. The analysis of the information shows an increase in the catch of aquatic organisms in the world, and in recent years, the total catch has amounted to more than 177.80 million tonnes. For food purposes, 157.40 million tonnes were used, with an annual consumption of 20.2 kg per person. The mass share of Ukraine in the total volume of fish products in the world is 0.2%. Ukraine is import-dependent in terms of aquatic organisms. The latest technologies for processing fish products are related to the development of methods for assessing the quality of raw materials and products, the creation of low-waste technologies for the extraction of biologically active compounds and the formation of multicomponent food products based on plant and animal raw materials, and the use of biotechnological and physical methods to improve product quality. The involvement of a new raw material object, the freshwater toothless mollusk, for food purposes has been noted, and many culinary recipes from this species with additives of plant materials have been developed. However, there is a lack of research in the area of improving the technologies and formulation composition of fish pastes, which will make it possible to formulate food products with specified properties of biological value to meet human needs. The practical significance of the analysis is to identify promising trends in aquaculture technologies, taking into account Ukraine's own raw material base

Keywords: fishing industry; new technologies; multi-component products; new raw materials; fish pastes; freshwater fish; dietary supplements

Introduction

The state and development trends of the fishing industry play an important role in ensuring an adequate standard of living and development of the country. Meeting the needs of the population with quality fish products is a priority for the fishing industry. To solve this problem, it is necessary to know the available raw materials, potential types of raw materials, and the main trends in the fish products market. Many scientists have made a significant contribution to the study of the state, effective directions of development of the fishery complex and prospects for technologies for processing aquatic products. A. Trofymchuk *et al.* (2021) analysed the current state and trends in the development of fisheries in Ukraine and the world for 1996-2020. They noted changes in the catch of aquatic organisms, exports, and imports of fish products. The level of consumption of fish products by the population was shown. The main promising directions and strategies for the development of the fishery were substantiated. N. Myskovets (2020) highlights the state of the fishing industry in Ukraine as a whole and separately in the Rivne region. The paper examines the performance indicators of fisheries' enterprises, identifies the most powerful ones, specifies the most popular fish species, and identifies the prospects for the development of the fisheries' industry.

The state and prospects of development of the fish market of Ukraine were studied by T. Volkhova & N. Holembovska (2020). The

results showed an increase in global fish production and consumption. In Ukraine, the annual consumption of fish and fish products is significantly lower than the global average. The main factors that influence the consumption of fish and fish products are their cost and the level of income of the population. It is shown that the state of the fishery of Ukraine is neglected. The fish market in Ukraine is represented by imported products. Scientists believe that in the near future, we should not expect a significant improvement in the situation with filling the domestic market with domestic products. T. Yaroshevych & O. Paholyuk (2020) assessed the state and directions of development of the Ukrainian fish market, identified negative and positive trends in its functioning. Based on the results of the research, they proposed promising areas for the development of the fish industry to provide the population with food products of high protein content. L. Kupinets & O. Shershun (2022) substantiated methodological approaches to assessing the capacity of the national and regional fisheries and aquaculture market. The structure of the fish market is studied, and the factors influencing its dynamics are identified. The dependence of the market on imports is estimated. Recommendations for the development of domestic fish farming and aquaculture are provided. L. Mykhalchyshyna & I. Sinenok (2020) identify unfavourable conditions for the development of aquaculture as the reasons for the predominance of imported raw materials in the fish market. The authors propose to develop a strategic plan for the sustainable development of the fishing industry and the direction of aquaculture development.

Based on their research, the scientists come to a common conclusion that the main effective way to obtain aquatic bioresources is through the development of aquaculture. To increase the efficiency of fish farming, it is proposed to grow valuable fish species: sturgeon (*Acipenseridae*), salmon (*Salmoninae*), tilapia (*Tilapia*), channel catfish (*Ictalurus punctatus*) and clarias (*Clarias gariepinus*). The feasibility and prospects of modern aquaculture areas using improved fish farming conditions are also confirmed by studies presented in the works of foreign scientists (Wang *et al.*, 2021; Valenti *et al.*, 2021; Qi *et al.*, 2021). Modern technologies for processing fish products are based on the use of new types of raw materials, aquaculture facilities, and the creation of low-waste and integrated technologies for processing aquatic organisms. Innovations are related to the development of new methods for assessing the quality of raw materials and finished products, the use of biotechnological and physical methods to improve quality and safety (Kim, 2021). Promising areas of fish and seafood technology include the formation of multicomponent food products of increased nutritional and biological value based on aquatic organisms, plant, and animal raw materials (Racioppo *et al.*, 2021; Dhanabalan *et al.*, 2023).

Despite the significant number of works by domestic and foreign scientists, the issues of the current state and effective directions of fisheries development require constant monitoring and analysis for the successful operation of the country's fisheries complex. Particular attention should be paid to the state and conditions of functioning of the fishing industry in times of war and the choice of technology for aquatic products to ensure food security. The purpose of the study was to examine the current state, main trends and prospects for the development of the fish processing industry in the world and in Ukraine.

To achieve this goal, the following research objectives were set:

- to study the dynamics of the volume of production, its structure and the main factors influencing the catch of aquatic bioresources in the world and in Ukraine;
- to analyse the level of consumption of fish and fish products in the world and in Ukraine, in accordance with the recommended norms;

➢ to study the main trends in fish and seafood processing in the world and in Ukraine, and to identify promising technologies for aquatic products.

In the course of the study, general scientific and special methods were used: statistical analysis, comparative analysis, synthesis, integrated systemic approach, theoretical generalization, as well as structural-functional and abstract-logical methods. The state of world fisheries and aquaculture was analysed on the basis of data from the Food and Agriculture Organization of the United Nations (FAO) (The State of World Fisheries and Aquaculture ..., 2022). To analyse the current state of the domestic fishing industry, information from the State Statistics Service of Ukraine and the State Agency for Land Reclamation and Fisheries of Ukraine was used. The materials used for these studies included statistical data on the extraction of aquatic bioresources, the state of aquaculture production, and the level of consumption of fish and fish products in the world and in Ukraine. The studies also used scientific articles by domestic and foreign scientists, legislative documents, analytical information, and forecasts by experts in the fish industry. The study of the main areas of aquaculture processing technology in the world and Ukraine was conducted using a comparative analysis of scientific papers by domestic and foreign scientists published in the Scopus, Web of Science, Journal Citation Reports, Scimago Journal & Country Rank, and Google Scholar databases.

The current state of fisheries in the world and in Ukraine

In the 21st century, the world recognizes the significant contribution of fisheries and aquaculture to food security and nutrition. In 2020, about 225 million tonnes of aquatic products were supplied to world markets (Fig. 1) (The State of World Fisheries and Aquaculture..., 2022). The volume of industrial fishery products accounted for 51% of the total, and aquaculture products for 49%. Commercial fisheries accounted for 63% of the total volume of production, while inland waters accounted for 37%. In addition, 36 million tonnes of algae were supplied to the markets, 97% of which was produced mainly in marine aquaculture.

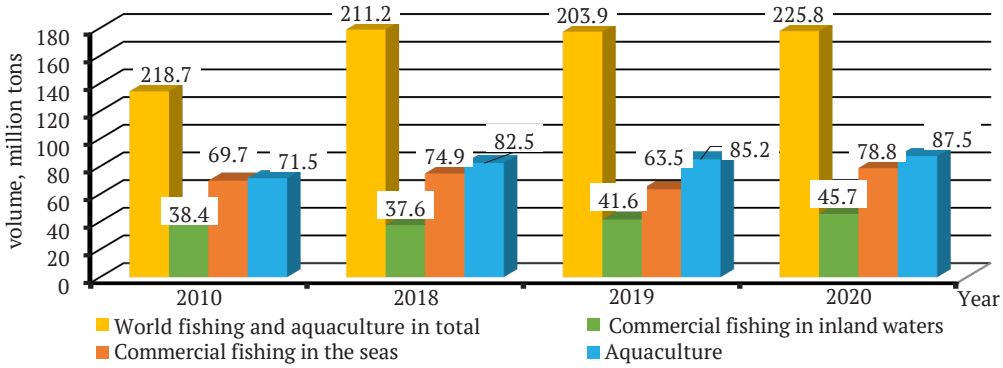

Figure 1. The volume of extraction of aquatic bioresources in the world

Source: The State of World Fisheries and Aquaculture ... (2022)

More than 89% of the aquatic bioresources harvested were used for food purposes. The rest was used to produce fishmeal and fish oil. The volume of aquatic bioresources harvested in Ukraine decreased over the period 2010-2022. Figure 2 shows the total catch of aquatic bioresources in Ukraine (Extraction of aquatic bioresources..., 2023).

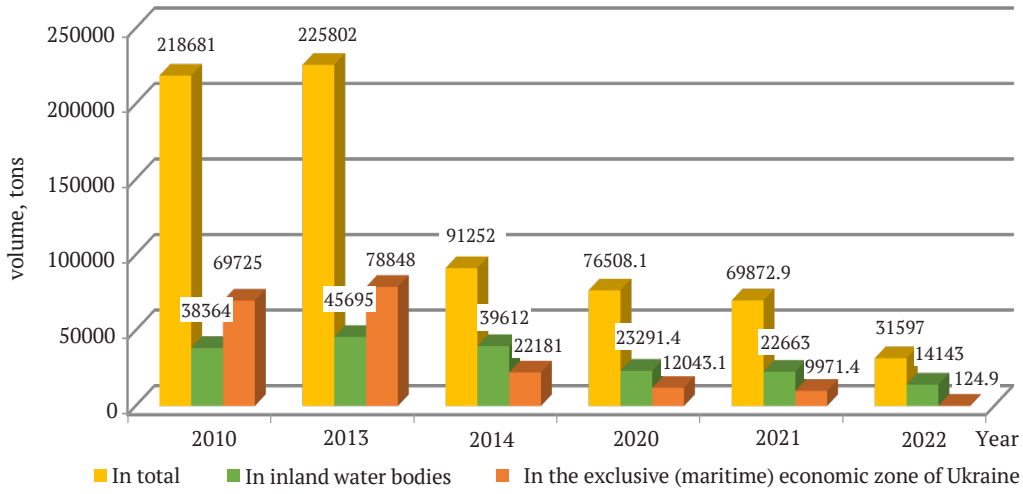

Figure 2. The volume of extraction of aquatic bioresources in Ukraine
Source: Extraction of aquatic bioresources ... (2023)

A sharp decline compared to previous periods was observed in 2014, due to the annexation of Crimea. Ukraine has lost its main fishing area, namely marine fish, which accounted for a significant share of the overall structure of the fishery. In 2022, fish catches declined dramatically as a result of the war. The total catch in all fishing areas amounted to 31.6 thousand tonnes of aquatic bioresources, which was only 45.2% of the corresponding figure for 2021. Commercial fishermen caught 14 thousand tonnes of biological resources in inland water bodies, which was 62.4% of the previous year. Only 124.9 tonnes were caught in the Black Sea (1.3% of the 2021 figure), and only 24 tonnes (0.5% of the 2021 figure) were caught in the Sea of Azov, which is fully controlled by Russia, before the occupation (Extraction of aquatic bioresources..., 2023). Commercial fishing in 2022 took place under conditions of a partial or complete ban on navigation in large areas of Ukrainian waters. At the same time, commercial fishing in the Sea of Azov and the Black Sea was blocked, except for certain areas of Mykolaiv and Kherson regions. Fishing beyond Ukrainian jurisdiction in waters covered by the Convention on the Conservation of Antarctic Marine Bioresources was suspended with the introduction of martial law in Ukraine, which complicated the process of replacing the crew of vessels that caught Antarctic krill (Public report..., 2022).

In most regions of Ukraine where hostilities took place, fisheries suffered significant material damage due to damage to hydraulic systems and structures, buildings, production equipment and other property, as well as fish kills. The mining of certain areas made it impossible to access the production facilities of enterprises and conduct technological operations (Public report..., 2022). Analysis of the volume of fish harvested shows more stable trends in aquaculture production. This indicates the need to support and develop this area of the fishing industry (Production of aquaculture products..., 2022). The level of consumption of fish and fish products is an indicator of food supply to the population, which must be maintained in accordance with physiologically sound norms. Figure 3 shows the dynamics of consumption of fish and fish products in the world and in Ukraine in 2010-2021.

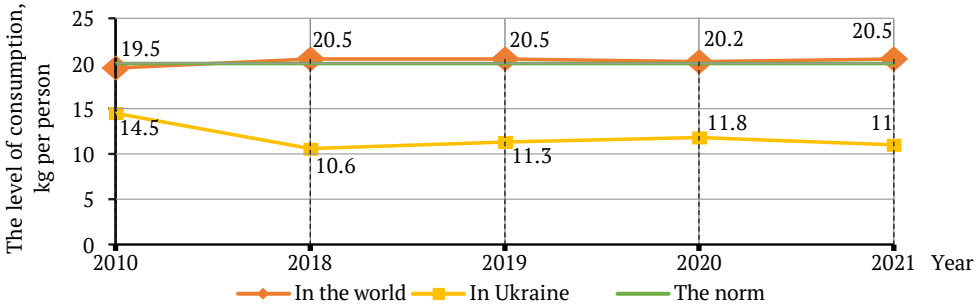

Figure 3. The consumption of fish and fish products in the world and in Ukraine
Source: T. Yaroshevych & O. Pakholiuk (2020); The State of World Fisheries and Aquaculture (2022)

Between 1961 and 2019, global consumption of food products from aquatic bioresources increased by an average of 3.0% per year. Per capita consumption of aquatic animal products increased by 1.4% per year, from 9.0 kg in 1961 to 20.5 kg in 2019. In 2020, this figure slightly decreased to 20.2 kg, but returned to the previous level the following year. Oceania consumes the most fish per person per year – 27.5 kg, followed by Asia – 25.1 kg, North America – 23.7 kg, Europe – 21.6 kg, South America – 10.7 kg, and Africa – 9.8 kg (The State of World Fisheries and Aquaculture..., 2022). In recent decades, the per capita consumption of aquatic bioresource food products has been primarily influenced by the growth in the supply of these products, changes in consumer preferences, technological development, and income growth.

In Ukraine, meeting the needs of the population through a stable supply of fisheries and aquaculture products remains a challenge. This leads to low consumption of fish and fish products. In 2021, Ukrainians consumed 11 kg of fish per capita, which is only 55% of the recommended norm. In 2022-2023, there was no significant increase in the consumption of fish products by Ukrainians. It was determined that the domestic demand for fish products is 540 thousand tonnes, but the supply is 4.3 times less (Bespyatov, 2022). The regions and countries of import of fish products to Ukraine are Western Europe, Central/Eastern Europe, the Middle East, South America, North America, Norway, Spain, Iceland, Sweden, Denmark, the Netherlands, Greece, France, Iran, Chile, Latvia, Lithuania, Estonia, and the United States of America. Export regions and countries: Central/Eastern Europe.

Compared to the total global catch of aquatic organisms, Ukraine's share of the world's fisheries averaged 0.4% before the military actions, and 0.2% in the last year. Ukraine produces more than 100 types of food products. The main ones are frozen, chilled, salted, smoked fish, canned fish, preserves, culinary products, and fish meal. Non-food fish is used for the needs of fur farming and livestock farming (State Agency of Recreation and Fisheries of Ukraine, 2023). Ukraine needs an import substitution programme. It is necessary to determine the species structure of aquatic bioresources that have the potential to be grown in aquaculture and introduce a system of investment in this area; introduce a system for confirming legal imports and catches of fish in inland waters, a system for monitoring compliance with the law and penalties for trade in fish of dubious origin and quality; and increase the competitiveness of domestic fish products (Kupinets & Shershun, 2022; State agency of recreation and fisheries of Ukraine, 2023). Numerous studies have shown that raw materials of aquatic origin contain a variety of biologically active compounds and are considered as a source for

creating foods balanced in terms of basic and essential nutritional factors in accordance with FAO/WHO (World Health Organization) recommendations (Brandhorst & Longo, 2019; Rocha *et al.*, 2021). Therefore, it is advisable to analyse modern technologies for processing aquatic organisms and identify promising areas.

Main areas of aquatic organisms processing technology

The analysis of the state and prospects of fish raw material technology shows the following main areas of research:

- improvement of methods for objective assessment of quality and safety of raw materials and products;
- development of low-waste technologies for processing raw materials;
- improvement of traditional technologies;
- development of functional food products;
- attracting new sources of raw materials for food production.

The following methods should be used to improve the objective assessment of the quality and safety of raw materials of aquatic origin and products made from them. The elastic properties of raw materials (ability to deform) are one of the important characteristics of their quality (Lebska *et al.*, 2021). However, these parameters have been studied fragmentarily and there is no data establishing their dependence on other criteria. The first studies of this indicator in relation to changes in pH were conducted on the muscle, adipose tissue, and skin of the Black Sea catfish *Squalus acanthias* (Sydorenko *et al.*, 2021). The regularities of changes in the rheological properties of fish depending on the storage time and temperature regime were established, which made it possible to obtain graphs of the strain force values of samples of different shelf life and to compare the strain time and strain values. The results of the physical properties were used to optimize the shelf life parameters of shark, on the basis of which mathematical models were developed to describe changes in the main physical and chemical properties under different storage parameters.

A quality index method (QIM) was developed for the example of ice-stored pufferfish (*Lophius piscatorius*) to quickly and efficiently determine the freshness of fish. This study was conducted to determine more reliable freshness parameters for ice-stored *Lophius piscatorius*. Sensory and microbiological analyses were carried out on a QIM basis, updating a previously proposed quality index (QI) scheme. Total viable counts and specific spoilage organisms were determined by microbiological analysis of tail muscles, evaluating their correlations with QI scores over time. The revised QI scheme included 3 characters, namely appearance, eye and fin, with a total of 18 deficiency points. A positive linear correlation was observed between the QI score and storage time, so that the time of sensory rejection (day 8) could be predicted within ± 1 day using the developed scheme. At the point of sensory rejection, the microbial spoilage flora loads were not high enough to be associated with the assessed changes, probably due to the morphology of the spearfish, in which the tail muscles are isolated from the gills and internal organs, the main sources of bacterial contamination. The proposed scheme offers a ready-to-use assessment of the freshness of abalone, although further validation is required. The determination of the shelf life of seafood is generally determined by microbiological, chemical and sensory analysis. Among these methods, colour changes are part of the sensory analysis and are preliminary acceptance criteria from the consumer point of view. A feed-forward artificial neural network (ANN) model was developed to predict the shelf life of seafood based on colour values. Furthermore, the predicted and observed values of shelf life were fitted, and the regression coefficient was found to be 0.85. According to the results of this study, the proposed ANN model is accurate, reliable, and adequate for estimating the shelf life of seafood (Fasuan *et al.*, 2022).

Rancid taste, pH and thiobarbiturate number (TBARS) are important parameters of food oxidation quality that are analysed in a time-consuming and destructive way. Non-destructive food characterization can be achieved by correlating these data with a computational vision. C. Marques *et al*. (2020) investigated the use of digital images of fish burgers to sensory predict the results of rancid taste, pH and thiobarbiturate number (TBARS) in these products. A mobile phone acquired digital images in a controlled environment, and 768 shades of grey were made using histograms. The models from the digital images of the object, sensory rancidity, pH and TBARS data, using the mean centre method and SIMPLS (statistically inspired modification of the partial least squares) algorithm, revealed models with > 0.97 R2. Thus, any digital image of this batch of hamburgers inserted into a model to predict rancid taste, pH and TBARS has a high level of prediction reliability.

Water activity is of interest in terms of estimating the amount of free water in food, and shows how strongly water is structurally and chemically bound in food. This indicator determines the suitability and degree of water content in food products, especially for microbiological activity. A study was conducted on the water activity index (aw) in the skin and muscle tissue of smoked catfish samples, which were products of traditional and advanced processing methods (Fasuan *et al.*, 2022). The samples differed significantly with mean aw values of 0.85 and 0.81, respectively, when tested immediately after purchase in selected open markets. The isolated spoilage fungi were identified by their phenotypic appearance and morphological characteristics. The presence of *Aspergillus fumigatus, A. niger, A. flavus* and *Penicillium* was detected. The aw value in all tested samples was higher than the Codex standard for smoked fish, smoked fish with aroma and dried fish, which is 0.75 aw or less (10% moisture or less), and shows the need to use this indicator to control pathogenic bacteria and spoilage fungi. One of the areas of aquatic organism processing technology is the development of low-waste technologies for processing raw materials. Aquatic raw materials contain an average of 30-50% of muscle tissue, with the rest being skin, bones, liver, gastrointestinal tract, gonads, etc. Therefore, one of the important tasks of raw material technology is to use all parts of the body of aquatic organisms. In this area, research on crustacean technology using the example of the Black Sea grass shrimp *Palaemon adspersus* is of interest, as it has made it possible to extract carotenoid lipids and a complex of enzymes with collagenolytic effects from inedible body parts in a single cycle (Bal-Prylypko *et al*., 2020; Lebsky, 2022). Lipids with carotenoids, due to the content of carotenoids – astaxanthin and omega-3 polyunsaturated fatty acids – are considered functional ingredients and can be used as a dietary supplement.

Squid cartilage has received little attention in the processing of these animals. C.Y. Huang *et al.* (2018) investigated the possibility of separating chondroitin sulphate (ChS) from squid cartilage of *Dosidicus gigas* by enzymatic extraction and sonication. Alkalase, papain or Protin NY100 were used as proteases. The results determined the efficiency of alkalase in the extraction of ChS compared to other enzymes. The results of this study provide an environmentally friendly and efficient process for the extraction and purification of ChS and are important for the use of these compounds for the development and production of nutritious foods or pharmaceuticals. Fish bones are by-products of aquatic and fish processing that are often discarded. However, it is considered to be beneficial for health as it contains many essential nutrients. Recent studies have identified the anti-inflammatory effects of fish bone fermented using *Monascus purpureus* in LPS-induced RAW264.7 cells by regulating the NF-κB pathway (Chen *et al.*, 2023). It was determined that fermented fish bones suppress inflammation and can be used as a multifunctional natural product.

Improvement of traditional technologies' production of products from hydrobionts and attraction of new sources of raw materials

In order to expand the range of products, scientists N. Bozhko *et al*. (2018) investigated the feasibility of an unconventional combination of raw materials to create combined and functional foods. Thus, the above-mentioned authors developed recipes for minced meat for the production of meat breads and semifinished products with partial replacement of meat raw materials with fish. It was found that the developed minced meat systems had 6-6.5 times lower ultimate shear stress and elasticity compared to the control sample, which indicates greater tenderness and juiciness of minced meat and finished products. It was determined that the combined meat and fish minced products have a better ability to adsorb and retain fats in their composition. The stability of the emulsion of minced meat with the addition of fish raw materials was on average 12-15% higher than that of minced meat of the standard recipe. Adding raw materials of aquatic origin to the recipe increased the emulsifying ability of minced meat by 8.9%. The developed meat and fish breads had a 5.3-8.5% higher yield of finished products compared to products according to the basic recipe. As a result of the organoleptic evaluation, it was found that the partial replacement of meat raw materials with fish raw materials does not worsen the sensory and physicochemical characteristics of meat breads. The research shows that meat and fish breads and semifinished products based on improved recipes can be recommended for production by meat processing enterprises. Recent studies have confirmed the feasibility of combining meat and fish raw materials, which allows enriching food products with essential amino acids, trace elements, omega-3 fatty acids and improving organoleptic properties (Pylypenko *et al*., 2021). The positive effect of combining meat raw materials with hydrobionts has also been proven in sausage technology. N. Bozhko *et al*. (2021) showed the feasibility of combining duck meat and freshwater fish in semi-smoked sausages. I. Pylypenko *et al*. (2021) improved the technology of cooked chicken sausages with the addition of seafood.

Raw materials of aquatic origin are characterized by the content of polyunsaturated fatty acids (PUFAs), vitamins, carotenoids, and microflora, which contribute to the rapid process of lipid oxidation and its deterioration. Therefore, one of the main areas of technology is to maintain the quality of raw materials. The main trends in this area should be considered. This is how the prospects of using Sous-vide technology have been proven. Sous-vide (SV) is a technology for low-temperature cooking of food products in a vacuum, which allows for reliable control over the sensory indicators and microbiological safety of products while strictly adhering to technological regulations (Zhao *et al*., 2022). In recent years, Sous-vide, or vacuum cooking, has been used to produce food and beverages in both the food industry and restaurants around the world. SV is considered to transform traditional cooking into more nutritious and healthy cuisine. SV has the advantage of precisely controlling the temperature and heating time to improve the quality, colour, flavour and nutritional value of food. A study on vacuum packaging (VP) found a positive effect on the preservation of PUFAs in *Seriola quinqueradiata* yellowtail meat, inhibiting the development of bitter odour in this fish during storage and preventing deterioration of its quality during cooking (Mukojima *et al*., 2023). These data indicate the feasibility of using VP to prevent deterioration of fish meat quality. Meanwhile, there are some challenges and prospects for this new food processing technology.

The maturation of preserves is a complex process in which the so-called "bouquet" of aroma, taste, consistency, protein, and lipid breakdown is formed. T. Lebska *et al*. (2021) developed an improvement in the technology of maturation of preserves from the meat of the

Black Sea gastropod *Rapana thomasiana* using radiation technologies. The authors investigated methods for improving the technology of processing rapana meat to ensure long-term storage of the finished product without the use of artificial preservatives. The technology is based on the preliminary preparation of the semifinished product, which includes defrosting, sorting, cutting, washing, checking, portioning, blanching, and cooling. The choice of a dose of 2 kGy is substantiated. It is established that the sensory properties of the finished product do not change after microwave treatment. The system of microwave treatment of canned meat for softening the structure is described. The shift of kinetic energy in the electron field by means of thin targets is used to form the required radiation field of different sizes. It is proved that after pico-wave irradiation with a dose of 2 kGy, canned rapana meat is microbiologically safe and can be stored for 90 days at 4 ± 2°C. The technological scheme for the preparation of preserves from rapana meat using py-wave irradiation is presented. The studies indicate the feasibility of using irradiation technology, as it ensures the maturation of low-lying hydrobiotics, prolongs the shelf life of food products, and guarantees safety and high quality.

A technology for low-temperature heating of fish at ⩾ 30°C has been developed that promotes proteolysis of meat and does not cause discolouration associated with protein unfolding under these conditions (Takahashi *et al*., 2023). The free amino acid content (FAC) increased with the time of heating at 30°C. Fish samples were softened at 30°C for 120 min. The inosine-5'-monophosphate (IMP) content and total viable bacteria count were relatively constant at 30°C, regardless of the heating time (0-120 min). Thus, low-temperature heating at 30°C for 120 minutes was optimal for accelerating the fermentation of large amberjack meat, resulting in improved flavour and texture. This new technology significantly enhanced proteolysis and therefore achieved the desired properties such as softening the texture and increasing the amount of free amino acids while preventing protein denaturation, which is usually caused by conventional low-temperature heating. In addition, it is more beneficial than conventional ageing because it significantly reduces the duration of ageing, promotes safety and maintains the IMP content.

The expediency of improving the technology of processing small, unprofitable fish and expanding the range of food products from them has been substantiated (Golovko *et al*., 2019). It was proposed to enrich freshwater fish meat with microelements by adding dietary supplements based on chelate complexes to salt or tuzluk. The salting process was carried out in three ways. According to the first method of dry salting, the fish was mixed with sodium chloride NaCl with the addition of a dietary supplement in the amount of 20-25% and 0.1% by weight of raw materials, respectively. According to the second brine method, the fish was kept in a solution of sodium chloride NaCl in the amount of 2 kg of salt per 1 kg of raw material. The amount of dietary supplement was 0.1% by weight of raw material. According to the third method of salting, fish raw materials were pre-treated with ultrasound, after which they were salted in a brine tank with the same concentrations of sodium chloride and dietary supplement. The fish salting process lasted 6 days. For the methods of brine salting and brine salting with pretreatment with ultrasound, the homogeneity of the distribution of the trace element of the dietary supplement based on the chelate complex was established.

Functional food plays an important role in maintaining a healthy lifestyle and reducing risk factors for various diseases. A wide range of natural substances of plant and animal origin containing active ingredients that play a role in physiological actions deserve attention for their optimal use in maintaining health. The market for functional foods continues to expand, and

it is predicted that the global market will soon reach at least USD 91 billion. Particular attention in these studies is paid to raw materials containing ω-3 fatty acids (Baker *et al.*, 2022).

It has been proven that a multicomponent antioxidant blend is highly effective in imparting oxidative stability to edible oil. It is believed that the high efficiency of these blends is due to the synergistic effect of two or more components. The current study aims to analyse the synergistic effect of a flavonoid and its corresponding ester in improving the oxidative stability of sardine oil rich in ω-3 polyunsaturated fatty acids. The combination of rutin and rutin ester showed a maximum oxidation reduction of 54.2% at 100 mg/kg and 150 mg/kg. It has been determined that sardine (*Sardinella lemuru*) is one of the marine fish species that has a high content of omega-3 compared to other marine fish species (Fasuan *et al.*, 2022). The results of numerous studies over the past two decades have shown that ω-3 can prevent and treat coronary heart disease, diabetes, cancer, maintain kidney health, and play an important role in the central nervous system, brain, and eyes. One of the attempts to increase the economic value and preserve the nutritional content of sardine meat is to use it to make a sauce that retains biologically valuable ω-3 fatty acids.

The production of food and biological additives from *Palaemon adspesus* shrimp, common in the Azov-Black Sea basin, is one of the most promising areas of raw material use (Sydorenko & Petrova, 2021). Based on the assessment of the conducted research, recommendations on the technology of production of fish feed based on *Palaemon adspersus* shrimp are proposed. This will make it possible to more fully realize the nutritional potential of valuable protein-containing raw materials, rationally use domestic raw materials, and expand the range of aquatic products with rationalized amino acid and mineral composition. The study by A. Menchynska *et al*. (2021) is devoted to the enrichment of freshwater raw materials with additives of marine origin in the technology of fish pastes in order to improve the amino acid, fatty acid and mineral composition. The expediency of developing this area, which allows combining raw materials and creating food products with specified nutritional value properties, was determined.

The issue of attracting new sources of raw materials for food production is related to the study of amino acid, fatty acid, mineral composition of meat, the results of biomedical studies of one of the most common species of freshwater molluscs *Anodonta cygnea* Linne, 1758. The presence of all essential amino acids, biologically valuable fatty acids of the omega-3 family, and the absence of toxic mineral components were determined, which allowed recommending this raw material for use in the food industry. Culinary dishes and sauces made from *Anodonta cygnea* meat with high organoleptic properties and nutritional value were developed (Golovko *et al.*, 2019).

Studies were conducted to improve the formulation composition of minced meat products from the freshwater mollusc *Anodonta anatine*, which determined the feasibility of its enrichment with ginkgo powder as a source of antioxidants – flavonoids, tannins, organic acids, trace elements to improve functional properties (Helikh, 2019). Multicomponent fish pastes made from the meat of the freshwater mollusc *Anodonta anatine* were developed using the dietary selenium-protein supplement "Neoselen" for their enrichment with organic selenium. The regularities of the influence of the additive "Neoselen" on the chemical and mineral composition of freshwater aquatic pastes were determined. It was found that the addition of the Neoselen additive in the amount of 1%, 3% or 5% to the pastes allows enriching it by 14.8, 30.4 and 46.0 μg of selenium, respectively. The positive effect of the additive on the organoleptic, physicochemical, functional and technological parameters of fish pastes has been proven (Golovko *et al.*, 2019).

An analysis of the literature shows that the main area of research in the technology of fish products is to improve the formulation of various types of products, including preserves, minced products, sauces, and the formation of products using animal and vegetable raw materials based on the principles of food combinatorics. Most of the studies are devoted to the use of freshwater fish, such as carp, silver carp, and white cupid. There are no systematic studies of other freshwater fish, such as channel catfish, black catfish, brown catfish, bighead, black, bigmouth and other introductions. Therefore, conducting technological studies of these raw materials and developing new technologies is an urgent task for future research.

Conclusions

It is established that the fishing industry plays a significant role in ensuring food security and nutrition of the world's population. Based on the results of a study of the volume of aquatic bioresources harvested in the world, the article identifies trends in the increase in the catch of aquatic organisms. In recent years, about 225 million tonnes of aquatic products originating from global fisheries and aquaculture have been supplied to international markets. Out of this amount, 157.40 million tonnes of aquatic resources were used for food, which corresponds to an average consumption of 20.2 kilograms per person per year. In Ukraine, the volume of aquatic bioresources caught in the period 2010-2022 was decreasing. A sharp decline compared to previous periods was noted in 2014, due to the annexation of Crimea. In 2022, fish catches decreased significantly due to the war and amounted to 45.2% of the corresponding figure in 2021. Ukraine contributed 0.2% to the world's total fish production. In Ukraine, it remains a challenge to meet the needs of the population with fisheries and aquaculture products, which leads to low consumption of fish and fish products. For example, in 2021, the average per capita fish consumption in Ukraine was 11 kilograms, which corresponds to only 55% of the recommended norm. To date, there has been no significant increase in the consumption of fish products among Ukrainians. Based on the research conducted on the current state of fisheries in the world and in Ukraine, it has been established that the main effective way to obtain aquatic bioresources is to develop aquaculture using improved fish farming conditions.

Modern methods of processing fish products include the development of methods for assessing the quality of raw materials and finished products, as well as the development of technologies that minimise losses and allow the extraction of biologically active compounds, using biotechnological and physical methods to improve product quality. Technologies that involve the use of unconventional combinations of raw materials and the formation of multicomponent food products based on plant and animal raw materials are gaining popularity. Considerable attention is paid to the development of functional food products. The use of a new raw material, the freshwater toothless mollusk, for food purposes has been noted, and many culinary recipes have been developed from this species with additives of plant materials.

However, there is a lack of systematic technological research on freshwater introduced species in Ukraine, such as catfish, buffalo, and sturgeon. Therefore, a promising area for future technological research is the study of the above-mentioned fish species and the development of technology for such products available to the mass consumer as fish pastes, pates, sauces, etc.

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None.

Conflict of Interest

None.

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Стан та перспективи технологій переробки рибної продукціїї

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Анотація. Рибна промисловість відіграє суттєве значення в забезпеченні продовольчої безпеки та харчування населення світу. Тому проведення аналізу тенденцій розквіту промислу гідробіонтів у природних умовах та аквакультурі, особливостей використання сировини на харчування, ступені забезпеченності населення цією продукцією та нових технологій переробки представляє актуальне завдання для визначення пріоритетних напрямів удосконалення харчової і біологічної цінності продукції з гідробіонтів з урахуванням сучасних рекомендацій нутріціології. Мета дослідження полягала у вивченні сучасного стану рибної промисловості, інноваційних напрямів виготовлення продуктів з гідробіонтів для визначення перспективних напрямів технології риби та морепродуктів. Дослідження проводили з використанням порівняльного аналізу наукових праць вітчизняних та закордонних вчених, які розміщено в наукометричних базах Scopus, Web of Science, Journal Citation Reports, Scimago Journal & Country Rank та Google Scholar. Аналіз інформації свідчить про збільшення вилову гідробіонтів у світі і в останні роки загальний об'єм вилову складав понад 177,80 млн. тонн. На харчові цілі використано 157,40 млн. тонн при споживанні на одну особу в рік 20,2 кг. Масова частка України у загальному обсягу рибної продукції світу складає 0,2%. Україна імпортозалежна за постачанням гідробіонтів. Новітні технології

переробки рибної продукції пов'язані із розробленням методів оцінки якості сировини та продукції, створенні маловідходних технологій з вилученням біологічно активних сполук та формуванні багатокомпонентних харчових продуктів на основі рослинної та тваринної сировини, використанням біотехнологічних та фізичних методів з метою поліпшення якості продукції. Відмічено залучення нового об'єкту сировини – прісноводного молюска беззубки на харчові цілі та розроблено багато кулінарних рецептів з цього виду з добавками рослинної сировини. Однак, недостатньо досліджень у напрямку удосконалення технологій і рецептурного складу рибних паст, що дасть можливість формувати харчові продукти із заданими властивостями біологічної цінності для забезпечення потреб людини. Практичне значення проведеного аналізу полягає у визначенні перспективних тенденцій у технологій гідробіонтів з урахуванням власної сировинної бази України

Ключові слова: рибна промисловість; новітні технології; багатокомпонентні продукти; нова сировина; рибні пасти; прісноводна риба; дієтичні добавки

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Improving the technology for the production of raw dried beef products

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Abstract. The relevance of this work lies in the need to reduce the negative impact on human health of sodium nitrite (food additive E250), which is added to meat products, in particular to raw dried

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sausages, in order to accelerate their maturation and give them the shades familiar to consumers. The aim of the work is to improve the technology for the production of raw dried beef products based on the use of modern biotechnological approaches, sea salt and the natural colouring agent betanin, and beetroot juice as a substitute for sodium nitrite. This goal was achieved through the implementation of a mixed salting method, whereby the surface of the meat semi-product was rubbed with a reduced amount of salt, including 0.0005 kilograms of sodium nitrite per kilogram of meat weight, compared to standard technology, and the rest of the salting mixture, which contained 0.0045 sodium nitrite, was injected deep into the semi-product as an aqueous solution. The source of nitrite was beetroot juice rich in nitrate ion, 0.03 dm^3 of which contained 0.0052 kilograms of sodium nitrate, sufficient to synthesize 0.0045 kilograms of nitrite ion per kilogram of meat raw material. The chosen salting method reduced the amount of sodium nitrite from 0.015 to 0.005 kilograms per kilogram of meat product compared to the classical method, and the addition of beetroot juice made it possible to give the product a uniform colour throughout. Contamination of the product with dangerous microflora was prevented by adding a preparation containing bacteria of the *Pediococcus acidilactici* and *Staphylococcus carnosus* strains to the syringe solution. A positive effect of *Pediococcus acidilactici* was found, which was achieved by accelerating the pH of the meat mass to 5.0 ÷ 5.5, which stopped the growth of most dangerous microorganisms, including *Shigella spp., Salmonella spp*., *Clostridium difficile* and *Escherichia coli.* The product was protected from the development of *Listeria monocytogenes* bacteria by bacteria of the *Staphylococcus carnosus* strain. The proposed technology can be used in the food industry in the manufacture of raw meat products, which will significantly reduce the negative impact of sodium nitrite on human health

Keywords: meat products; raw dried products; beef; pickling; bacterial preparation; sodium nitrite; quality and safety of finished products

Introduction

The main areas for improving the technology of manufacturing raw smoked and raw dried products are the intensification of the technological process and the use of optimal processing modes, which ensures high nutritional value of the products. Colour is the first feature by which consumers assess the quality and suitability of meat products. If the appearance of the product is unsatisfactory, it creates the impression that the taste of the product is also unsatisfactory. Nitrite is the most common preservative in the meat industry. It improves the flavour and aroma of the product, preserves the reddish-pink colour of meat and prevents the risk of bacterial contamination of meat, but it has a negative impact on human health. That is why one of the challenges of modern nutritional science is to reduce the negative health effects of sodium nitrite (food additive E250) added to meat products, such as smoked and raw dried sausages and similar products. The negative effects of nitrites as an additive to meat were first reported in the early 1950s and 1960s, when the compound N-nitroso (NOCs) was discovered (Jin *et al.*, 2018). Previous studies have suggested that nitrosamines (in particular, consumption of meat products) are associated with certain types of cancer (Gyawali & Ibrahim, 2014). Subsequently, the amount of sodium nitrite used in the production of meat products has been limited.

Some researchers are paying more attention to replacing sodium nitrite with plant extracts, bacteria, specific bacterial strains and high hydrostatic pressure (HHP) to remove/reduce nitrite (Holembovska *et al.*, 2017;

da Silva Souza *et al.*, 2020; Macari *et al.*, 2022). Extracts and ingredients from plants are an acceptable alternative to nitrite. Some plants (herbs, vegetables, fruits, and spices) contain different types of phenolic compounds of different types, which are beneficial for human health as they have excellent free radical scavenging activity (Alahakoon *et al.*, 2018). S.K. Jin *et al.* (2018) prove that the formation of carcinogens N-nitrosamines in the interaction of sodium nitrite with amino acids found in meat and meat products and when heated can pose a potential risk of cancer development. The maximum permissible concentration of sodium nitrite residue in the manufacture of sausages is 0.005 mg/kg, and for special and baby food products – 0.003 mg/kg.

Every year, advanced technological solutions appear, new directions and trends are created. In recent years, the use of nitrites in the production of cured meat products has become an acute and complex issue due to their multifunctionality. On the one hand, nitrites have a positive effect on the colour, taste, aroma, and shelf life of meat products, while on the other hand, they can be a precursor to the formation of a powerful carcinogen, nitrosamine. The presence of free sodium nitrite in meat products poses a certain risk to human health, as nitrite is a toxic substance. Possible ways to reduce the content of sodium nitrite in meat products are of great practical importance. However, the absence of substances that can functionally replace sodium nitrite does not allow it to be excluded from the recipe and requires a search for a way to reduce its concentration in finished products.

A well-known method is the use of blood from slaughtered animals as an ingredient that can be added to cooked sausage formulations to improve the biological value of the product and increase the content of heme iron. Blood can be used effectively to colour finished products, thereby reducing the residual sodium nitrite content in gastronomic products (Khorunzha *et al.*, 2019).

The aim of the study is to improve the technology for the production of raw dried beef products using modern biotechnological approaches, sea salt, and the natural colouring agent betanin.

Literature Review

The problem of reducing the sodium nitrite content of meat products is the subject of intensive scientific research. As a compromise between the requirements of health authorities and the interests of consumers, it is sufficient to use nitrite ion in amounts ranging from 2 to 14 milligrams (3.3 to 10.0 milligrams of sodium nitrite) per kilogram of meat to achieve the desired effect. However, under such conditions, the time for preserving the desired colour is short, and therefore, according to WHO standards, in products intended for human consumption, the permissible level of nitrite ion consumption is increased to about 0.6 milligrams per kilogram of weight (about 0.5 milligrams in terms of nitrite ion), which is achieved by adding 100-150 milligrams of $NaNO_2$ to minced meat in the traditional way of consuming sausage products (Cherednichenko & Bal-Prylypko, 2020; Mushtruk *et al.*, 2023).

The problem is partially solved by adding substances with antioxidant properties to salt mixtures, for which ascorbic acid is most often used (Rosier *et al.*, 2022; Ugnivenko *et al.*, 2022). According to some studies, the negative impact of sodium nitrite in meat products is practically not felt, especially since a significant amount of this salt is bound by meat myoglobin, and after entering the body, the enzymes responsible for *NO* formation generate nitric monoxide from nitrite, where it is responsible for numerous physiological functions, including intracellular respiration (Tan *et al.*, 2022).

As a preservative, nitrite is difficult to replace because it can perform many functions simultaneously. Thus, reducing or eliminating the use of nitrite is a major challenge for the meat industry. Scientists are conducting

in-depth research to investigate the antibacterial agent and organoleptic effects of various alternative compounds and technologies that can be used as substitutes for nitrite. Consequently, the production of safe meat products now plays an important role in the meat industry to be able to avoid the direct use of nitrates and nitrites. Ways to reduce the percentage of residual nitrite include the use of natural pigments of animal and vegetable origin, as well as the use of antioxidants, which can simultaneously provide the desired colouring effect while minimizing the inclusion of nitrite salts in the meat product (Bozhko *et al.*, 2017). J. Haque *et al*. (2023) are wary of the use of significant amounts of sodium nitrite in mixtures used in the curing of raw meat, due to the negative impact on the body condition of living beings: for rats, the LD50 value is 180 milligrams of sodium nitrite per kilogram of body weight, for humans – 71 mg/kg.

G.S.B.S. de Medeiros *et al.* (2022) studied in their work the negative health effects of sodium nitrite (*food additive E*250) added to meat products, such as smoked and raw dried sausages and similar products, to accelerate their maturation and give them the usual pink to dark red colour according to the established mechanism. G. Riel *et al*. (2017) found no differences in the lightness parameter for sausages containing different amounts of parsley extract powder (PEP), but a difference was found for the parameter indicating redness. The authors concluded that the increase in yellow colour was due to the presence of plant pigments. They found that nitrite (100 or 125 mg/kg) combined with green tea catechins (300 mg/kg) protected sausages from depigmentation. P. Aliyari *et al*. (2020) found that samples (beef sausages) without nitrite but with more pomegranate peel and pistachio green onion extracts showed more yellowing than control samples with nitrite (120 ppm). F.M. Manihuruk *et al*. (2017) suggested the use of red dragon skin (*Hylocereus polyrhizus*) as a natural colourant and antioxidant.

Optimization of production technology poses a twofold task, which includes finding ways to reduce the dosage of sodium nitrite in the selected raw dried meat products and reduce the level of bacterial contamination associated with the duration of the maturation process after salting.

Materials and Methods

Experimental studies were conducted in 2023 in the laboratories of the Departments of Meat, Fish and Seafood Technology, Microbiology, Virology, and Biotechnology of the National University of Life and Environmental Sciences of Ukraine. The material used for the study was top-grade lean beef, which contains the highest relative amount of protein and, when lean meat is lean, has little adipose tissue waste. The surface of the meat was treated with a salting mixture of sea salt with additives of dextrose and sodium nitrite, and the inner layers were treated with a syringed aqueous solution of a mixture of ascorbic acid sea salt, sodium nitrite and the bacterial preparation B-LC-78.

The work was carried out using the methods generally accepted for this type of product to determine the physicochemical, organoleptic, rheological, functional, technological and microbiological quality indicators of meat products during the maturation process and ready-to-eat: the mass fraction of nitrite was determined according to DSTU ISO 2918:2005 (2007) by colouring solutions containing nitrite anion in pink-red colour of varying intensity depending on the nitrite concentration under the influence of the so-called Grissom-Ilosvay reagent; redox potential (RP) was determined by the electrometric method using the multifunctional device "Combo"; microbiological safety indicators were determined according to generally accepted methods, which included determining the number of bacteria of the Escherichia coli group (coliforms), pathogenic microorganisms, sulphite-producing clostridia and staphylococci; water activity was determined

by dew point according to the method at a temperature of 25 ± 1°C (Slobodianiuk *et al.*, 2018).

The task of reducing the dosage of sodium nitrite in the product was solved in two ways. The method of dry rubbing the surface with a salt mixture, traditionally used for salting raw meat, was replaced by a mixed salting method, in which no more than 15% of the amount of salt substances used in the traditional technology, including no more than 0.0005 kilograms of sodium nitrite per kilogram of raw meat, was used to rub the surface of the meat. The rest of the substances used for salting were added in the form of an aqueous solution by introducing the bulk of them into the inner layers of meat in a state dissolved in the salting liquid, which did not require a long time for nitrate ion diffusion into the deeper layers of meat, avoided unnecessary losses due to hydrolysis on the surface, and thus ensured almost quantitative interaction with myoglobin throughout the depth of the salted product according to the mechanism shown in Figure 1. At the same time, we also avoided "over-salting" of the cornerstone layers of meat in the event of insufficient penetration of the components of the salt mixtures into the inner layers of the salted product.

At the same time, we abandoned the use of sodium nitrite in favour of nitrate, which is present in large quantities in a dissolved state in beetroot juice. This method of salting reduced the irreversible loss of nitrite due to the evaporation of nitric oxide (II) as a result of the slow diffusion of $NaNO_2$ into the deeper layers of the meat raw material, which is characterized by its acidic properties:

$$NaNO_2 + H+ \rightarrow HNO_2 + Na+$$
$$3\ HNO_2 \rightarrow HNO_3 + 2\ NO\uparrow + H_2O.$$

After the salting was completed, the mixture was kept for 3 days to ripen the meat component, cut into flakes 6-7 millimetres thick and dried in the open air without access to direct sunlight at a temperature of up to 40°C until the mass fraction of moisture decreased by no more than 20%. Next, pieces of the dried product were cut into flakes 6-7 millimetres thick, sprinkled with a mixture of spices and transferred to a consumer transport container.

Results and Discussion

A series of studies showed that the proposed salting method significantly reduced the amount of nitrite ion used in salting by three times, while bringing the colour of the finished raw dried product closer to the usual consumer colour throughout the thickness due to the natural colouring agent betanin present in beetroot juice. Based on a series of studies, it was determined that a sufficient level of myoglobin binding to nitroso-myoglobin is achieved when the total processing of meat raw materials is 0.005 kilograms of $NaNO_2$, for which it was sufficient to use 0.0052 kilograms of sodium nitrate (an amount equivalent to 0.045 kg of sodium nitrite after reduction of nitrate contained in 0.03 dm^3 of beetroot juice with an actual content of 1.45 g/dm^3 of $NaNO_3$. The process of nitrate reduction to nitrite was significantly accelerated by the addition of ascorbic acid to the salt mixture as a substance with reducing properties, as indirectly evidenced by the redox potential of the meat system, while the corresponding characteristic of the control sample systematically increased upon contact with air oxygen (Fig. 1).

The analysis of the transformations shown in Figure 1 allows concluding that the end product of nitrate and nitrite metabolism in the human body is nitrogen monoxide, and the constant intake of nitrate/nitrite with food can cause systemic irritation of the mucous membranes of the gastrointestinal tract due to the formation of free radicals and a mixture of nitrate and nitrite acids. The optimization of production technology has a twofold task, which includes finding ways to reduce the dosage of sodium nitrite in the selected raw dried meat products and to reduce the level of their bacterial contamination associated with the duration of the maturation process after salting.

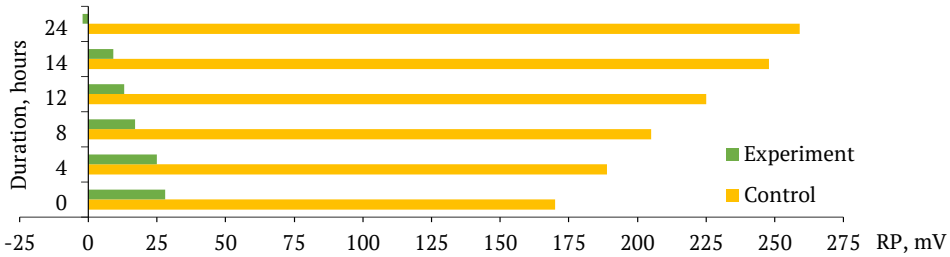

Figure 1. Dynamics of changes in the redox potential of raw dried meat flakes during the salting process

Source: developed by the authors

Salting by the proposed method also made it possible to virtually stop the process of microbiological contamination of the entire mass of the freshly salted product with toxicogenic and hazardous microorganisms, which is insufficient when salting by the classical method of adding sodium nitrite to the salting mixture, which, in addition to participating in the formation of the desired colour of the finished product, also inhibits the vital activity of microorganisms, both harmful and beneficial. However, due to the toxicity of nitrite and its insufficient antibacterial activity, the possibility of reducing the level of contamination of meat products with harmful and toxicogenic microorganisms of the genera *Pediococcus acidilactic*i and *Staphylococcus carnosus* as components of the bacterial preparation B-LC-78 was tested.

The introduction of *Staphylococcus carnosus* bacteria into food products since the 1950s has shown no signs of a dangerous effect on consumer health. Their use also helps to improve the flavour of meat products and provides a strong antagonistic effect against *Listeria monocytogenes*. The main reason for choosing the *Pediococcus acidilactici* strain, which is capable of synthesizing bacteriocins of the pediocin class, which are harmful to numerous microorganisms that are dangerous to health, including *Shigella spp., Salmonella spp., Clostridium difficile, Escherichia coli*, is that they quickly achieve pH values close to 5.0, at which the rate of reproduction of dangerous strains of microorganisms is minimal. The addition of a bacterial preparation has a positive effect on product safety, as the period of bacterial growth of the bacteria it contains is much shorter than that of the vast majority of undesirable microflora. The kinetics of the reproduction of lactic acid bacteria compared to the control, where this process occurs much more slowly, is shown in Figure 2.

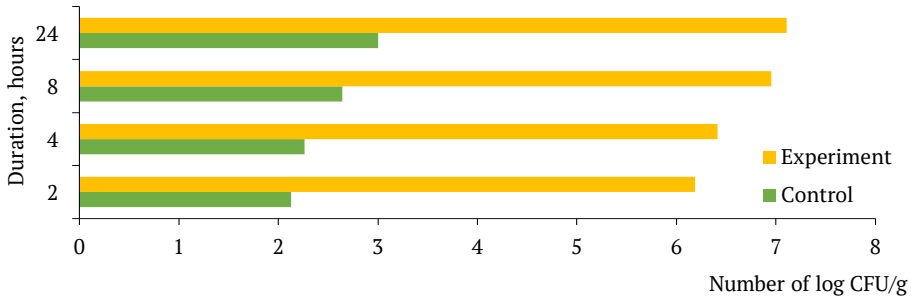

Figure 2. Dynamics of changes in the number of lactic acid bacteria during salting of raw beef

Source: developed by the authors

The dynamics of changes in the composition of hazardous microflora was studied within 72 hours in relation to bacteria of the Escherichia coli group (*E. coli*), mesophilic aerobic and facultative anaerobic microorganisms (MAFAM), salmonellae, bacteria of the Staphylococcus aureus strain, moulds, and yeasts. The determined indicators showed a practical stop to the growth of pathogenic microorganisms, and an increase in the number of bacteria of the E. coli group was detected only in relation to control samples (Table 1).

Table 1. *Dynamics of changes in microbiological indicators of control and experimental samples of meat flakes during 72 hours of salting*

	Duration of pickling, hours				
	2	12	24	48	72
			Escherichia coli bacteria		
Control	$1.0 \cdot 10^1$	$1.0 \cdot 10^1$	$1.0 \cdot 10^1$	$1.0 \cdot 10^2$	$1.0 \cdot 10^3$
Experiment	$1.0 \cdot 10^1$	$1.0 \cdot 10^1$	$1.0 \cdot 10^1$	$1.0 \cdot 10^1$	$1.0 \cdot 10^1$
			Mold/yeast		
Control	$1.0 \cdot 10^5$	$1.0 \cdot 10^5$	$1.2 \cdot 10^5$	$1.4 \cdot 10^5$	$1.5 \cdot 10^5$
Experiment	$1.0 \cdot 10^5$	$1.0 \cdot 10^5$	$1.1 \cdot 10^5$	$1.2 \cdot 10^5$	$1.2 \cdot 10^5$

Source: developed by the authors

After 3 days of maturation of the salted meat component, the pieces of meat were cut into flakes 6-7 millimetres thick and laid out for drying at a temperature not exceeding 40 ^{0}C without direct sunlight until a residual water content of about 20% was reached within 4 days. After completion of the production cycle, the flakes were sprinkled with a mixture of spices and left for storage for 180 days. The kinetics of water activity changes in the control and test samples of beef flakes are shown in Figure 3.

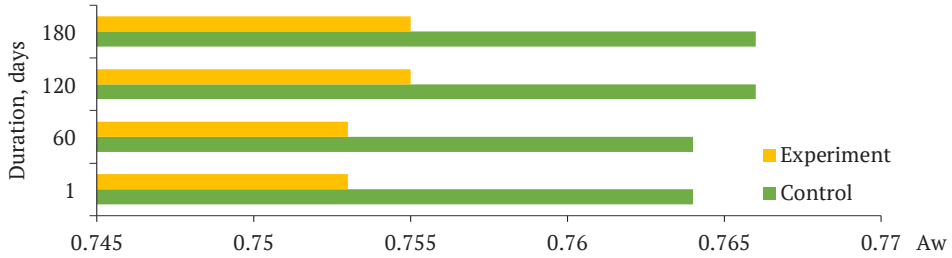

Figure 3. Dynamics of changes in water activity in samples of raw dried beef flakes during long-term storage

Source: developed by the authors

The data obtained indicate a higher level of safety of the control composition samples in terms of the probability of reproduction of hazardous microflora. The tendency of a faster decrease in the level of water activity in the product of the experimental composition compared to the control can be explained by the higher content of microorganisms introduced with the starter cultures, the proteolytic activity of which contributes to the swelling of elastin and collagen. Based on the results, it was found that the introduction of the bacterial preparation B-LC-78 into the mixture used to salt almost pure meat raw materials in terms of bacterial contamination leads to the practical absence of harmful microflora,

respectively, and an increase in the level of bacterial safety of the product both immediately after the completion of the manufacturing process and during prolonged ageing of the product (Table 2). The raw dried beef flakes were free of Escherichia coli, pathogenic microorganisms, sulphite-producing clostridia, *L. Monocytogenes, Staph. Aureus*, which indicates that the test samples are safe and suitable for consumption.

Table 2. *Microbiological indicators of the safety of the experimental sample of raw dried beef flakes*

Indicator	The content of dangerous microorganisms	Method of determination
Escherichia coli (coliforms), in 1.0 g	Not found	ISO 4831:2006
Pathogenic microorganisms, including salmonella, in 25 g		ISO 6579-1:2017
Sulphite reducing agents clostridia, in 0.1 g	Not found	ISO 15213:2003
L. monocytogenes, in 25 g		ISO 11290-1:2017
Staph. aureus, in 1.0 g		GOST 10444.2-94

Source: research conducted by the authors

According to microbiological criteria, all sausage samples meet the requirements of the current regulatory documents. The finished product does not contain bacteria belonging to the *E. coli* group, the Salmonella genus or sulphite-producingclostridia. Relevant studies were carried out by L. Bal-Prylypko *et al*. (2022) on the example of mixtures of standard (control) and experimental composition (Table 3):

Table 3. *Composition of the standard salt mixture, kg/100 kg of meat*

The name of the component	Control	Experiment
Kitchen salt	3.5	–
Sea salt	–	3.1
Water	–	6.4
A mixture of spices	1.2	1.2
Sodium nitrite	0.015	0.005
Beet juice	–	0.03
Dextrose (glucose)	1.0	0.65
Sodium isoascorbate	0.07	–
Ascorbic acid	–	0.085
Bacterial preparation B-LC-78	–	0.018

Source: L. Bal-Prylypko *et al*. (2022)

Similar studies were conducted by J. Haque *et al*. (2023), who investigated fermented sausages using accelerated technology. The results of their research showed that the use of accelerated technology for the production of fermented sausages does not affect the microbiological safety of products and can significantly reduce the drying time of the product. The data obtained indicate that at a low level of bacterial contamination of meat raw materials, the same product safety is achieved as when using the traditional process.

M. Shynkaruk & O. Baluk (2021) addressed the problem of improving the quality of cured meat products using starter cultures. In the development of meat product technology, there

is a tendency to use food additives made from plant materials in combination with starter cultures to improve the quality of finished products. To reproduce the colour of meat products, starter cultures should contain denitrifying bacteria. The biological basis for the formation of sausages as a food product is lactic acid bacteria, which contribute to the biotransformation of the main components of meat with the formation of compounds that determine the smell, taste, aroma, and consistency; changes in the physicochemical parameters of minced meat, which can lead to the growth of bacteria that cause meat spoilage. The use of sourdough starter cultures in the production of meat products not only reduces the time of the technological process, but also ensures the microbiological safety of the finished product.

M. Stoica *et al.* (2022) examined the impact of plant powders. extracts and plasma to replace all or part of conventional $NaNO_2$ in meat products. The authors also presented the functionality of $NaNO_2$ in meat products and the costs of its replacement. E. Vossen & S. De Smet (2015) showed the effect of $NaNO_2$ on protein oxidation. In addition, the potential use of 3-nitrotyrosine as a specific marker for reactive nitrogen species-mediated nitration was investigated. Overall, no clear antioxidant effect of $NaNO_2$ against carbonyl formation in the isolates was observed. 3-Nitrotyrosine was present in all samples, but no clear effect of $NaNO_2$ addition or oxidation time was observed. G. Ma *et al.* (2022) studied the effects of low doses of sodium nitrite on meat colour, myoglobin oxygenation status, myoglobin aggregation and myoglobin structure using infrared spectroscopy. The results showed that the redness index of meat increased continuously compared to the control after the addition of low dose sodium nitrite. The results indicate that low doses of sodium nitrite promoted the dynamic transformation of the nitrosylated myoglobin peptide fragment, which in turn preserved the colour of the meat.

Similar studies on microbiological safety indicators in finished products were conducted by B. Łaszkiewicz *et al.* (2021). Different groups of bacteria were tested, and it was found that a number of factors dramatically affect the bacteriostatic effect of sodium nitrite. The pH of the medium influenced the level of nitrite causing inhibition, thus tending to confirm the hypothesis that unbound nitric acid is the active form. During autoclaving, the anaerobic growth of *Staphylococcus aureus, Streptococcus salivarius,* and *Streptococcus mitis* was inhibited by significantly lower nitrite levels than if glucose had been added to the medium after autoclaving. X. Wang *et al*. (2022) studied the effect of different sodium nitrite concentrations on the quality and protein oxidation of salted meat during 21 days of beef curing. Their results showed that the carbonyl group, dithirosine, and surface hydrophobicity of salted meat were significantly reduced by the addition of sodium nitrite. At the same time, total nitrogen and aerobic plate content decreased significantly, while pH values increased significantly with increasing nitrite concentration compared to the control group. Importantly, this phenomenon was also observed in salted meat treated with low doses of sodium nitrite. Consequently, they also found that the quality of salted beef can be improved by adding low doses of sodium nitrite to inhibit protein oxidation during the curing process.

Conclusions

A method for the production of raw dried beef flakes by treating the surface with a mixture of sea salt, dextrose and sodium nitrite, and the inner layers of meat raw materials by syringing a salting liquid containing sea salt, ascorbic acid, dextrose, sodium nitrite, beetroot juice and bacterial preparation B-LC-78 was investigated. It has been shown that the use of a combined salting method, which involves the introduction of beetroot juice containing nitrite ion obtained by reducing the nitrate ion of the

inherent juice with ascorbic acid, into the syringe salting solution, allowed for a threefold reduction in the dosage of nitrite ion and improved the colour characteristics of the product due to the presence of the natural colourant betanin in beetroot juice, which is similar in colour to the colour of cured meat products. The presence of a bacterial preparation containing bacteria of the *Pediococcus acidilactici* and *Staphylococcus carnosus* strains in the solution allowed almost completely stopping the development of pathogens and toxicogenic microorganisms in the mass, which suggests an increase in the level of bacterial safety of the product both after the manufacturing process and after prolonged exposure of the finished product. The dynamics of changes in the water activity in the product of the prototype sample is explained by the higher content of introduced microorganisms, the proteolytic activity of which contributes to the swelling of elastin and collagen, which indicates a higher level of safety of the control samples in terms of the probability of reproduction of hazardous microflora.

Prospects for future research include conducting comprehensive analyses of bacterial preparations in comparison with other bacterial preparations, their impact on pH reduction, microflora, and the formation of a distinct taste and structure of raw dried sausages due to the development of microflora. This technology can be implemented in the food industry in the manufacture of meat snack products and will significantly reduce the negative impact of sodium nitrite on human health, but these studies require further refinement.

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None.

Conflict of Interest

None.

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Удосконалення технології виготовлення сиров'ялених продуктів з яловичини

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Анотація. Актуальність роботи полягає у необхідності зменшення негативного впливу на стан здоров'я людини нітриту натрію (харчової добавки Е250), який додають у м'ясні продукти, зокрема в сиров'ялені ковбаси, з метою прискорення процесів їх визрівання та надання звичних споживачам відтінків. Мета роботи полягає в удосконаленні технології виготовлення сиров'ялених продуктів з яловичини, яка базується на використанні сучасних біотехнологічних підходів, морської солі та природного барвника бетаніну та бурякового соку, як замінника нітриту натрію. Реалізація поставленої мети відбувалась шляхом реалізації змішаного способу посолу, за яким поверхню м'ясного напівпродукту натирали зменшеною до 15 %, порівняно із стандартною технологією, кількістю використовуваних для солей, у тому числі 0,0005 кілограма нітриту натрію на кілограм м'ясної маси, а іншу частину посолочної суміші, яка містила 0,0045 нітриту натрію, шприцювали вглиб напівпродукту у вигляді водного розчину. Джерелом нітриту був багатий нітрат-іоном буряковий сік 0,03 дм^3 якого містили 0,0052 кілограми нітрату натрію достатнього для синтезу 0,0045 кілограму нітрит-іону на кілограм м'ясної сировини. Обраний спосіб соління дозволив зменшити порівняно з класичним методом кількість нітриту натрію з 0,015 до 0,005 кілограма на

кілограм м’ясного продукту, а додавання бурякового соку дозволило надати продукту рівномірного забарвлення по всій товщині. Забруднення продукту небезпечною мікрофлорою попереджували додаванням у шприцювальний розчин препарату, який містив бактерії штамів *Pediococcus acidilactici* та *Staphylococcus carnosus*. Встановлено позитивний ефект від застосування *Pediococcus acidilactici*, який досягався прискореним доведенням pH м’ясної маси до 5,0 ÷ 5,5, за якого припинялось розмноження більшості небезпечних мікроорганізмів, зокрема *Shigella spp*., *Salmonella spp*., *Clostridium difficile* та *Escherichia coli*. Захист продукту від розвитку бактерій *Listeria monocytogenes* відбувався за допомогою бактерій штаму *Staphylococcus carnosus*. Запропонована технологія може бути використана в харчовій промисловості під час виготовлення сиров’ялених м’ясних продуктів, що сутєво знизить негативний вплив нітриту натрію на здоров’я людини

Ключові слова: м’ясні продукти; сиров’ялені продукти; яловичина; соління; бактеріальний препарат; нітрит натрію; якість та безпека готових виробів

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Technological solutions for effective production on beef cattle breeding farms in the conditions of Ukraine

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Abstract. Beef cattle breeding in Ukraine is considered to be a promising and socially important livestock sector, which is experiencing a systemic decline in production. The purpose of the study was to find the most effective options for organizing production in beef cattle breeding. The analysis was based on the production data of an agricultural enterprise with more than 4.5 thousand heads of meat cattle, including more than 1.7 thousand cows. Taking into account the company's

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development strategy, which provided for the expanded reproduction and sale of bull-calves and culled breeding stock, the production indicators of the farm's operation under the cow-calf system and the complete cycle with the rearing of young animals to slaughter conditions were analysed. The analysis of these production options was carried out for the conditions of using year-round and seasonal (from February to April) calving on the farm. It was found that when calving throughout the year, the number of cattle places in the premises and pens will be relatively constant. In the case of seasonal calving, the structure of the herd changes significantly during the year. Sales of finished products during seasonal calving should take place in relatively short periods of time and in large groups. In particular, the monthly sales of bull-calves for fattening in the cow-calf system during seasonal calving will be on average 11 times higher than during year-round reproduction in the herd. With a full breeding cycle, the batches of bull-calves for slaughter will differ less, but will occur only in the spring months. Seasonal calving during the complete production cycle resulted in a 1% reduction in silage and 3% reduction in hay consumption and a 10% increase in pasture grass consumption. The full cycle of raising bull-calves for meat makes it possible to increase the total live weight of cattle sold by 59%, increase sales revenue by 54% and reduce total feed costs per 1 tonne of live weight by 20%. The practical significance of this study is to obtain results that can be used in the Ukrainian beef cattle industry to plan efficient production organization

Keywords: cattle; cow-calf system; fattening; feed costs; beef

Introduction

Ukraine is experiencing a systemic reduction in the raw material base for some types of meat, which is explained by the crisis in livestock production (Ishchuk, 2020). According to the State Statistics Service of Ukraine (Animal production of Ukraine, 2021), in the second half of the last century, meat production of all major types in Ukraine was actively increasing until the early 90s. Subsequently, by 2000, meat production decreased by 62%. The most difficult situation was in cattle breeding, as beef production fell by 83% over 10 years. After this decline, meat production in Ukraine began to grow and has stabilized over the past three years at 2.4-2.5 million tonnes. The stabilization was driven by alternative meat types to beef – poultry (which has doubled in quantity compared to the most productive year in 1990) and partly pork. As of 2021, only 59 kg of all types of meat were produced per capita. With cattle meat production totalling 310.5 thousand tonnes in 2021, the total production of beef and veal per person was only 7.5 kg. According to N. Kopytets & V. Voloshyn (2021), the main producers of beef and veal are households, which account for more than 70% of production, although in 1990, according to the State Statistics Service of Ukraine (Animal production of Ukraine, 2021), this figure did not exceed 9%. The analysis of data on beef production in farms of various forms found that large agricultural enterprises, which should provide the basis for meat production and have the ability to control product safety and form large batches of cattle for slaughter, produce less than 2 kg of beef per person, and their total share in gross production is 26%. This is due to a steady decline in livestock numbers, which continued after 2000, while other competitive livestock sectors were able to stabilize or increase production. Over the past 16 years alone, the number of cattle sold for slaughter by agricultural enterprises has decreased by 60%, which is 7% more than in all categories of farms.

One of the reasons for the decline in beef production is the low economic attractiveness

of its production due to low purchase prices for livestock. Thus, as of April 2021, as noted by V. Ivchenko *et al.* (2021), the average purchase prices for live cattle for slaughter depended on the category of animals, but ranged from UAH 27.9 to 40.5 per kilogram of live weight. In the European Union (Ivchenko *et al.*, 2021), purchase prices for cattle for slaughter are on average 96% higher than in Ukraine, and in some countries (Belgium and Italy), the difference reaches 134-142%. At the same time, the future prospects for beef production are clear. The world is witnessing an increase in demand for quality meat products (Berher, 2020). In an analytical study by N. Eroğlu *et al.* (2019), the authors report that there is a high demand for beef in Turkey and forecast a 14% increase in consumption between 2019 and 2028. This high demand requires finding ways to efficiently produce beef for domestic consumption and increase exports. The problem of producing high-quality beef can be solved by developing specialized beef cattle breeding. There are various systems of beef cattle management that differ in their efficiency. As noted by D. Broom (2021), extensive grazing and the use of feedlots are considered the least sustainable beef production systems, while semi-intensive forest grazing systems and managed grazing systems in areas where crop production is unprofitable are considered the most sustainable. To stabilize beef production in Ukraine, there is a need to find the most efficient beef production systems. The aim of this study was to identify the most appropriate options for organizing production on beef cattle farms.

Literature Review

Since the 1990s, as noted by O. Kozak & O. Hryshchenko (2019), beef production in Ukraine has declined significantly, due to a decrease in the total number of cows and young animals raised for meat production. It was planned to increase beef production by developing specialized beef cattle breeding, as this industry is not related to milk production and can be developed in areas with difficult farming conditions, and beef cattle make efficient use of pastures, natural fodder and post-harvest residues. For this purpose, a 20-year programme for the development of beef cattle breeding was developed by A.A. Getya *et al*. (2013). Meat cattle breeding is of social importance, as it can be developed in remote areas where daily logistics are difficult, and is also effective in areas with low soil fertility (Ugnivenko *et al*., 2016). Due to the persistent unfavourable changes in the dietary patterns of the population, according to the Institute of Food Resources of the National Academy of Agrarian Sciences (Tymchenko, 2015), the beef cattle industry is strategic in terms of food security, but its condition remains critical.

The main disadvantage of beef cattle breeding is the limited productivity of the cow, which is caused by the ability to raise only one calf per year. In dairy farming, milk is produced during lactation to make up for the cost of maintaining the main herd. Farms that produce both beef and milk have significantly higher productivity of dietary protein and energy per hectare than specialized beef production systems (Mosnier *et al*., 2021). Raising young dairy cattle for meat does not involve the costs of the rest of the herd. Beef cattle breeding is different. The sale of business calves or young stock bred to the final condition should compensate for the costs of not only this part of the herd, but also for the maintenance and feeding of cows, bulls and replacement stock, so 2-3 times more feed energy is consumed per unit of production in beef cattle than in dairy farms (Ugnivenko *et al*., 2016). The higher costs of raising beef cattle are compensated by the increased yield, quality, and processability of beef. Beef from specialized breeds has better flavour properties, and some breeds are prone to marbling, which makes beef and crossbred cattle more expensive than dairy cattle (McCabe *et al*., 2022).

Beef production schemes can vary. The classic option for beef cattle breeding is to organize seasonal reproduction using tour calving and mating campaigns (Ugnivenko *et al.*, 2016). This production option is most suitable for the efficient use of natural fodder lands and cultivated pastures in the spring and summer and reducing the cost of keeping and feeding cows in the winter. Seasonal reproduction makes it possible to carry out complex work operations (such as insemination, calving organization and control, calf weaning, cow evaluation) in a short period of time, as well as to form large levelled groups of animals for further rearing and sale. Raising cattle ready for slaughter usually involves several stages: cow-calf system, rearing and fattening (Peel, 2003). In Ukraine, the production organization with a complete herd turnover is common. In farms, young animals are raised until slaughter on the farm where the breeding herd is kept. P. Putsenteilo (2016) notes that different forms of farm production organization are possible, but it is more advisable to specialize farms. Some farms should raise calves in suckling and sell them to fattening enterprises after weaning of bulls and heifers being already the part of a herd. Fattening plants and sites ensure the final rearing and production of young cattle with optimal slaughter conditions. Specialization of farms at different stages of beef production allows for more efficient use of resources and feed. According to A. Ugnivenko *et al*. (2016), young cattle need to be provided with fast growth on the background of balanced nutrition to effectively use the biological basis for muscle tissue development, and breeding herds should be kept using extensive technologies and maximum use of pastures and natural lands to reduce costs. With these features in mind, beef cattle breeding herds can be part of natural ecosystems. It is recommended to use them to increase the ecological and recreational value of the forest and reduce the likelihood of fires (Casasús *et al.*, 2007), as moderate grazing reduces the amount of shrubs and dry grass.

The efficiency of raising livestock for meat also depends on the sex of the animals. Bull-calves tend to be more productive, so according to H. Koknaroglu *et al*. (2005), they are used more often in fattening enterprises. Improvements in technology and breeding are gradually increasing the productivity of beef cattle. In particular, the live weight of calves at the time of weaning is constantly increasing. According to American researchers (Lalman *et al.*, 2019), from 1983 to 2017, there was an increase in the live weight of weaned calves, which, taking into account variability in the areas where farms are located, averaged 0.5 kg per year. Significant progress has also been made in a number of other livestock productivity traits.

The attractiveness of beef cattle breeding depends on economic indicators. Prices for fattened cattle account for approximately 50% of the variation in profitability and depend on the balance of the market. In countries with developed beef cattle production, such as Australia, J. Wong (2020) notes periodic fluctuations in slaughter cattle prices due to waves of demand for commercial cattle and breeding stock for herd reproduction. The use of techniques to increase cattle productivity using growth stimulants and other technological methods affects consumer perceptions and has led to increased demand for beef produced without stimulants, the production technology of which is being actively researched (Aboagye *et al.*, 2021). Among the options for producing high-quality beef are (Archer *et al.*, 2004) grass-fed (high volume diets using pastures, green mass and hay, balanced with other feeds and additives) and grain-fed (highly concentrated diets). In other words, there is a wide variety of options for organizing beef production in the world, and in Ukraine, the search for the most rational organization of the technological process remains relevant.

Materials and Methods

The research was carried out by analysing various options for the cultivation and sale of

livestock, calculated based on the results of production activities in 2021-2022 of one of the agricultural enterprises of Ukraine, with a livestock population of more than 4.5 thousand heads of beef cattle, including more than 1.7 thousand cows of several specialized breeds (in particular, Aberdeen Angus, Charolais, and Limousin, and Hereford). No animals were directly involved in the study. For ethical reasons, the name of the private enterprise on the basis of which the study was conducted will not be disclosed, as the publication contains sensitive data on production volumes and sales prices. The company's beef cattle production had a complete cycle. The breeding stock was used employing the cow-calf technology. Weaned calves aged 6-8 months were separated by sex and put to grow. Bull-calves were sold for meat at the age of 12-14 months. The breeding stock with calves were kept on pastures in summer and in group untethered housing in winter. The bull-calves for growing and fattening were kept indoors in group sections formed by age and fed a mixed diet. Calving in the herd was year-round but uneven throughout the year. Reproduction in the herd was extended, with almost all heifers suitable for reproduction being bred and inseminated at the age of 14 to 18 months. The general parameters of breeding and reproduction are shown in Table 1.

Table 1. *Parameters of reproduction of livestock and cattle rearing*

Indicator	Value
Culling of cows, %	12
Yield of calves per 100 cows, %	84
The average age of introduction of heifers into the herd, months	24
Die-off and culling of suckling calves, %	3.5
Duration of the suckling period, months	7
Live weight of weaned calves, kg	250
Age of sale of bull-calves for meat, months	12-14
Live weight of bull-calves during sale for slaughter, kg	450

Source: author's development

The study examined the efficiency of production organization at the enterprise under conditions of year-round calving of cows (used on this farm) and the transition to seasonal reproduction, which is used in beef cattle breeding in most temperate countries. The study used data on livestock availability, animal reproduction and growth parameters, and the enterprise's development strategy. Two models of final product production were studied under two options for organizing livestock reproduction. The first model is the cow-calf system, where weaned bull-calves are sold for growing and fattening. The second model is a complete production cycle, with the sale of bull-calves for slaughter. Heifers were not included in the sales plan due to the farm's strategy of expanded reproduction in the coming years. In both models, cull cows and bulls were used as additional products, so their number and live weight were determined. The study determined the optimum live weight of bull-calvess for meat production, analysed the features of the production cycle, the annual dynamics of production and output of finished products, the need for feed for different production options, annual production volumes and the cost of final products, and feed consumption per cent of beef produced. Feed consumption was calculated using the rations of livestock of different production groups used on the farm (Table 2).

Table 2. *Daily feed requirement and structure of rations for production groups*

Indicator	Sex and age groups of livestock						
	cows	heifers	repair heifers	suckling heifers	suckling bull-calves	bulls	fattening bull-calves
Fodder requirement for 1 head, fodder unit	10	6.7	6	3	3.5	13.5	7
the structure of the diet in the autumn-winter period							
silage, %	34.8	34.8	50	34.8	34.8	34.8	10
compound feed, %	33.2	33.2	24	33.2	33.2	33.2	78
hay, %	15.2	15.2	17	27	27	27	12
straw, %	11.8	11.8	9	—	—	—	—
the structure of the diet in the spring-summer period							
compound feed	29	29	20	29	29	29	*
green fodder (pastures)	71	71	80	71	71	71	*

Notes: * fattening bull-calves are grown year-round on diets that correspond to the autumn-winter period in terms of composition and structure

Source: author's development

The duration of the spring-summer period, during which pasture fodder is used, was from May to September inclusive. The energy value of fodder was determined in fodder units, since reporting and statistical information in the economy is provided in these units of measurement.

Results and Discussion

To ensure the efficient functioning of farms in meat cattle breeding, the substantiation of the requirements for livestock that will be sold for slaughter becomes important. The main characteristic of cattle for slaughter is pre-slaughter live weight. This factor affects the duration of the production cycle on the farm and also affects feed costs, quality, and mass of carcasses, etc. The choice of criteria for establishing the optimal live weight of young animals for slaughter is quite wide, but considering that high-quality and elite beef is obtained from specialized meat cattle, and the steak part has the highest value among carcass cuts, it was accepted to focus on the weight of bull-calves during the period of cessation of active growth of the longest muscle of back widthwise. According to the research of A. Ugnivenko *et al*. (2022), carried out in Ukrainian meat and black-and-white dairy breeds, the largest cross-sectional area *m. Longisimus dorsi* in the area between the 12th and 13th ribs is manifested when the live weight of bull-calves is from 451 to 500 kg (Fig. 1).

At a live weight of up to 450 and over 500 kg, the area of the "muscle eye" of the studied breeds was smaller. Since the live weight of bull-calves of 450-500 kg under conditions of intensive breeding can be obtained at an early (12-14 months) age, when bull-calves have relatively low fat deposition and moderate feed consumption for live weight gain, this weight range should be considered optimal. Production on a beef farm can take place in the form of an unfinished cycle according to the "cow-calf" system, during which the young weaned from cows are sold for fattening in other enterprises and the finished cycle of production with the sale of young for slaughter. The production cycle on such farms differs significantly both in terms of structure and duration (Fig. 2). The start of production according to the "cow-calf" system corresponds to the time of insemination of cows and heifers, and the production cycle

includes fattening and suckling calves. The full duration of the production cycle until obtaining marketable products on such a farm is 16 months, but taking into account the fact that cows partially combine the next calving and previous lactation, the technological process lasts 12 months, with the receipt of weaned calves every year.

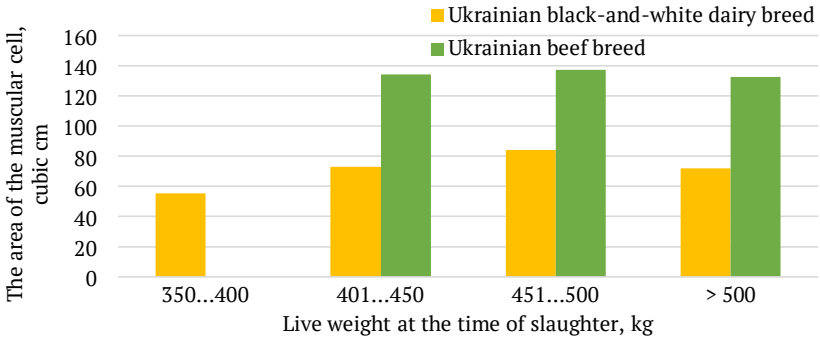

Figure 1. The area of the muscular cell of bull-calves, depending on the live weight before slaughter

Source: A. Ugnivenko et al. (2022)

On a farm with a finished cycle of production in the broodstock, the production cycle includes the same periods, but after weaning of the calves, rearing and fattening of the young is added. The total duration of the production cycle on such a farm will be 6 months longer than the "cow-calf" system. The extension of the production cycle contributes to the increase in the number of livestock on the farm, but due to the extended cultivation of young animals, it will contribute to the growth of the gross live weight of the reared livestock.

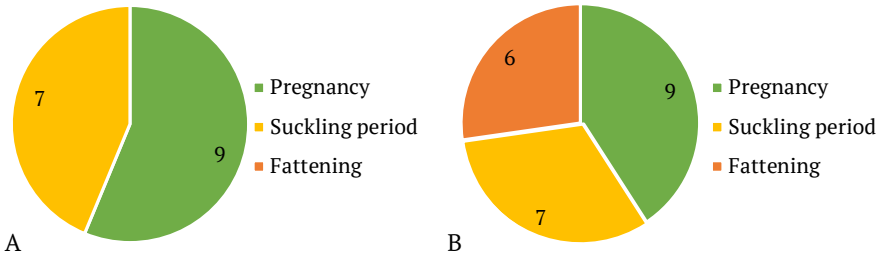

Figure 2. Duration of the production cycle on the farm (months) using the cow-calf system (A) and the completed production cycle (B)

Source: author's development

In addition to the duration of the production cycle, it is possible to use two different forms of organization of livestock reproduction in beef cattle breeding, in particular year-round and seasonal calving. There is an opinion that seasonal calvings have certain advantages over year-round calvings, due to the consolidation of labour-intensive operations (calving, insemination), the ability to form large homogeneous groups of animals and the most optimal use of pastures. At the same time, a detailed comparison of these forms of organization of reproduction of beef cattle in the conditions of Ukraine was not carried out.

The movement of livestock throughout the year under the conditions of year-round calving with their distribution maintained throughout the year and seasonal calving in February-April was modelled, which is provided by tour mating campaigns in May-July. Under the conditions of obtaining year-round calving at the beginning of the year, the total number of cattle is 4.882 heads, and for seasonal reproduction it is 310 heads less (Table 3). The decrease in herd size during seasonal calvings is due to the peculiarities of the organization of the production process and the redistribution of livestock, in particular, there will be no suckling calves at the beginning of the year.

Table 3. *Population of cattle of different gender and age groups*

No.	Sex and age groups of beef cattle	Number of heads	
		for year-round calving	for seasonal calving
1	Cows	1752	1752
2	Heifers	726	867
3	Repair heifers (over 7 months of age)	922	961
4	Suckling heifers	453	—
5	Suckling bull-calves	450	—
6	Bull-calves from 7 to 14 months	577	961
7	Bulls	22	22
	In total	4882	4572

Source: author's development

The dynamics of livestock in groups of livestock, under different options for the organization of reproduction, is shown in Figures 3 and 4. Under the conditions of obtaining relatively uniform calvings throughout the year, a trend of a gradual increase in the number of cows, which is provided for by the strategy of expanded reproduction of the herd, is clearly observed. The growth of the brood stock will reach 36% for the year. In all groups, the number of cattle during year-round calving will be relatively stable. This implies the need to have a certain number of places in the premises and pens to keep the corresponding accounting groups of livestock, and the filling of sections for keeping animals will be relatively constant.

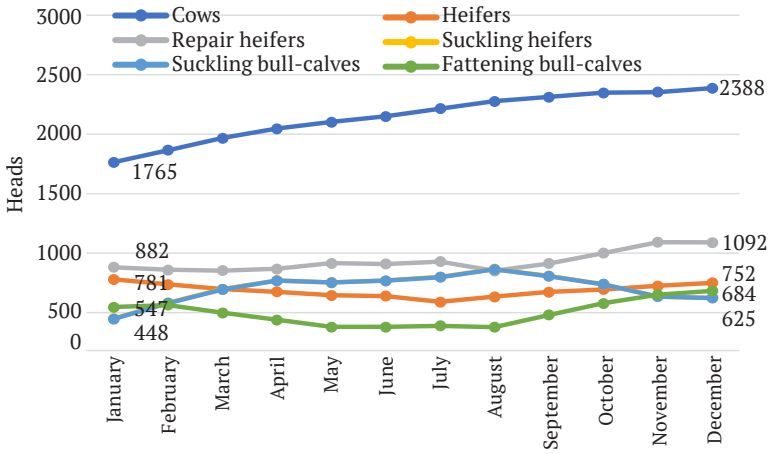

Figure 3. Size of livestock groups with relatively uniform calvings throughout the year
Source: author's development

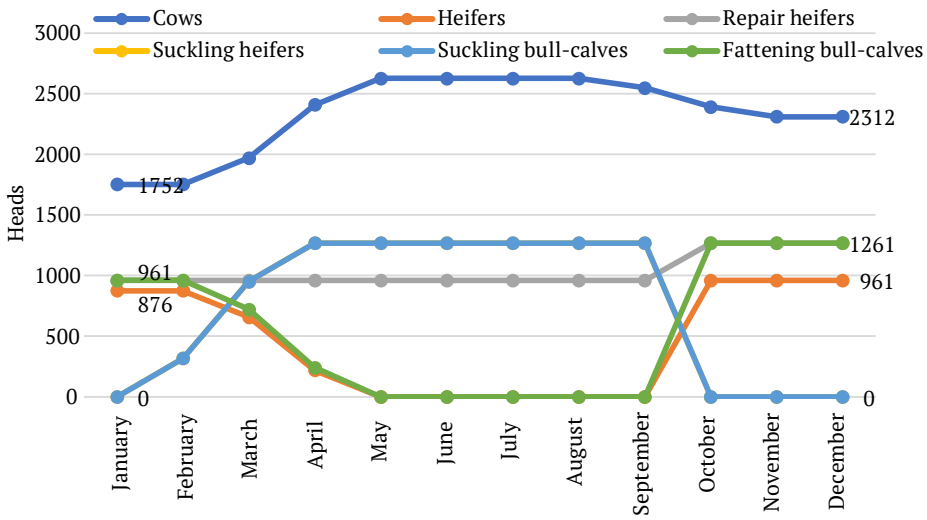

Figure 4. The size of livestock groups for obtaining seasonal tour calvings
Source: author's development

With seasonal tour calving, the year-end increase in the number of cows will reach 32%, which is 4 percentage points less than with year-round calving. The difference is due to the way cows are culled, as with seasonal calving they are removed from the herd in the autumn, before the start of the winter period, while with year-round calving they are gradually removed. The structure of the herd changes significantly during the year with seasonal calving. In particular, fattening cows and heifers are in the herd only from October to April, while suckling calves are in the herd from February to October. During most of these periods, the number of cattle in the groups is at its maximum level and hardly changes. For example, from April to September, the number of suckling calves with cows will be more than 2.5 thousand. This simplifies the organization of care for cows with calves, but requires large areas in pens and premises. For comparison, with year-round calving, suckling calves will be in the herd all year round, but their number will range from 0.9 to 1.7 thousand. The solution to the problem of space for cows with suckling calves is to use pasture-based housing. Thus, in farms with pasture, the organization of seasonal calving will be more appropriate. Year-round calving reduces the need for headspace by levelling the number of cattle groups throughout the year, and is more appropriate on farms that do not have sufficient pasture or are focused on rearing animals in pens.

An important element of production on beef cattle farms is the sale of finished products. With year-round calving, the production of livestock groups will be spread over the whole year, while with seasonal calving, the sale of animals should take place in relatively short periods of time (Fig. 5).

With year-round calving, a cow-calf farm can sell groups of bull-calves ranging from 38 to 198 head for fattening each month. The difference in the size of the weaned calf product groups will depend on the uniformity of calving throughout the year. In the case of seasonal calving, weaned calves are received in October. The group of bull-calves to be sold for fattening will be about 1.3 thousand heads. This is numerous bulls, which increases the risk of lower prices or delays in sales, which in turn are associated with additional feed costs.

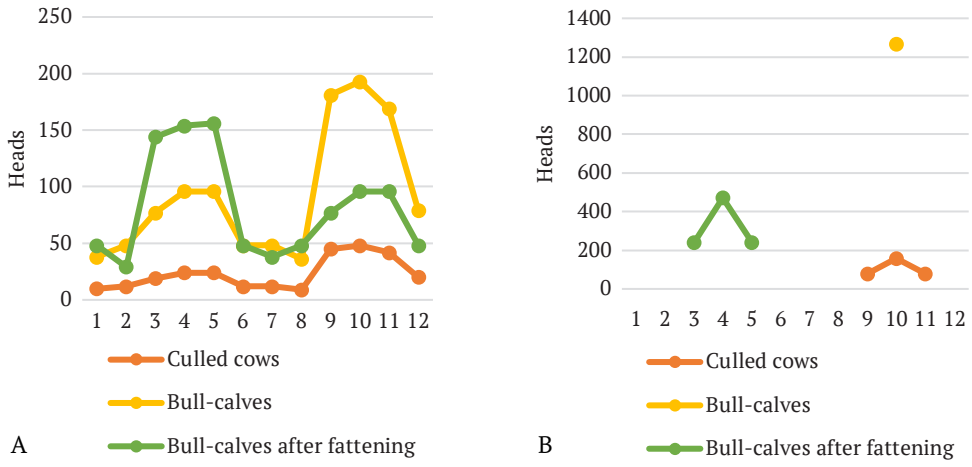

Figure 5. Predicted dynamics of production of the main types of products during the year for year-round calvings (A) and seasonal calvings (B)

Source: author's development

A similar situation exists with the sale of cattle from a farm with a complete cycle of growing young stock. With year-round calving, groups of bull-calves for slaughter ranging from 38 to 156 heads and cull cows from 10 to 48 heads are formed every month. The gradual sale of relatively small groups of cattle allows forming long-term contracts with processing companies on the most favourable terms. Receiving large batches of bull-calves for slaughter that need to be sold within three months requires finding wholesale buyers capable of processing such livestock. Under conditions of synchronized production on other farms with seasonal reproduction, there may be a period of oversupply, followed by a long period of lack of cattle for slaughter.

The system of production organization in beef cattle breeding can affect the use of different types of feed by livestock, which is due to changes in the structure of the livestock herd during the year (Table 4).

Table 4. *The need for fodder for a herd of beef cattle per year*

Sex and age groups of livestock	The need for fodder, quintals				
	silage	compound feed	hay	straw	greens (grass)
Year-round reproduction of livestock					
Cows	76842	21118	16782	23687	118792
Heifers	17850	4610	3898	5502	23211
Repair heifers	29997	3942	5100	4909	33077
Suckling heifers	7027	2088	2726	—	12986
Suckling bull-calves	8179	2432	3173	—	15130
Bulls	1139	304	442	—	1613
Fattening bull-calves	3599	8544	4319	—	—
In total	144633	43038	36440	34098	204809
Seasonal calving					
Cows	77606	22906	16948	23922	141203
Heifers	18977	3200	4144	5850	729
Repair heifers	34152	4385	5806	5588	35288

Table 4. Continued

Sex and age groups of livestock	The need for fodder, quintals				
	silage	compound feed	hay	straw	greens (grass)
Suckling heifers	3986	2129	1546	—	20662
Suckling bull-calves	4654	2485	1806	—	24105
Bulls	1173	352	455	—	2219
Fattening bull-calves	3973	9431	4767	—	—
In total	144521	44888	35472	35360	224206

Source: author's development

The analysis of feed requirements for a calendar year showed that the use of year-round and seasonal calving did not lead to significant changes in the use of different types of feed measured in kind. With seasonal calving, there is a slight decrease in the need for silage (up to 1%) and hay (up to 3%) and a 4% increase in the need for compound feed and 10% increase in pasture grass. This difference is not critical for the farm and is less than the loss of some types of feed during storage and feeding. Thus, in farms with a complete production cycle, the annual ration structure will not significantly depend on the distribution of calving throughout the year. The total annual production volumes on a farm with seasonal and year-round calving differ slightly (Table 5). This is partly due to the shift in production of final products from year-round calving to the following year.

Table 5. *Volumes of production on the farm for the year*

Indicator	A group of animals for realization		
	cow-calf system (weaned bull-calves for fattening)	culled cows (bulls)	finished production cycle (bull-calves for slaughter)
Year-round reproduction of livestock			
Implementation per year, heads	1109	277 (7)	982
Live weight of 1 head, kg	250	550 (900)	450
Gross live weight, quintals	2772.5	1586.5	4419.0
Cost of gross live weight, thousand UAH	26061.5*	6187.4**	40212.9***
Seasonal calving			
Implementation per year, heads	1268	316 (7)	952
Live weight of 1 head, kg	250	550 (900)	450
Gross live weight, quintals	3170.0	1801.0	4284.0
Cost of gross live weight, thousand UAH	29798.0*	7023.9**	38984.4***

Notes: Cattle sales prices are calculated per 1 kg of live weight. * The expected sale price of bull-calvess for further fattening is UAH 94, taking into account the sale prices of young animals for slaughter of the I category; ** Selling price of cows and bulls for slaughter is UAH 39. The ratio of the shares of animals of different categories is taken into account in the calculation. Cows: lean – 30%, category I – 35%, category II – 45%. *** The selling price of bull-calves for slaughter is UAH 91. The ratio of the shares of animals of different categories is taken into account in the calculation. Bull-calves, I category — 85%, II category — 13%, sale of cattle — 2%. Cattle categories for slaughter were determined according to DSTU 4673:2006 (2011)
Source: author's development

With expanded reproduction and year-round calving, the full cycle of rearing young animals for meat makes it possible to increase the total live weight of sold young animals by

59% and revenue from their sale by 54% compared to the cow-calf system. In the case of seasonal calving, the difference between the different options for organizing the farm's work is smaller, due to the receipt of weaned calves at the same time throughout the year. In particular, the full cycle of growing young animals makes it possible to increase the live weight of bull-calves for sale by 35% and their total cost by 31%. After the farms switch to a simple reproduction system, there will be no difference in the number and live weight of cattle for slaughter or fattening during seasonal and year-round calving, but the full cycle of rearing will significantly increase the number of marketable products.

Due to the extended rearing of young animals on a farm with a complete production cycle, more feed is consumed. In order to estimate the feed consumption per total live weight of livestock intended for sale, we added the gross live weight of culled cows and bulls to the weight of weaned calves intended for fattening (cow-calf system) and bull-calves raised for slaughter (full cycle of rearing). The results of the analysis are shown in Table 6.

Table 6. *Feed costs per 1 kg of live weight of livestock, depending on the final product production option*

Indicator	Cow-calf system (the main product is weaned bull-calves for fattening)	finished production cycle (the main production is bull-calves for slaughter)
Year-round reproduction of livestock		
Total weight of livestock for sale, quintals	4359.0	6005.5
Annual costs of fodder on the farm, quintals fodder unit	132458.1	145054.9
Feed consumption per 1 kg of live weight, kg of fodder unit	30.3	24.2
Seasonal calving		
Total weight of livestock for sale, quintals	4971.0	6085.0
Annual costs of fodder on the farm, quintals fodder unit	136846.2	150751.0
Feed consumption per 1 kg of live weight, kg of fodder unit	27.5	24.8

Source: author's development

The total feed costs take into account the feeding needs of all livestock groups, but they are recouped only through the sale of calves intended for fattening or bull-calves bred for slaughter and cull cows and sire bulls. The clear result is that per 1 kg of live weight of all livestock intended for sale, feed consumption will be higher when the farm operates under the cow-calf system. On a farm with year-round calving, with a full cycle of growing and fattening young animals, the total feed costs per 1 kg of live weight of cattle intended for sale will be 20% lower. The complete cycle of rearing bull-calves for meat during seasonal calving allows for a 10% reduction in feed consumption per 1 tonne of live weight. When comparing the efficiency of feed use on a farm with a complete cycle of growing young stock for seasonal and year-round calving, no significant difference in feed consumption was found. The difference of up to 10% was for the cow-calf system, which is explained by the receipt of some weaned calves in the following year, which led to worse performance in year-round calving.

This study presents a simulation model of a beef cattle population based on actual data and

component variables that can be used to compare the effectiveness of technical strategies on a farm. A similar technique has been used to evaluate the most efficient model of cattle reproduction and, according to O.A. Ojeda-Rojas *et al*. (2021), this research method has all the advantages over a physical experiment, as it does not require significant costs and changes to the actual production system on farms before the final result is obtained.

A. Ugnivenko *et al*. (2016) believe that the cow-calf technological operation is the main, most complex and important for obtaining healthy and cheap calves for fattening. It includes all types of work during the inter-calving cycle of a cow, including insemination of the breeding stock grazing on pastures, organization of feeding and housing during the stall period. All of this should be done with economical use of labour and inputs so that calves are not too expensive after weaning. The author of the publication argues that it is advisable to use seasonal (mainly early spring) calving in beef cattle herds, with calves weaned in autumn. The current study did not confirm a clear advantage of early spring calving. There was a slight redistribution of the need for different types of feed, which had almost no effect on the total cost of feed per cent of live weight of livestock intended for sale. At the same time, seasonal calving is associated with obtaining marketable cattle in short periods, which creates risks of its sale, although the cultivation of homogeneous groups of animals is easier in terms of technology. M. Michaličková *et al*. (2015) argue that strict adherence to the principles of seasonal reproduction of beef cattle, with calving in January-March, is critical for a cow-calf system, as it facilitates efficient grazing management and reduces feeding costs during spring. When deciding on the option of organizing reproduction on a farm, it is also advisable to consider the impact of the season on livestock productivity and value. It was found (Titterington *et al*., 2017) that cows calving in June had the shortest and November the longest period between calvings. G.W. Henry *et al*. (2016), based on an analysis of 19 years, determined that autumn calving was more profitable than spring calving for different diets and weaning ages, due to changes in the price of weaned calves. These data confirm the conclusions that the use of year-round calving allows for a relatively even distribution of the positive and negative effects of year factors on livestock productivity and sales prices. In the case of seasonal reproduction, it is important to carefully justify the period of mass calving, taking into account the peculiarities of fodder production, cyclical changes in livestock productivity throughout the year and prices for calves and young animals for slaughter.

The study found that in terms of conversion of feed into live weight of commercial cattle, own fattening is more efficient than production under the cow-calf system. But in the studies of A.R. Huerta *et al.* (2016), it was found that the organization of in-house fattening has a number of other risks, including water depletion, terrestrial ecotoxicity, photo-oxidant formation, freshwater ecotoxicity, etc. that need to be taken into account when setting up a farm. In the context of climate change and the depletion of natural resources, the option of organizing beef production is of great importance. Young beef cattle can be raised for meat using semi-intensive pasture and intensive feedlot systems. The use of extensive systems significantly increases the need for feeding areas. The feasibility of building fattening complexes with intensive cattle breeding for meat is evidenced by the 64% saving compared to irrigated pastures (Broom, 2019).

The study was conducted in an intensive farming area, where field forage production ensures high yields of fodder crops and makes it possible to provide a full cycle of livestock production within one enterprise, from the cow-calf system to the sale for slaughter. However, this production system may have limitations in other environments. The study by Y. Liu *et*

al. (2023), conducted in Inner Mongolia (China), found that in beef cattle breeding areas where effective feed supply has not yet been established, it is difficult to meet the needs of numerous cattle, so own feeding can lead to stunted growth of young animals and negatively affect income. In Canada, different types of farms are widespread, ranging from exclusively cow-calf to exclusively feedlot production. S.C. Sheppard *et al*. (2015) note that the production organization of farms is significantly dependent on natural and climatic conditions, and production systems in the prairies differ from those in the eastern provinces of Ontario and Quebec. In particular, the prairies have earlier and shorter calving seasons, winter grazing, barley-fed diets with a lower proportion of corn, and more seasonal feeding zones. In Ukraine, the organizational system of beef cattle farms should also take into account the natural and climatic conditions and availability of feed resources, but with the fact that the price of cattle is much lower than in many countries with developed livestock production, as reported by V.M. Ivchenko *et al.* (2021), it is currently advisable to produce beef from beef cattle in a complete production cycle and under conditions of own efficient pasture and field fodder production with high quality and low cost of feed.

Another factor in the efficiency of beef cattle herds is the duration of cow use. The farm we used as a baseline for our analysis relies on extended reproduction with long-term productive use of cows (on average, about 8 years). Studies conducted by A.G. Sessim *et al.* (2020) confirm the feasibility and expediency of this approach. In particular, they point out that the economic efficiency of a farm depends on cows remaining in the herd as long as possible, the best cow efficiency indicators are for culling cows at the age of 13, and for farms – when culling cows at the age of at least 6 years. In other words, the cow-calf system is most efficient when cows reach full maturity in terms of age and live weight. This creates effective prerequisites for the expanded reproduction or sale of over-repair heifers.

Thus, to ensure efficient production in beef cattle breeding in Ukraine, farms should focus on the full cycle of obtaining, growing and fattening cattle to a live weight of 450-500 kg and the long-term use of cows in the herd. The decision to introduce seasonal or year-round reproduction should be made taking into account the availability of production areas and rational approaches to selling cattle for slaughter.

Conclusions

The development of the beef cattle industry is possible only if the most efficient model of farm operation is chosen. The analysis of production options on a beef cattle farm showed a significant advantage of the complete production cycle over the cow-calf system. With the cow-calf system, the production cycle is shorter by 6 months and total feed costs are approximately 10% lower, but with a full cycle of growing young cattle for meat, the total live weight of cattle for sale can increase by 59%, which makes it possible to reduce feed costs per 1 tonne of live weight by up to 20%.

The seasonality of calving, which is traditionally used in beef cattle breeding to improve production efficiency, does not have a clear positive impact. In addition to increasing the productivity of cattle calving at certain periods of the year, as pointed out by the authors of a number of literature sources, tour calving allows cattle to be sold in a short time. Receiving large batches of livestock for sale increases the risks for beef cattle farms and limits the flow of funds for most of the year. The production effect of using seasonal tour calving is a slight redistribution of the share of different types of feed, an increase in the need for pasture grass and a decrease in hay and silage. Early spring calving is advisable for farms that operate a cow-calf system and rely on pasture as the main source of feed. With a complete cycle of

raising cattle for meat and fattening them on the farm, the difference in feed requirements for different types of feed will be insignificant.

To ensure efficient production in Ukraine, it is advisable to combine the cow-calf system and a complete cycle of growing bull-calves for meat on beef cattle farms. The decision on seasonal reproduction of cattle using tour calving should be made taking into account the type of fodder lands, availability of production areas on the farm and the possibility of profitable sale of cattle. Prospects for further research are to study the most effective schemes for organizing the feeding of beef cattle in different phases of the production cycle, taking into account the natural and climatic zones of farms, the characteristics of available feedlands and the impact on cattle health and beef quality.

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Conflict of Interest

None.

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Технологічні рішення ефективного виробництва на фермах з розведення м'ясної худоби в умовах України

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Анотація. М'ясне скотарство в Україні вважають перспективною та соціально значимою галуззю тваринництва, в якій спостерігають системне скорочення виробництва. Мета дослідження полягала в пошуку найбільш ефективних варіантів організації виробництва у м'ясному скотарстві. Для проведення аналізу використані дані виробничої діяльності сільськогосподарського підприємства з поголів'ям понад 4,5 тис. голів худоби м'ясного напряму продуктивності, зокрема більше 1,7 тис. корів. З урахуванням стратегії розвитку підприємства, яка передбачала розширене відтворення і реалізацію бугайців та вибракуваного маточного поголів'я, було проаналізовано виробничі показники від роботи ферми за системою «корова-теля» і закінченого циклу з вирощуванням молодняку до забійних кондицій. Аналіз цих варіантів організації виробництва проводили для умов

використання цілорічних і сезонних (з лютого по квітень) отелень на фермі. Виявлено, що за отримання отелень впродовж року кількість головомісць в приміщеннях і загонах буде відносно сталою. За сезонних отелень структура стада впродовж року змінюється суттєво. Реалізація готової продукції за сезонних отелень повинна відбуватись у відносно короткі проміжки часу та великими групами. Зокрема місячна реалізація бугайців для відгодівлі за системою «корова теля» за сезонних отелень буде в середньому у 11 разів більша, ніж за цілорічного відтворення в стаді. За повного циклу вирощування партії бугайців для забою будуть відрізнятись менше, але припадатимуть лише на весняні місяці. За сезонних отелень під час закінченого циклу виробництва виявили зменшення потреби в силосі до 1 % і сіні до 3 % та збільшення потреби в пасовищній траві на 10 %. Повний цикл вирощування бугайців на м'ясо дає можливість збільшити загальну живу масу реалізованої худоби на 59 %, виручку від реалізації на 54 % та зменшити загальні витрати кормів на 1 ц живої маси на 20 %. Практичне значення даного дослідження полягає у отриманні результатів, які можуть бути використані в м'ясному скотарстві України для планування ефективної організації виробництва

Ключові слова: велика рогата худоба; система «корова-теля»; відгодівля; витрати кормів; яловичина

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Study of the effectiveness of the design of the oil removal channels of screw presses for squeezing out oil

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Abstract. The relevance of the study is due to the problem that is typical for different types of structures of screw press zeer corps, namely, determining the optimal gap for oil yield, which has practical and economic feasibility. In this regard, this study is aimed at analysing the existing types of zeer corps, identifying their advantages and disadvantages to find methods to improve their design and increase oil yield. The leading methods for solving this problem are empirical research methods, which allow comprehensively considering the existing types of structures based on observation and, through comparison and experiment, to find a rational solution to the problem. The paper analyses the features of technical means for oil separation in presses and extruders, substantiates the practicality of the existing design and indicates the complexity or simplicity of designs in the scientific literature. The need to supplement the existing terms for various designs of the oil separator bodies and possible ways to improve the process of oil separation into different fractions are identified. Experimental studies were carried out with a set of semi-hulls of the zeer sections with different gaps. This made it possible to identify a smaller percentage of cake shedding through the zeer sections, with a corresponding reduction in the gap. The results of oil yield were obtained depending on the established gap in the semi-hulls of the slotted elements of the zeer camera and the heating temperature of the hulls. A decrease in the percentage of shedding with a decrease in the gap in the zeer camera was found. The studied design of the zeer camera type confirmed the versatility and simplicity of its design, which facilitates its maintenance and replacement. For each processed tonne of seeds, due to the increase in the amount of oil squeezed out, the profit of a farmer or enterprise that improves twin-screw extruders by adjusting the gaps as follows will increase accordingly

Keywords: oil production; zeer camera; twin-screw press-extruder; oil output; shedding of oil cake

Introduction

Mechanical pressing or pressing is the most common method of extracting vegetable oils from oil-containing raw materials in all countries of the world. The use of the continuous production method in the design of screw presses and extruders, as well as the ability to convert them to meet production requirements, stimulates the further development of this equipment (Choton *et al.*, 2020). In countries with developed machine building, the technological equipment for oilseed production is, in most cases, universal, and can be used to extract oils from various types of oil-bearing fruits and seeds. Screw presses made by world-renowned manufacturers can be adapted to different types of oilseeds in a short period, depending on the design of the press. Large plants (which have high oil extraction efficiency) use complex equipment that is expensive and always imported. Most of the existing oilseed screw presses for small and medium-sized crushers were designed for a specific type of seed. Therefore, in many developing countries that produce their screw presses for local needs, there is a step-by-step development and improvement of screw presses for pressing oils from several types of oil-bearing fruits and seeds. This will allow farmers and processors to have a machine that can handle many types of oilseeds and will reduce production costs and increase the productivity of their enterprises (Olaoye *et al.*, 2020). In agricultural countries, there is a lack of affordable and efficient solutions for home oil production. The ideal answer to these specific questions is provided by modified screw presses (Gawas *et al.*, 2023).

Screw presses and oil press extruders are simple in design, easy to maintain, and do not require highly skilled technicians to operate. The by-product of oil production, cake, can be used as animal feed (Amiolemhen & Eseigbe, 2019). The safety and simplicity of the whole process is an advantage compared to more efficient solvent extraction equipment. Screw presses used in small-scale agricultural oil mills typically have a capacity of 40 to 200 kg/h. However, screw presses are relatively inefficient, as approximately 10-18% of the oil remains in the cake at the output (Hudzenko *et al.*, 2020).

In the work of M. Hudzenko *et al.* (2020) describes the concept of oil and cake separation. The authors distinguish three typical schemes for the design of the zeer corps in screw presses, namely the design of the oil drainage holes in the zeer corps. 1) Drilled holes: This type of oil separation scheme has round holes in the zeer corps for oil drainage. The main advantage of this arrangement is that no additional parts are required for the oil separation system. The zeer corps is manufactured in a monolithic, cylindrical shape. However, the oil separation holes in this system are not adjustable. 2) Tie-down housing with slats. The zeer cylinder is assembled from individual zeer bars, which are fixed in the body frame, forming the inner surface of the zeer cylinder, in which the screw shaft is placed, and the oil is squeezed out. The gaps between the zeer bars are created by installing calibration gaskets between them or by special tides or cuts on one of the zeer bar side surfaces. By using shims of different thicknesses, gaps of different sizes can be achieved. In addition, in this scheme, the set of strips is made in such a way that the inner surface of the zeer cylinder takes the shape of a "brush". This is necessary to ensure that the oil-containing material friction against the cylinder walls, which significantly reduces the possibility of its rotation with the screw shaft. The material must not rotate, as rotation will not cause the material to move translationally along the shaft axis, and therefore no oil will be squeezed out. 3) Sleeve rings: In this type of oil drainage arrangement, the zeer corps consists of flat triangular or hexagonal plates separated by sleeve rings, which are placed on frame tubes. This arrangement allows for greater flexibility in adjusting the press drainage gaps and results in a very simple assembly that can be easily maintained.

Determining the optimal operating parameters of screw presses allows for economical use in terms of labour, energy and operating time, thereby reducing the cost of production. Improving process efficiency and finding alternative methods of machine setup have always been of utmost importance when studying mechanical oil pressing processes. There are many methods that can be used to improve process efficiency, and there are many components and combinations of components that can be used in the process (Bako *et al.*, 2020).

Most of the above-mentioned scientific papers on the improvement of screw presses for oil extraction usually consider options for constructive improvement of the geometric parameters of screw shafts, select rational shaft speeds, gaps in the press matrix at the oilcake outlet, temperature limits for heating the oil-containing material or the press body, consider seed moisture, etc. However, the influence of the shape, number, and location of the oil outlet holes in the zeer corps remains poorly understood in scientific papers. When comparing the features of each typical design scheme of the zeer corps of screw presses with the zeer corps of twin-screw press extruders, it was found that the latter have significant differences. Therefore, given that the design of oil extrusion twin-screw presses is poorly studied in the scientific literature, the topic of this paper is relevant.

The aim of the study is to analyse the existing designs of oil drainage channels of screw presses and determine the rational layout of the zeer corps of a twin-screw press extruder for oil extraction.

Literature Review

Mechanical pressing can be defined as a physical process of partial separation of a liquid phase (oil) from a heterogeneous solid-plastic raw material under the influence of external forces. The degree of separation of the liquid phase mainly depends on the design type of the pressing equipment and the properties of the oil-containing raw material to be mechanically pressed (Bako *et al.*, 2017). Due to the complexity of the phenomena that occur during pressing, there is no single theory of the process, and the concepts known so far are only semi-theoretical concepts that seek to summarize aspects observed in the laboratory or during the operation of industrial equipment (Ogunlade & Aremu, 2020).

It is well known that the basic principle of operation of a screw shaft press (Fig. 1) for pressing oil is the movement of oilseeds along the working chamber from the loading mouth and their gradual compression towards the oil-cake outlet chamber. The actual pressing process takes place under the action of an active body (screw or screw shaft), which first compresses the oil-containing raw material in order to eliminate voids with air between its particles. Compression of the oil-containing seeds is carried out by reducing the free volume of the channels of the screw shaft's working area. Increasing the pressing force means reducing the volume of the particles, which leads to the separation of oil from their capillaries, along with the separation of oil on the surface of the particles. It should be borne in mind that the increase in pressure on oil-containing raw materials should be gradual, so that the crushed particles of the solid phase do not clog the capillaries and block the oil flow through the special slots of the zeer camera (Alonge & Jackson, 2019).

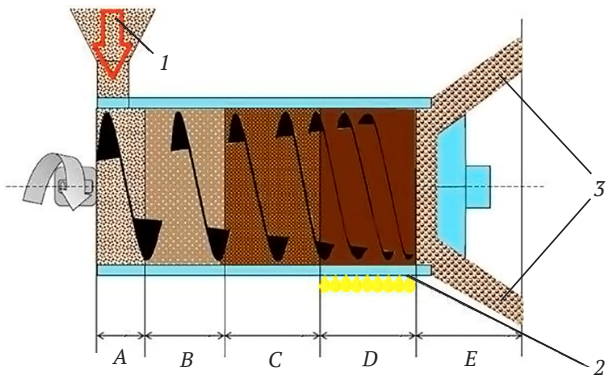

Figure 1. Schematic image of a screw press for pressing oil

Notes: A – power supply zone, B – transportation zone, C – compression zone, D – oil removal zone, D – oil cake exit zone, 1 – oil-containing raw materials, 2 – oil, 3 – oil cake

Source: developed by the authors

In the power supply zone A and transportation zone B of the oil-containing material, there is free space between the seeds. Therefore, air is displaced, and the raw material is compacted in the compression zone. The mechanical compression must constantly increase the compaction of the material and also compensate for the loss of volume when the oil escapes through the openings of the zeer camera. In a single screw press, the material is moved along the screw axis only by friction against the inner wall of the working chamber. The pressure responsible for squeezing the oil is due to the restriction of flow at the press outlet, which causes a pressure gradient that induces a pressure flow opposite to the material flow. The combination of the

two flows determines the feed rate, so that the performance of the press depends on the speed of the screw (Alonge & Jackson, 2019). Due to the diversity and complexity of the mechanisms involved in this dynamic process (transport, shear forces, compression, filtration...), the scientific literature suffers from a lack of data on the development of restrictions and oil leakage along the screw. Despite significant recent advances in press design and automation, it remains difficult to predict the performance of continuous pressing based on a theoretical approach (Bogaert *et al.*, 2018).

The process conditions of the screw press have a significant impact on the oil pressing efficiency. These conditions are defined in (Bogaert *et al.*, 2020) as: seed quality, body heating temperature and product outlet temperature, seed feed rate, screw rotation speed and screw profile, which can determine the degree of filling of the screw shaft, friction, and pressure increase. Thus, the effect of pressure on pressing efficiency can be studied by applying different moisture content in the seeds and operating modes (conditions) during the oil pressing process, as well as different screw configurations. For all tested seed moisture content, the oil pressed at 60 and 75°C was higher than the amount of oil pressed at 45°C, and the oil yield improved with increasing pressing temperature.

To obtain high-quality press performance, the seeds or pulp fed into the press must have a certain moisture content and temperature, which depend not only on the type and quality of the raw material, but also on the type of screw press. The parameters of moisture and temperature processing of peppermint and pulp are determined empirically for each individual case. Oil extraction from the pulp takes time. That is, the longer the pressing process, the higher the oil yield. However, as the speed increases, the duration of the pressing process decreases. For this reason, the speed of the screw shaft in modern presses does not exceed 60-70 rpm. Moreover, as shown by the studies described in M. Hudzenko *et al.* (2020), the residual oil content of the pulp decreases rapidly at the pre-pressing stage and slowly at the final pressing stage. A deeper analysis of foreign works (Supriyadi *et al.,* 2019; Chowdhury & Mahmud, 2020; Yate *et al.*, 2020) revealed that most authors (Beerens, 2007; Siregar *et al.*, 2015; Hudzenko *et al.*, 2020) divide screw presses into two main types according to the design of the zeer corps:

1) "hole cylinder press" – perforated cylinder. Oil drainage holes are cylindrical in a monolithic body. They are mainly intended for individual use and small farms. The vast majority of presses of this type operate using cold pressing technology, but before starting work, the body is heated with electric heating elements. Moreover, the outer hole has a larger diameter than the inner one, and can be half the thickness of the casing, while the other half is drilled to the inside of the casing with a smaller diameter. This difference is to prevent it from becoming clogged with oilcake spillage. The oil drainage area is located far away from the oil cake outlet area, as the pressure on the oil cake is highest in the oil cake outlet area. Therefore, if the oil drainage holes are placed close to the oil cake outlet, the oil holes will quickly become clogged with cake. The dry meal comes out of the nozzle. There is a heating system on the oilcake drain. The heat ensures a higher oil yield and a lower residual oil content in the cake. In this type of screw press, different types of seeds can be pressed by changing the nozzle and the speed of the screw shaft (Ionescu *et al.*, 2014).

2) "strainer press" – a tie-down sieve press. The designs of these types of presses are quite diverse, but they are united by common characteristics:

- the zeer sections are mounted along the entire length of the screw shaft (except for the section with the intake coil);
- longitudinal (slotted) oil drainage holes formed by

– the gaps between the zeer bars (grates), which are connected to each other by bars, which in turn are tightened in a special frame;

– the width of the calibration washers between the zeer plates; the protrusions on the bushings of the zeer plates' side surfaces;

– the zeer cylinder is made to be disassembled in the horizontal or vertical plane and consists of separate sections.

In most cases, strainer presses operate using cold pressing technology. However, there are press designs that include frying or electric heating.

The paper by P. Evon *et al*. (2021) describes the advantages of the modular design of twin-screw extruder housings, namely the ability to swap different working sections in the extruder. The authors note the ability to effectively configure the screw depending on the specified needs, using a variety of elements with different screw profiles. The correct choice of a screw configuration kit is an important factor in maximizing the quality of extruded products.

Based on the analysis of scientific papers and websites of screw press manufacturers, it was found that the choice of the zeer body design scheme depends on the designed capacity of the press. Given that twin-screw presses have a capacity of 150 kg/h, it is more appropriate to use a sieve type of the zeer corps. Among the many patents for twin-screw presses, there are often structurally complex zeer cameras (with numerous parts and combined with heating elements), which significantly increase the complexity of manufacturing, maintenance of the structure, and, accordingly, the final cost of the product. Therefore, such factors as ease of maintenance, quick replacement of worn-out parts, and the cost of the zeer sections during the operation of twin-screw presses are crucial for choosing the design scheme.

Materials and Methods

Experimental studies were carried out in production conditions at the enterprise PE "Plasma" in 2019. The equipment of the press line consisted of a serial twin-screw press extruder EK 75/1200 manufactured by SPE "Extruder" (Kharkiv). The main technical characteristics of the EK 75/1200 press extruder are shown in Table 1.

Table 1. *Technical characteristics of the EC 75/1200 press extruder*

Indicator	Size
Productivity (for unthreshed sunflower seeds), kg/h	150-175
Installed power, kW	18.3
Power consumption, kW	up to16
Power of the electric motor, kW	7.5
Power of electric heaters, kW	up to 12
Heating temperature of the housings (depending on the raw material), °C	up to 150
Shaft rotation frequency, rev/min	30-60

Source: passport for the operation of the EC 75/1200 press extruder

The body of the twin-screw press extruder (Fig. 2) consists of successively arranged sections with an impermeable wall (heating sections) 2, 3, 4, 6 and zeer sections 5, 7, which alternate with each other and are bolted together. The working elements of the worms are separate screw nozzles 10 and groups of grinding nozzles 11, offset from each other by 15° to form a screw channel, so that their tops are located along the screw line. The auger shafts of the technological unit are disconnected from the drive shafts. A die 8 is

attached to the last zeer section 7, which, together with cone nozzles 9, forms a regulating outlet slot for the cake. Each section with an impermeable wall 2, 3, 4, 6 is equipped with an electric heating element located around its outer wall, which allows for controlled heating of the section walls by adjusting the electric current.

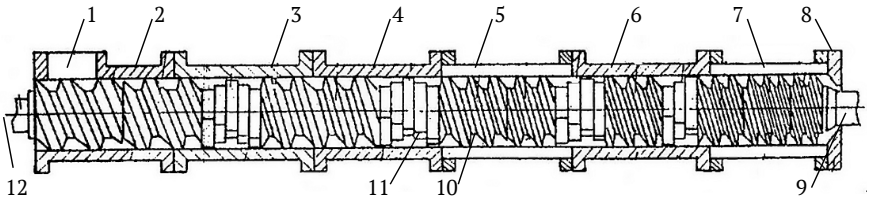

Figure 2. Scheme of the modular design of the twin-screw press extruder
Notes: 1– loading neck; 2, 3, 4, 6 – sections of corps heating; 5, 7 – zeer sections; 8 – matrix; 9 – conical nozzle; 10 – screw nozzles; 11 – groups of cams; 12 — shaft
Source: developed by the authors

The grinding nozzles located inside the heating sections ensure that the processed material is kept at the optimum temperature by intensive mixing inside the section and prevent the seeds from losing their mass in the form of spillage. As the sections with an impermeable wall alternate with the zeer oil-pressing sections, the zeer sections receive a uniformly heated crushed seed mass at the optimum temperature. The walls of the zeer sections are heated by heat transfer from the walls of the heating sections. The design and technological parameters of the experimental press extruder, the geometric parameters of the screw shaft, the composition, and characteristics of the measuring devices are described in (Hudzenko *et al.*, 2020).

The drive and the body heating system were controlled from the control panel, which is made as a separate unit. The control panel scheme of the press extruder is implemented on the basis of the Microchip 16F874 microcontroller, with a digital display implemented on LCD indicators that display the values of the set and monitored parameters. During the experiment, the temperature values in two heating zones (the first zone – sections 2, 3, the second zone – section 6), the current consumed by the electric motor and the voltage of each of the three supply phases were recorded. Temperature measurements in the two heating zones of the press extruder body were performed using thermocouples with KTY-81 elements from Philips, and temperature control is carried out using a thermal automation system.

The raw material under study was a batch of whole rapeseed with a moisture content of 8.2%, which was determined by a moisture tester WILE-55 from Farmcomp. The seeds were cleaned on a magnetic and air-sieve separator. The choice of devices and measuring equipment was made on the condition that they ensure the accuracy of measurements regulated by standard methods described in more detail in the work (Hudzenko *et al.*, 2020). For the experiment, the mathematical planning methodology developed in the course of previous studies was used, and the central compositional plan of the second order was chosen as the basis. The data obtained during the experiment was processed using the computer software Microsoft Office Excel 2016.

Experimental studies were close to production conditions, so in order not to violate the technological conditions of oil extraction, the flow of seed mass into the extruder hopper was not interrupted, and all measurements were carried out when the extruder reached a steady state. All readings from the control panel were made every minute, and the oil yield was determined

by the control unit of time of 10 minutes. During this time, the oil, and cake squeezed out of the press extruder were collected in special containers, which were then weighed using Domotec Plus DT52 electronic scales. The selected oil was settled, and the proportion of oilcake (small particles) in it was determined. Thus, the oil yield was calculated based on equation (1):

$$V_o = \left(\frac{m_{oil\ cake}}{m_o} - m_{shedding\ of\ oil\ cake}\right) \times 100, \quad (1)$$

where V_o – output of oil, %; $m_{oil\ cake}$ – weight of oil cake, kg; m_o – mass of oil, kg, $m_{shedding\ of\ oil\ cake}$ – mass of shedding of oil cake, kg;

All control measurements in this study were repeated three times, and the data obtained were averaged.

Results and Discussion

The housing of twin-screw press extruders is manufactured by SPE "Extruder" in a prefabricated block fashion. It consists of separate sections connected in series: with a feed opening, with impermeable walls (heating sections) and zeer sections (for oil separation). The sieve section of a twin-screw press extruder (Fig. 3) consists of a body-frame 1 and four half-bodies of slotted cylindrical elements 3. The frame of the zeer section (Fig. 3a) consists of three hollow metal plates that are permanently connected to each other at a certain distance. They have mounting holes located at the edges for bolting to other sections of the press extruder body and inside the plates for fixing the bodies of the slotted cylindrical elements.

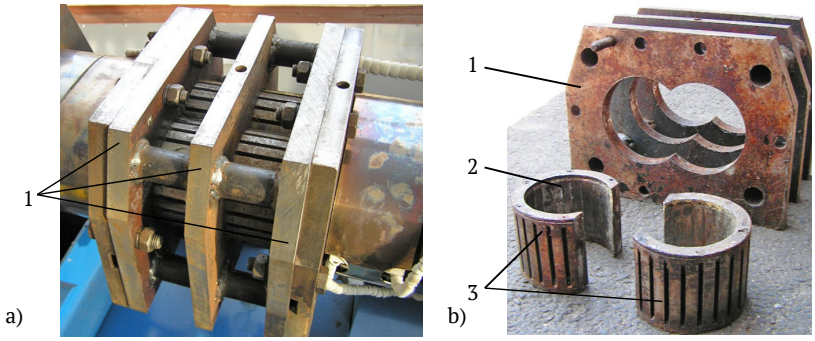

Figure 3. General view of the zeer sections

Notes: a) mounted in the corps of the press-extruder, b) disassembled into component elements; 1 – body-frame; 2, 3 – plate and half-shells of slotted cylindrical elements

Source: developed by the authors

The main body of the zeer camera is formed by assembling two half-hulls of slotted cylindrical elements that are pressed into the body frame. Rigidly connected to each other, they form an internal cylindrical surface, the guide of which is the circumference of two circles of equal diameter, the centres of which are located at a distance less than the diameter of the circle but greater than half of it. This is a characteristic feature of twin-screw press extruders, in which the working bodies are in mutual engagement.

The half-body of the slotted cylindrical element (Fig. 4) is made composite. It has a corps 1 in the form of a half-case of a zeer, which has longitudinal wide slots on the lateral surface from the outside, and is lined with zeer plates 2 from the inside, which are tightly adjacent to each other along the entire length, and in the middle section of the contact have longitudinal grooves, which form slots for oil flow. In this case, the oil slots coincide with the slots of the slotted cylindrical element. The end sections of the plate are rigidly connected to the half-

housing by spot welding, and are additionally fixed to the side of the half-housing by flanges 3 with necks. Each flange is attached to the end of the half-hull with screws 4.

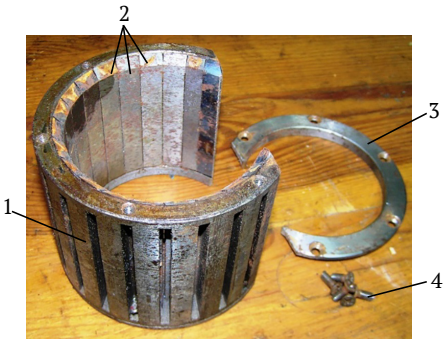

Figure 4. Half-body of a slotted cylindrical element
Notes: 1 – corps; 2 – zeer plates; 3 – flange; 4 — screws
Source: developed by the authors

The advantages of this design of the zeer section include: reliability; ease of replacement of individual worn plates; and quick replacement of slotted cylindrical element bodies. The two-layer design of the slotted cylindrical element half-body, with the inner layer – the zeer plates – resting on the outer body, requires less material costs for repair, as only worn-out plates are replaced. After all, only the inner layer is subject to wear during operation.

The dimensions of the gaps between the plates are determined by the structure of the raw material being pressed and its initial oil content. According to the manufacturer's recommendations, the gap size for pressing rapeseed and sunflower seeds is 0.45 mm. However, during the operation of these types of presses and for experimental studies, half-bodies of slotted cylindrical elements with gaps for the first zeer section of 0.4 mm and the second – 0.2 mm were ordered from the factory. According to the manufacturer's design, there are two zeer sections for the EK-75/1200 press brand, and they alternate with heating sections (Fig. 5).

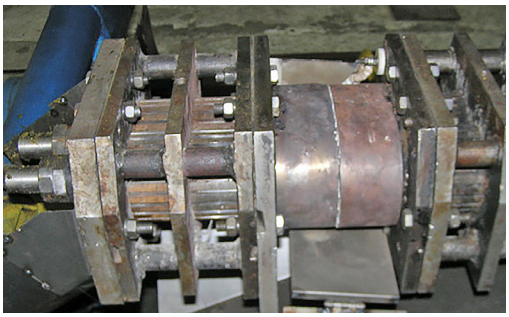

Figure 5. Location of zeer chambers during experimental studies on EK-75/1200 extruders
Source: developed by the authors

In most of the papers with experimental studies (Evon *et al.*, 2016; Carré, 2022), the oil pressing process was carried out under different operating conditions to evaluate their

impact on oil yield, press capacity, energy consumption, etc. In S.M. Sheikh & K.S. Zakiuddin (2019), a report is compiled to provide some insights into oil pressing technology that can help improve rural development in terms of oil extraction by small-scale crushers. Different types of designs and advanced developments are described in detail, with operating parameters and mechanisms used. Their analysis is useful for designing similar equipment, and the trends in the influence of various factors of the press's design parameters on oil yield are described. For example, when processing Jatropha curcas L. seeds using a screw press, the variables studied were the extraction temperature (50°C, 70°C and 90°C), screw speed (40 rpm, 50 rpm and 60 rpm) and the diameter of the hole in the press die (11 mm, 12 mm and 13 mm). As a result, the highest oil yield was obtained at the highest temperature, lowest rotational speed, and using the smallest die bore diameter (Yate *et al*., 2020). As expected, the performance of the screw press decreased as the oil yield increased, but the energy consumption remained almost unchanged over the evaluated range of operating conditions. The prevailing conditions were 90°C, 40 rpm and an 11 mm diameter outlet nozzle for the oilcake. However, these are complex and challenging studies.

In the work of K. Alabi *et al*. (2022), authors describe in detail the methodology for calculating the design of a single-screw press for pressing palm oil. However, in such works, the optimization of the size of the gaps in the zeer cameras is not specified. The authors point out that their press is simple in design, easy to operate and maintain. However, they agree that the technology of oil production on their press needs to be further optimized. Future work should investigate the impact of pressing process variables (such as time and temperature) on oil yield and productivity.

The validity of the choice of the initial variable parameters adopted by us is confirmed by the research and conclusions presented in M. Mursalykova *et al*. (2023). The authors argue that under the initial conditions, the yield of safflower oil increased with a decrease in moisture content, the size of the oil outlet channel, and a decrease in rotation speed. However, this is not enough to obtain the optimal parameters of the process under consideration. To make a final decision on the choice of optimal modes of the process under study, it is necessary to conduct a series of experiments on changes in humidity, pressure, and temperature. The authors also note that when the humidity drops below 8%, the yield of safflower oil decreases due to an increase in the temperature of the oil press, as the oil "burns out". Increasing the moisture content above 10% also reduces the oil yield, as excess moisture makes it difficult to press the cake efficiently.

To obtain a more reliable assessment of the experimental results for the twin-screw press extruder, as established in previous studies described in (Hudzenko *et al*., 2020), the initial variable parameters were the heating temperature of the housings. The size of the gap in the die was set to 4.2 mm, and the shaft speed was set to 42 rpm. These values were left with the values obtained in previous studies, because at these values, an increase in oil yield was observed. During the experiment, the following scheme of the arrangement of the zeer sections and the size of the gaps in them was used (Table 2).

Table 1. *The scheme of setting gaps in the zeer sections of the EK 75/1200 press extruder*

No. of the experiment	The size of the gaps of the gap in the zeer sections, mm	
	The first zeer section	The second zeer section
1 Experiment	0.4	0.4
2 Experiment	0.4	0.2
3 Experiment	0.2	0.2

Source: developed by the authors

Based on the obtained experimental results and computer processing, the graphical dependence of the yield of rapeseed oil on the size of the gap in the zeer sections (Fig. 6) at different heating temperatures of the housings is shown.

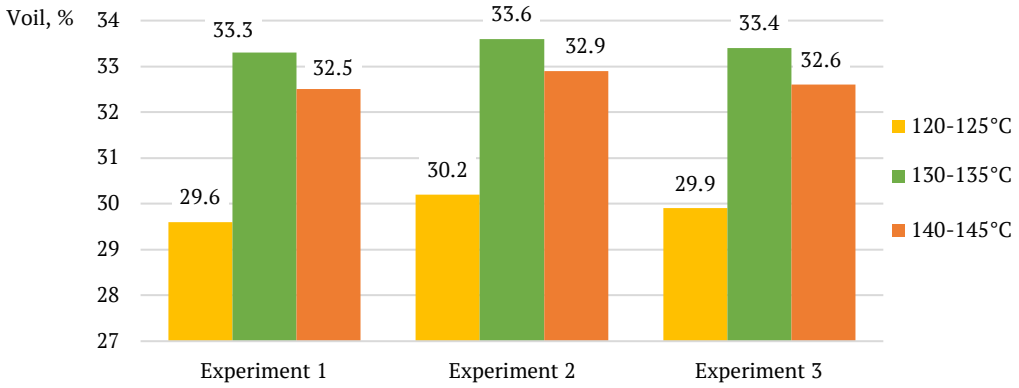

Figure 6. Dependence of the yield of rapeseed oil on the size of the gap in the zeer section at different temperatures of heating the housings

Source: developed by the authors

When comparing the obtained values of rapeseed oil yield, the effectiveness of using reduced gaps in the zeer cameras (experiment 2 and experiment 3) is obvious. However, when a gap of 0.2 mm was set in the first oil filtration zone (experiment 3), a slight decrease in the percentage of oil and more sintering of the cake petals was observed. At different heating temperatures of the press extruder body, the temperature of the oil at the outlet of the extruder was fixed at 87-100°C.

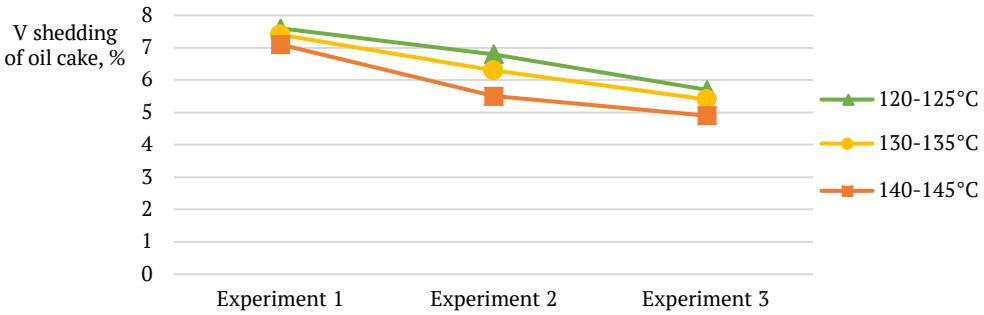

Figure 7. Dependence of the yield of fallout (small cake particles) of rapeseed oil through the slits in the zeer section at different temperatures of heating the housings

Source: developed by the authors

It should be noted that the percentage of oilcake shedding decreased with a decrease in the size of the gap (experiment 2 and experiment 3), and there is a general tendency to its decrease with an increase in the temperature of heating the shells. Thus, considering the obtained indicators of oil yield, for further operation and further research, the value of the gaps of the zeer cameras that was adopted in Experiment 2 will be selected.

In the work of C. Cravotto *et al.* (2023) focuses on the advantages of the modular design of twin-screw extruders. An improved design of a twin-screw extruder is described and proposed as an innovative process for oil extraction with a combination of extraction process. Modified twin-screw extrusion processes with solvent injection pumps were evaluated. The solvents tested included water, phosphoric acid-acidified alcohols, and fatty acid methyl esters (FAME). Among them, FAME proved to be the most effective extraction solvent, recovering up to 98% of the total oil (based on the residual oil content of the meal). Because two separate filtration modules (zeer cameras) can be separated to produce a first filtrate consisting of the pressed oil from the pressing stage and a second filtrate after the solvent extraction stage. These combined processes have great industrial potential due to their efficiency and flexibility. However, the analysed papers on twin-screw extruders did not reveal any studies like ours. The work of M. Ionescu *et al*. (2015), in which the quantitative distribution of oil along the zeer camera was studied during oil extrusion on a single-screw press of low capacity.

In the work of W. Li *et al*. (2007), the authors noted the disadvantages of single-screw presses for pressing rapeseed oil, and a double-screw press was developed to implement cold pressing of peeled rapeseed seeds with double low hulling. Multistage compression was used in the pressing chamber, and the geometrical parameters of the path ensured a relatively thin layer of oil-containing material during pressing. The total theoretical compression ratio of the twin-screw press was 23.0, and the ratio of the length to the diameter of the pressing chamber was 11.5, with the pressing time extended to 180 s. The oil content of the cold-pressed cake from the cleaned rapeseed was about 15%. The cold pressed cake was obtained at a temperature below 70°C, which met the requirements of the cold pressing process. Two screws rotated in different directions, and the zeer corps was of the sieve type with longitudinal holes. The press capacity was 45 tonnes per day.

The advantages of the modular design of twin-screw extruders allow for the arrangement of the zeer cameras in several ways: placed alternately behind the heating chambers, or one after the other at the end. Therefore, in further studies, it is advisable to conduct additional experiments by mounting the zeer sections one after the other at the end of the body, while investigating the quality and percentage of oil yield.

Conclusions

The study obtained new scientific results that expand the understanding of the regularities of the process of oil squeezing in twin-screw press extruders through the gaps of the zeer camera at different sizes. The studies experimentally confirmed that the oil yield depends on the temperature in the working area of the press extruder and the size of the gap in the zeer camera. In experiment 1, with a gap in the zeer camera of 0.4 mm and an increase in the heating temperature of the extruder body from 120 to 135°C, an increase in oil yield from 29.6 to 30.2% was recorded. And with further heating to 145°C, the oil yield decreased to 32.5%. In experiment 2, with a gap in the zeer cameras of 0.4 mm and then 0.2 mm, with an increase in the heating temperature of the extruder body from 120 to 135°C, an increase in oil yield of 2.1% was recorded. In experiment 3 (with further heating to 145°C), a slight decrease in oil yield by 0.1-0.3% was recorded. At the same time, the percentage of oilcake shattering with a decrease in the size of the gap of the zeer cameras from 0.4 mm to 0.2 mm decreased from a maximum of 7.6% to 5.7%, i.e. by 2.2%. Thus, the general nature of the change in the size of the outlet gap in the zeer sections affects the oil yield and the percentage of oil cake shattering. However, these parameters should be considered in conjunction with other design parameters of the press extruder to investigate the energy consumption of the oil extraction

process. In twin-screw press extruders with a capacity of 100 kg/h or more, it is more appropriate to use a sieve type of zeer corps. Among the many patents for twin-screw press extruders, there are often structurally complex zeer cameras (with many parts and combined with heating elements), which significantly increase the complexity of manufacturing and maintenance of the structure, and, accordingly, the final cost of the product. Therefore, such factors as ease of maintenance, quick replacement of worn parts, and the cost of zeer sections during the operation of twin-screw press extruders are crucial for choosing its design scheme.

Based on the results of this study and the analysis of similar works, further research will be promising in clarifying the percentage of oil squeezed out of each individual zeer section. And also, given the modular design of the press extruder body sections, it was concluded that in further research it is also possible to mount the zeer sections one after the other at the end of the body, while examining the quality and percentage of oil yield. Overall, the twin-screw press extruders have achieved significant improvements in oil yield and quality.

Acknowledgements

None.

Conflict of Interest

None.

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Дослідження ефективності конструкції олієвідвідних каналів шнекових пресів для відтискання олії

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Анотація. Актуальність дослідження зумовлена проблемою, яка характерна для різних видів конструкцій зеєрних корпусів шнекових пресів, а саме визначення оптимального зазору для виходу олії, що має практичну і економічну доцільність. У зв'язку з цим дане дослідження спрямоване на аналіз існуючих типів конструкцій зеєрних корпусів, виявлення їх переваг і недоліків з метою знаходження методів до вдосконалення їх конструкції та збільшення

виходу олії. Провідними методами для вирішення цієї проблеми є емпіричні методи дослідження, що дозволяють на основі спостереження комплексно розглянути існуючі типи конструкцій та шляхом порівняння і експерименту знайти раціональний варіант розв'язку поставленої задачі. В роботі проаналізовано особливості технічних засобів для відділення олії в пресах та екструдерах, обґрунтовано практичність існуючої конструкції та вказано на складність чи простоту конструкцій в науковій літературі. Виявлено необхідність доповнення існуючих термінів до різноманітних конструкцій зеєрних корпусів, та можливі шляхи вдосконалення процесу відділення олії на різні фракції. Проведено експериментальні дослідження з набором півкорпусів зеєрних секцій з різними зазорами. Це дозволило виявити при відповідному зменшенні зазору менший відсоток осипки макухи через зеєрні секції. Отримано результати виходу олії в залежності від встановленого зазору в напівкорпусах щілинних елементів зеєрної камери від температури нагріву корпусів. Виявлено зменшення відсотку осипки зі зменшенням зазору в зеєрній камері. Досліджена конструкція типу зеєрної камери підтвердила універсальність і простоту її виконання, що полегшує її обслуговування та заміну. З кожної переробленої тони насіння, за рахунок збільшення кількості відтиснутої олії, відповідно, зросте і прибуток фермера чи підприємства, які вдосконалять двогвинтові екструдери відрегулювавши зазори вказаним чином

Ключові слова: виробництво олії; зеєрна камера; двогвинтовий прес-екструдер; вихід олії; осипка макухи

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Sow and piglet productivity improvement in the farrowing department using milk substitutes

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Abstract. Modern pork production technology requires more piglets from sows to ensure the industry's profitability. The physiological reserve of sows' milk production at multiplicity above 14-18 piglets is often insufficient, which requires a constant search for ways to solve the problem of "hyperfertile sows". The study aims to investigate the effectiveness of using milk replacers from different manufacturers in sow nests under conditions of multiple farrowings on the productivity and behaviour of suckling piglets and sow conditions. The experiment was conducted in 2023, with 36 sow nests in the farrowing shop and 513 suckling piglets. Nests with a litter of 13 or more were selected and three groups were formed. In the control group, piglets were raised without additional feeding with milk replacers. The group II piglets were fed with Alternative Milk Junior as a source of additional nutrition from 10 days of age until weaning. Piglets of group III received a Commercial Analogue of milk replacer. Group II was characterised by a higher survival rate – of 93.03% and, a higher live weight – of 7.84 kg, which led to higher values of average daily weight gain – 222.47 g. The nests of the II and III experimental groups (consuming milk replacer) were more aligned, which significantly outperformed the analogues of the control groups by 31.2% and 14.7%. Piglets of group II were in a calmer state and therefore spent the most time on rest – 60%, in contrast to animals of the control group – 50% and group II – 58%. Additional

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nutrition of piglets in the nests of "hyperfertile sows" reduces the load on sows during lactation allows to obtain animals in factory condition and reduces the number of unprofitable days. The practical significance of the experiment is to determine an effective milk replacer as a source of supplementary nutrition for suckling piglets in the nests of "hyperfertile" sows

Keywords: pigs; technology; suckling period; feed additive; live weight; gain; safety; behaviour; sow condition

Introduction

The maintenance and feeding of suckling sows and suckling piglets are the main and most important technological process in the reproduction of pig stock in farms of different sizes and management systems. The issue of increasing the productivity of these technological groups of pigs is currently being addressed by breeding and genetic, technological solutions, by improving feeding technology with the use of functional feeds, etc. (Baxter *et al.*, 2020). Today, scientists and practitioners have made significant progress in increasing sow fertility. Nowadays, 14-20 piglets born and 13-18 live piglets per nest are not uncommon. However, this creates new challenges, complicating animal management (Nicolaisen *et al.*, 2019; Lykhach *et al.*, 2023).

Milk substitutes in pig production are not a new concept. Almost every farm has experience in their use, as there is a demand for this product because it is necessary to quickly solve the problem of milk deficiency in sows for various reasons. And there is no need to look for a faster way – just dissolve the powder in warm water. Indeed, in recent years, the use of these products has become an increasingly traditional practice both on foreign and domestic farms, when more than 30 piglets are often weaned from a sow per year. Therefore, these substitutes in the technological process can be used not permanently, but only when the sow does not produce enough milk; and as a permanent element of the structural approach in conditions when sow litters are becoming more and more fertile (Maximizing the genetic…, 2023).

P.J. Maas *et al.* (2023), producers are now able to obtain numerous farrows thanks to scientific advances in genetic companies, modern and better housing conditions, strong constitution and animal resistance, and improved feeding technology and management models. However, the process of increasing sow milk production is less progressive. Consequently, with additional piglets in the nest, the amount of milk consumed by one animal decreases. This has led to increased attention from producers to milk substitutes as a means of solving this relatively new problem. Given the trend towards multiple genetics, more and more pork producers are turning to milk replacers. Such technological solutions help to minimise the stress on piglets from moving them between farrowing units.

G. Yordanova *et al.* (2021) due to increasing sow fertility, the number of piglets with low birth weights (0.85-1.05 kg) in the nest is increasing. Therefore, producers are looking for ways to preserve and feed weak piglets until weaning. Milk powder substitutes produced by the industry need to be dissolved to a consistency of 10-15% to obtain a more liquid solution. As a rule, one kilogram of liquid milk replacer has a nutritional value equivalent to 0.5-0.75 kg of sow milk. Given the high milk consumption potential of piglets, this concentration does not slow down their growth and development. The closer the characteristics of the substitute are to natural milk, the higher the piglets' productivity. However, the price of such a product will be correspondingly high (Blavi *et al.*, 2021).

Piglets' digestive system is more adapted to digesting dairy products. Therefore, dairy ingredients such as skimmed milk, whey, buttermilk, lactose, and their derivatives should be the quality basis. In addition, a good substitute should contain easily digestible lipids, sucrose, possible flavour enhancers, vitamins, trace elements, organic acids and, if necessary, the necessary veterinary drugs. Also, vegetable proteins after the purification procedure (soy concentrate, potato and pea protein, wheat gluten, etc.) can be used as partial substitutes, but only in small proportions. They reduce the price of the product, but also the quality. Lecithin is commonly used as an emulsifier. Milk replacers used in the modern technological process contain immunoglobulins, as milk is rich in these functional proteins that support the health of suckling piglets. There are three main sources of immunoglobulins for milk replacers: dried bovine colostrum (high cost), dried animal plasma (high cost and banned in some countries) and egg immunoglobulins (for specific diseases in piglets) (Thomson & Friendship, 2019; Kobek-Kjeldager *et al.*, 2021). Milk replacers that do not contain immunoglobulins only provide nutrition for piglets but do not provide protection. Therefore, such products (milk replacers) can only compensate for 50% of the functions of natural sow milk (Return of milk..., 2023).

Thus, genetic improvements can increase the profits of pig producers, but without proper management and conditions for rearing sows and suckling piglets, genetics alone is irrelevant. L. Blavi *et al.* (2021) clearly states that the use of milk replacers in pig production allows for reducing the percentage of deaths of weak piglets under sows (large farrowings in gilts, problems with lack of milk in sows with mastitis-metritis-agalactia syndrome, low birth weight of piglets, and other problems); increase the number of business piglets per sow per year due to additionally fed piglets; obtain weight-even nests at weaning, which is crucial in industrial pig production, with fluctuations in sow milk production; stimulates rapid live weight gain in piglets from the first weeks, which is important at early weaning (21-24 days); weak piglets gain maximum weight and form a stable immune system by introducing immunoglobulins into the product, as well as form a complete intestinal microflora by introducing probiotics.

Thus, the study aimed to investigate the effectiveness of the use of different milk replacers in the nests of suckling sows under conditions of multiple farrowing on productivity, safety and behavioural indicators of suckling piglets and sow conditions under industrial technology.

Materials and Methods

As part of the experiment, which took place in 2023, 36 nests of suckling sows in the farrowing room with 513 suckling piglets (breed: Large White × Landrace × Maxter terminal line) kept at the farm of the private enterprise "*Victoria*" in the Mykolaiv region were studied. Experimental studies were conducted in the farrowing shop, where the conditions of keeping experimental animals complied with VNTP-APC – 02.05 "Pig enterprises (complexes, farms, small farms)" and recommendations of genetic companies on keeping (2005). Animals of the experimental groups were kept in identical premises with boxed separation according to the design and set of equipment of AgroDana LLC (Ukraine). In each group, during the suckling period, piglets were kept in individual pens on a fully lattice floor, measuring 2.4×1.8 m, with the sow fixed in the centre of the pen. A combination of local heating sources was used as a source of local heating for the experimental animals: an infrared incandescent lamp, an electric heating mat and a brooder (Tsarenko *et al.*, 2004). The experiment started from the moment of the farrowing of sows and ended with the weaning of piglets. The duration of the suckling period was 28 days. According to the analysis of the index of fertility of the main sows in the context of two farrowing cycles, the

average value of this index was determined – 13.56 goals per farrowing.

Accordingly, sow nests with a litter of 13 or more were selected for the experiment and three experimental groups were formed according to the experimental scheme (Table 1). In the farrowing shop, sows of all groups were provided with free-range feeding (except for farrowing day – 1.0 kg/head) and used compound feed "Lactating sows". The nutritional value of the diet provided is as follows: per kilogram of product weight, it contains 163.9 g of crude protein and provides metabolic energy in the amount of 2990.4 Kcal. The farrowing shop used pre-starter feed from Tsekhave LLC, Ukraine, in the form of pellets from homemade cows, which was provided from day 7 to day 28. The nutritional value of this feed is 185.0 g of crude protein and 325.0 Kcal of metabolic energy per kilogram. The main diet for lactating sows in the experimental groups was a compound feed of our production, which included a protein, mineral and vitamin supplement from Tsekhave LLC (Ukraine). The composition of the main diet "Lactating sows" included 40.0% wheat, 40.0% barley and 20.0% protein, mineral and vitamin supplement "Tsekhavit Sow Concentrate Lactation".

Table 1. *Experimental design for the use of milk substitutes during the suckling period (28 days)*

No.	Group	Amount, heads		Number of piglets at birth, heads	Milk replacer usage conditions	Period, days
		sows	piglets			
I	control	12	170	14.17	"Lactating sows" feed	0-28
					pre-starter feed for suckling piglets	7-28
II	experimental	12	172	14.33	"Lactating sows" feed	0-28
					pre-starter feed for suckling piglets	7-28
					"Alternative Milk Junior" milk replacer	10-28
III	experimental	12	171	14.25	"Lactating sows" feed	0-28
					pre-starter feed for suckling piglets	7-28
					"Commercial Alternative" milk replacer	10-28

Source: compiled by the author

An algorithm for the preparation and use of milk replacers in groups of experimental animals was developed: 1 kg of milk replacer powder was added to a container for preparation of 5.5 litres of warm water (45-50°C), then stirred constantly until completely dissolved. The mixture was fed immediately after preparation at a solution temperature of 38-40°C (piglet body temperature). The temperature of the mixture was monitored using a thermometer. In the case of atypical reactions from piglets, feeding of the substitute was immediately stopped and the electrolyte solution was given for 12-24 hours. When using a milk replacer, all feeders were washed in warm water with detergent. The piglets had constant access to water. The dishes from which the milk replacer was fed were located in the machine near the piglet drinkers. The frequency of milk replacer feeding was 6-8 times per day to feed weak and numerous nests. After 15 days of life, the substitute could be given in the required amount. The milk replacer was fed to the experimental groups using a conventional feeder starting from day 5 of life (Fig. 1). Composition of the product "Alternative Milk Junior" (Technical Specifications of Ukraine 15.7-35756835-001:2011): whey, milk-fat concentrate, skimmed milk powder, dextrose, soy concentrate, wheat gluten, salt, acidifier, lysine, methionine, a mixture of organic trace elements, vitamin and mineral premix, probiotic, flavouring, sweetener. Nutritional

content of Alternative Milk Junior (%) according to the manufacturer: crude protein – 21.5; crude fat – 16; crude fibre up to 0.5; lysine – 1.8; lactose – 40. Vitamin content (IU; mg/kg): vitamin A – 55,000; vitamin D – 4,500; vitamin E – 80; vitamin C – 120; vitamin B_1 – 18; vitamin B_2 – 23; vitamin B_6 – 10; vitamin B_{12} – 45; selenium – 0.3.

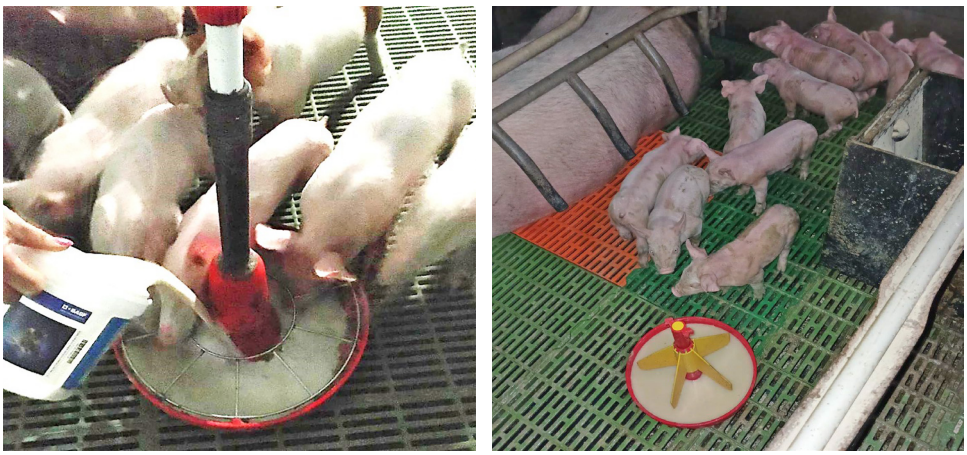

Figure 1. Example of feeding a milk replacer

Source: compiled by the author

Ingredients of the Commercial Analogue milk replacer product: skimmed milk powder, whey, milk and fat concentrate, soya concentrate, soya flour, vitamin and mineral mix, probiotic, flavouring, and antioxidant. Product nutritional content (%) according to the manufacturer: crude protein – 21; crude fat – 17; crude fibre 1.0; lysine – 1.7; lactose – 38. Vitamin content (IU; mg/kg): vitamin A – 55,000; vitamin D – 4,500; vitamin E – 80; vitamin C – 120; vitamin B_1 – 16; vitamin B_2 – 10; vitamin B_6 – 8; vitamin B_{12} – 40; selenium – 0.3. To ensure optimal microclimate parameters, ventilation in each farrowing box was provided by an exhaust axial fan and an aerodynamic inlet valve, which operated by creating negative pressure in the room. Manure was removed from the room using a traditional vacuum and gravity system. The frequency of emptying the baths under the slatted floor was 10-14 days. Sows were fed from nipple drinkers and suckling piglets from cup drinkers were placed 7 cm above the floor. All veterinary procedures were identical in both the experimental and control groups, according to the scheme adopted on the farm. The conditions of feeding, watering, housing, care and prevention of animals in the experiment were by European legislation on animal welfare and comfort (Council Directive 91/630/EU, 2008/120/EU, 2008; Council Directive 98/58/EU, 2008; Council Directive 2010/63/EU, 2010).

The productive traits of suckling piglets of these groups (Table 1) were studied by the following traits: number of piglets at birth (heads), live weight of each piglet at birth and weaning (28 days) (kg), number of piglets in the nest at weaning (heads), average daily growth of suckling piglets (g), safety (%) and nest alignment at weaning (Ibatulin & Zhukorskyi, 2017). The indicator of piglet nest alignment at weaning was calculated using the formula (Kovalenko, 2009):

$$NA = 0.625 \times M - (10 - P1) \times (10 - 1.875 \times P2), \quad (1)$$

where M – weight of the nest at weaning, kg; $P1$ – number of piglets at weaning, heads; $P2$ –

number of piglets that lag behind the average nest weight by 3 kg or more.

The behaviour of suckling piglets was monitored during the study period to determine the time spent on rest, movement, and feed intake according to generally accepted methods in pig production. The condition of sows in different technological groups was assessed based on measurements of the thickness of the back fat at point *P*2, located 65 mm to the left and down from the midline of the back at the level of the head of the last rib. Measurements of rind thickness were carried out before farrowing and on the day of weaning using a Renco ultrasound scanner (Ladyka & Khmelnychiy, 2023). After the end of the suckling period, the proportion of sows that entered heat and were inseminated within 7 days was determined (%). In the experimental groups, the daily consumption of feed and milk replacer was monitored by the group and the data were recorded in the experimental table. Deviations in the health of the animals and the veterinary care provided to them were also recorded daily in each group. The date and reason for the animals' withdrawal from the experimental groups and the weight of the animals that withdrew were recorded. The obtained results of the scientific and economic experiment were processed according to the generally accepted methods of variation statistics using computer equipment and application software packages *MS Excel* 2000 and *Statistica V.* 5.5 (Kramarenko *et al.*, 2019).

Results and Discussion

Improving the breeding qualities of sows is usually associated with an increase in sow fertility. Today, the achievements of geneticists and breeders in this area are quite advanced and average 14-18 gilts per farrowing. The main aspects of solving the problem of "hyperfertile" sows are to preserve the maximum number of animals before weaning, obtain high piglet growth energy, and keep the sow in factory condition and high milk yield. It should be noted that without the use of milk replacers, the planned high productivity of modern sow and suckling pig genotypes cannot be achieved (Ivanov *et al.*, 2009). The productivity and safety of suckling piglets depending on the use of milk replacers in the suckling period are presented in Table 2.

Table 2. *Productivity and safety of suckling pigs,* $\bar{X} \pm S_{\bar{x}}$

Parameter	Group		
	I control	II experimental	III experimental
Number of sows, heads	12	12	12
Number of piglets at birth:			
total, heads	170	172	171
per sow per farrowing, heads	14.17 ± 0.228	14.33 ± 0.219	14.25 ± 0.232
Nest weight of piglets at birth, kg	16.60 ± 0.269	16.73 ± 0.230	16.85 ± 0.253
Piglet weight at birth, kg	1.17 ± 0.008	1.17 ± 0.008	1.18 ± 0.005
Number of piglets at weaning at 28 days of age, heads	12.33 ± 0.133	13.33 ± 0.251***	12.92 ± 0.260*
Average live weight of one piglet at weaning, kg	6.80 ± 0.076	7.84 ± 0.140***	7.21 ± 0.187*b
Live weight of a nest of piglets at weaning, kg	83.74 ± 0.574	103.89 ± 1.015***	92.12 ± 0.850***c
Average daily weight gain of piglets in the suckling period, g	187.72 ± 2.393	222.47 ± 4.536***	200.97 ± 5.221**b
Piglet safety, %	87.49 ± 1.030	93.03 ± 1.088**	90.54 ± 0.762**
Nest alignment at weaning, points	67.86 ± 1.305	89.20 ± 1.790***	77.84 ± 1.329***c

Note: * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$ (compared to animals of the control group - group I); a – $p < 0.05$; b – $p < 0.01$; c – $p < 0.001$ (compared to animals of experimental group III with analogues of experimental group II) nests at weaning, points

Source: compiled by the author

The formed experimental and control groups were similar when they were set up for the experiment. Changes in the number of piglets at weaning were noted in the nests of sows whose fertility exceeded the average for the herd in the control and experimental groups when using milk replacer in the technology of growing suckling piglets starting from 5 days of life, according to the methodological recommendations. The number of piglets at weaning in the nests of the sows of the II experimental group (treated with the "Alternative Milk Junior") was 13.33, which is 8.1% higher than the control ($p < 0.001$) and 3.2% higher than the analogues of the III experimental group (treated with the "Commercial Analogue") ($p < 0.05$). Accordingly, the growing conditions, the presence of additional factors of feeding piglets of the experimental groups along with the basic technology influenced the piglet survival rate, which was higher in the nests of sows using milk replacers, so in group II 93.03% of piglets were preserved, in group III – 90.54%, which is higher than in the control group by 5.54 and 3.05% ($p < 0.01$), respectively. Similar experimental data were obtained by researchers L. Brossard *et al.* (2017), who found that the use of additional sources of piglet nutrition makes it possible to increase the safety performance by 0.8-1.5% on average per farrowing cycle. The presented recommendations allow for saving high-cost feed and investments in the industry at the level of 5-12% over the period of the full production cycle.

As such, the weight of piglets at weaning (28 days) can reach 9-10 kg. In reality, not all farms can reach 7-7.5 kg. Although the genetic potential has not yet been fully realised, the results have improved thanks to quality management in the farrowing house. The live weight of piglets at weaning is one of the main production indicators on a pig farm. The higher the piglets' weaning weight, the faster the pigs will reach a slaughter weight of 110 kg. It is necessary to use the high growth energy of piglets at the initial stages of development as efficiently as possible in order not to lose their early maturity potential, the previous studies conducted by P. Nevrkla *et al.* (2017) are consistent with the data obtained in the current study, namely, increased birth weight led to an increase in daily body weight gain from birth to weaning (28 days), as well as from birth to slaughter by 10-18% ($p < 0.05$, $p < 0.01$). High daily weight gain (250 g; 685; 998 g) allowed pigs to reach slaughter weight a month earlier and obtain a higher yield of lean meat (52.74 ± 2.82%).

The use of milk replacers from different manufacturers in both cases had a positive effect on the development and growth of piglet s, namely, gilts of group II had a higher weaning weight of 7.84 kg, which was 15.3% higher than the control ($p < 0.001$). Animals of the same group, when using the product of the animal feeding supplement "Alternative Milk Junior", in contrast to the product "Commercial Analogue", exceeded the peers of the third group by 8.04% ($p < 0.01$). An increase in the number of piglets in the nests of the II and III experimental groups and their live weight at the time of weaning led to higher values of the weight of the piglet nest at weaning. The highest value of this indicator was characterised by the representatives of the II experimental group – 103.89 kg, which significantly exceeded the analogues of the control group and the III experimental group by 20.15 and 11.77 kg ($p < 0.001$), respectively. Similar studies were obtained by S. Sugiharto *et al.* (2015) on suckling piglets as a result of feeding milk replacers. Namely, in piglet nests where cow whey was additionally used, an increase in piglet live weight at weaning at the age of 28 days by 0.36-1.12 kg ($p < 0.01$), nest weight by 12-16% ($p < 0.05$), and safety at the time of weaning from the sow within 1.1-2.3% was noted. In piglets of the experimental groups receiving high-quality milk replacers during the suckling period, 6% fewer cases of gastrointestinal diseases were observed.

When many piglets are born (more than 13-14 piglets), the proper growth and development of the piglets are hampered. The sow does not have enough milk in her body, especially at the end of the lactation period when the piglet's nutritional needs increase significantly. If certain technological measures are not taken, the weight of the piglets will be significantly reduced when they are weaned. In such groups, there will be smaller piglets that lack the nutrients necessary for normal growth and development. Stunted piglets often do not achieve maximum productivity and often do not survive in the competitive feed environment of pig farms. Our research is consistent with the experimental data of E. Ambroziak and A. Rekiel (2017), who noted that the live weight of piglets at birth correlates with the subsequent growth energy of gilts. Thus, the correlation coefficients for piglets of groups I (the lightest at birth) and IV (the heaviest at birth) were found to confirm the relationship between birth weight and body weight on the 7th ($p < 0.01$), 21st ($p < 0.01$) and 56th day of age ($p < 0.05$), with a tendency to decrease the calculated relationships. In addition, in group I, piglet weight at birth correlated with daily weight gain from day 1 to day 7 ($r = +0.365$, $p < 0.01$) and from day 1 to day 56 ($r = +0.291$, $p < 0.05$). With an increase in the average live weight at birth, the safety of piglets increased and was higher in group IV compared to group I by 13.64%. Birth weight ⩾ 1.60 kg provided the best growth rate and piglet survival. Thus, the position of scientists is unanimous regarding the need to support piglets in the suckling period with additional sources of nutrition (milk replacers), because in their absence, young animals are not able to achieve high and standard performance indicators.

Additional support for suckling piglets in the form of milk replacers in their diet from 14 days of age in combination with the basic technology significantly increased the average daily weight gain of young animals before weaning. The use of the milk replacer "Alternative Milk Junior" and its innovative composition made it possible to obtain a higher average daily weight gain of piglets at weaning at 28 days (group II) – 222.47 g, which exceeded the indicator of the control group (I) by 34.75 g ($p < 0.001$), and the commercial analogue (group III) by 21.5 g ($p < 0.01$). G. Yordanova *et al.* (2021), based on the results of a study on the development of piglets using different milk replacers in the suckling period and during rearing, found significant differences in the control and experimental groups. The highest average daily weight gain for the period up to 21 days was in pigs of group II, which is higher compared to group I (by 21.88%, $p \leqslant 0.05$) and group III (by 28.64%, $p \leqslant 0.01$). Regarding the average daily weight gain at 28 days (at weaning), significant differences between the control and the experiment were proved. The piglets of the second group with the addition of a special milk replacer had a higher growth of 6.04-12.94% ($p \leqslant 0.05$). The results obtained are consistent with our data from the scientific and economic experiments.

A special requirement of industrial pork production technology is to obtain levelled nests at weaning because piglets with significantly different live weights from the average nest size will be worse fed and pay for feed in increments during further rearing (Tsarenko *et al.*, 2004). It was found that the nests of piglets of the II and III experimental groups (consuming milk replacer) were more aligned at weaning at 28 days, which significantly outperformed the analogues of the control group (basic technology without the use of DM) by 31.2% ($p < 0.001$) and 14.7% ($p < 0.001$), respectively. In the control group, where piglets did not receive additional nutrition in the form of milk replacers, a greater number of piglets lagging in growth was observed because, after 18-21 days, sow milk production and pre-starter feeding did not fully meet the growing need for nutrients in young animals. In the context of experimental groups, it was noted that the young animals receiving the milk replacer ZSZM "Alternative Milk

Junior" (experimental group II) were more aligned – 89.2%, which is higher than the coefficient of nest alignment at weaning of analogues of group III by 12.7% ($p < 0.001$).

During the experiment, the behaviour of suckling piglets was monitored. The piglets of the II experimental group spent more time on feed intake in the total observation period – 14%. At the same time, animals of the control group spent 12-15% more time moving compared to their counterparts of the II and III experimental groups, respectively. The time spent on rest by piglets of the control and experimental groups was also different. It was found that the piglets of the II experimental group were in a calmer state and therefore spent the most time on rest – 60%, in contrast to the animals of the control group – 50% and the II experimental group – 58%. A. Middelkoop *et al.* (2019) revealed a greater behavioural response of piglets to different feeding combinations and, as a result, an increase in the time spent on feeding. Increased feeding behaviour significantly influenced the increase in growth performance of experimental piglets, namely an increase in average daily weight gain by 12-28 g, and a 2.5% increase in survival rate. The presence of several types of feed elements of different physical conditions (liquid milk replacer, pre-starter in the form of a granule with a diameter of 1.5-2 mm) in the farrowing machine, which were fed from feeders of different designs, provoked a significant increase in play and feeding behaviour in experimental pigs by 15-23%, and a decrease in aggression (cannibalism) by 18%. Increased feed intake by piglets during the suckling period had a positive effect on further high-fattening qualities of young pigs.

The profitability of this type of production is ensured by reducing unprofitable days in the technological process of the pig industry. Therefore, getting the sow into heat as soon as possible after weaning is crucial, as the main goal is to produce the maximum number of piglets per year. The degree of sow fatness at the end of the suckling period has a significant impact on this. After all, emaciated or thin animals give birth to a few piglets, while obese animals do not become pregnant, and if they do, they give birth to weak, non-viable offspring (Lykhach *et al.*, 2023). The thickness of the fat is an indicator of the sow's body reserves during critical periods (insemination, farrowing, weaning), the less fat she has, the less reserves she has. Sows of the experimental groups at farrowing were similar in fat thickness, the value of this indicator was in the range of 18.92-19.08 mm (Table 3), which corresponds to the normative values.

Table 3. *Sow fat thickness, ($n = 12$), $\bar{X} \pm S_{\bar{X}}$*

Indicator	Normative value of slicing thickness, mm	Group		
		I control	II experimental	III experimental
Thickness of farrowing fat, mm	16-20	18.92 ± 0.136	19.08 ± 0.162	19.00 ± 0.230
Thickness of farrowing fat at weaning (28 days), mm	14-16	13.00 ± 0.289	16.00 ± 0.230***	14.58 ± 0.253***c
Farrowing fat thickness loss during lactation, mm	2-4	5.92 ± 0.281	3.08 ± 0.136***	4.42 ± 0.295***c

Note: * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$ (compared to animals of the control group - group I); a – $p < 0.05$; b – $p < 0.01$; c – $p < 0.001$ (compared to animals of experimental group III with analogues of experimental group II) nests at weaning, points

Source: compiled by the author

In numerous nests of the control group I, along with low piglet productivity (Table 2), a significant decrease in the thickness of the sow's rind during the suckling period was noted.

Thus, at the time of weaning, the rind thickness of sows of group I was 13.0 mm and the animals were characterised by the highest loss of rind thickness during lactation – 5.92 mm. Feeding piglets with milk replacers during the period of their intensive growth made it possible to reduce the load on sows and get them in good condition at the time of weaning, as evidenced by the rind thickness of animals of group II – 16.00 mm and group III – 14.58 mm, which is 3 mm and 1.58 mm ($p < 0.001$) higher than the control, respectively. The loss of subcutaneous fat thickness during lactation in the experimental groups was lower and was within the normative range of 3.08-4.42 mm, which is consistent with studies of C. Farmer *et al.* (2017), which confirms the influence of sow condition in different physiological periods on their reproductive traits.

Experimental sows that had a rind thickness of 19.5-20.5 mm before farrowing, according to scientists, had a higher conditional milk yield by 15% and, significantly higher average daily weight gain of young animals by 10.2-16.4% ($p < 0.01$). Sows that had lower losses of rind thickness during lactation, within 3-5 mm, showed higher reproductive performance in subsequent productive cycles. The study of the duration of oestrus and the onset of complete fertilisation after weaning in sows of the II experimental group showed that in sows of this group, signs of oestrus were manifested faster, on a larger scale and more clearly. Sows came into a state of heat after weaning within 4.58 days, which was faster than in the control and III experimental groups by 3.67 and 0.84 days ($p < 0.05$), respectively.

Summing up the results of the scientific and economic experiment, it is worth noting that even sows with normal lactation according to the standard may not have enough functional teats for all piglets in the nest due to injury, disease, etc. Therefore, the best way to support sows during low lactation is to transplant and equalise the number of nests. However, this is not always possible, either because the number of suckling sows is too low, or the piglets are too old to be transferred. In such cases, the competition for milk between piglets is intense and growth and survival rates decline rapidly unless additional sources of nutrition are provided. For this reason, milk replacer has proven to be the best solution, especially for young piglets.

Conclusions

Based on the scientific and economic experiment conducted in the conditions of a pork production enterprise using intensive technologies, it was found that in numerous piglet nests (multiplicity above 14 heads) the use of milk replacers as an additional element of suckling piglets' nutrition is practically expedient and even mandatory. In the second experimental group, where milk replacer was used to feed suckling piglets, the number of piglets at weaning was 8.1% ($p < 0.001$) higher than in the control group and 3.2% ($p < 0.05$) higher than in the experimental group III. This, accordingly, affected the piglet survival rate, which was higher in sows' nests when using milk replacers, so in group II 93.03% of piglets were preserved, in group III – 90.54%, which is higher than in the control group by 5.54 and 3.05% ($p < 0.01$), respectively.

The use of a milk replacer in the technological scheme for growing piglets of group II resulted in higher average daily weaning weights of 222.47 g at 28 days, which is 34.75 g higher than in the control group (I) ($p < 0.001$) and 21.5 g higher than in the commercial analogue (group III) ($p < 0.01$). Aligned nests of piglets at weaning are the key to high growth energy during fattening. It was established that the nests of the II and III experimental groups (consuming milk replacer) were more aligned, which significantly exceeded the analogues of the control groups by 31.2% ($p < 0.001$) and 14.7% ($p < 0.001$), respectively. In comparison of the experimental groups, it was noted that the indicators of group II were more equalised – 89.2% and exceeded those of group III by 12.7% ($p < 0.001$).

A sufficiently high level of influence on the feeding behaviour of suckling piglets was proved by additional feeding with milk replacers. Piglets of the II experimental group were found to be in a calmer state and therefore spent the most time on rest – 60%, in contrast to animals of the control group – 50% and the II experimental group – 58%. Additional feeding of piglets with milk replacers during the period of their intensive growth made it possible to reduce the load on sows and get them in good condition at the time of weaning, as evidenced by the thickness of the rind in animals of group II – 16.00 mm and group III – 14.58 mm, which is 3 mm and 1.58 mm ($p<0.001$) higher than the control, respectively. The appropriate condition of sows contributed to a faster coming into heat after weaning and, as a result, a decrease in the duration of the idle period. Prospects for further experiments are to study the effectiveness of the use of milk replacers in the technological processes of growing suckling piglets and their effect on productivity, behaviour and microbiocenosis and morphometry of the intestinal epithelium.

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Conflict of Interest

None.

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Підвищення продуктивності свиноматок та поросят в цеху опоросу за використання замінників молока

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Анотація. Сучасна технологія виробництва свинини для забезпечення прибутковості галузі вимагає отримання від свиноматок більшої кількості поросят. Фізіологічний резерв молочності свиноматок при багатоплідності вище за 14-18 поросят часто буває недостатнім, що вимагає постійного пошуку шляхів вирішення проблеми «гіперплідних маток». Мета досліду полягала у вивченні ефективності використання замінників молока різних виробників у гніздах свиноматок за умови багаточисельних опоросів на продуктивність та показники поведінки поросят-сисунів і кондиції свиноматок. Дослід проходив у 2023 році, було досліджено 36 гнізд свиноматок в цеху опоросу і 513 голів поросят-сисунів. Були відібрані гнізда з приплодом 13 голів і більше та сформовано три групи. В контрольній групі поросята вирощувалися без додаткової підгодівлі замінниками молока. Представники ІІ групи починаючи з 10 доби життя і до відлучення отримували в якості джерела додаткового живлення ЗМ «Альтернатива Мілк-Юніор». Поросята ІІІ групи отримували «Комерційний аналог» замінника молока. ІІ група відзначалася більшим показником збереженості – 93,03%, вищою живою масою – 7,84 кг, що обумовило і вищі значення середньодобових приростів – 222,47 г. Більш вирівняними були гнізда ІІ та ІІІ дослідних груп (споживали замінник молока), які вірогідно переважали аналогів контрольної групи на 31,2% та 14,7%. Поросята ІІ групи перебували в більш спокійному стані, а тому на відпочинок витрачали часу найбільше – 60%, на відміну від тварин контрольної групи – 50% і ІІ групи – 58%. Додаткове живлення поросят у гніздах «гіперплідних маток» знижує навантаження на свиноматок у період лактації і дозволяє отримати тварин у заводській кондиції та зменшити кількість не прибуткових днів. Практичне значення досліду полягає у визначенні ефективного замінника молока як джерела додаткового живлення поросят-сисунів у гніздах «гіперплідних» свиноматок

Ключові слова: свині; технологія; підсисний період; кормова добавка; жива маса; приріст; збереженість; поведінка; кондиція свиноматки

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The effect of a diet based on semifinished products from plant and animal raw materials on reproductive capacity, growth, and development of the organism

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Abstract. The demand among the population for protein products, which are essential for a healthy diet, is a pressing issue today, which constantly requires scientists and manufacturers to search for alternative protein analogues. That is why the aim of the research was to study the impact of a diet based on plant and animal raw materials on the reproductive capacity, growth,

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Tkach, G., Omelian, A., Kushnir, Yu., & Altanova, O. (2023). The effect of a diet based on semifinished products from plant and animal raw materials on reproductive capacity, growth, and development of the organism. *Animal Science and Food Technology*, 14(4), 87-98. doi: 10.31548/animal.4.2023.87.

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and development of the body. In the experiment, the duration of pregnancy in pregnant females was determined; the average number of rats born per female of the respective group; the weight of females before pregnancy; the weight of females on the 7th, 14th and 21st day of pregnancy. The postnatal development of rats of the control and experimental groups was compared. In newborn rats, the following were determined: age of ear drum detachment; craniocaudal size at birth; craniocaudal size on the 5th day; age of hair coat appearance; age of eye-opening; weight of rats at birth; weight of rats on the 7th, 14th and 30th day of life. The results obtained indicate that there is no negative effect of the vegetable semifinished product using soya-wheat texture and meat cutlet on the reproductive functions of rats and the development of offspring. During the experiment, female rats showed no signs of toxicosis, visible pregnancy disorders, or physiological disorders. During the dynamic observation of the weight of experimental females in all experimental groups, no decrease in weight gain was recorded compared to control animals. The weight and postnatal dimensions of newborn rats of the experimental groups did not differ from those of the control. For the first time in laboratory animals, based on an integrated approach using modern research methods, the effect of long-term consumption of food based on semifinished products from soy-wheat texture and meat cutlets on the reproductive functions of rats and the development of offspring was studied, which is of practical value in the context of the health of females and offspring of mammals under the influence of an alternative nutritional factor

Keywords: polymorphism; restriction; electrophoresis; allele; amplification

Introduction

The normal course of energy metabolism at the molecular level results in the dynamic interaction of catabolism and anabolism. With food, a person receives macro- and microelements, substances necessary for the synthesis of organic compounds that act as regulators and biological catalysts, such as hormones and enzymes. To perform these functions, in different conditions and at different stages of the body's life, nutrients of the appropriate quality and quantity are required. Hence, the main requirement for a rational diet is that the quantity and quality of food meet the needs of the body. Failure to meet this requirement leads to various diseases and nutritional inadequacies, stunted growth, physiological and mental development (Sautchuk & Eliseev, 2022).

The growing demand among the population for meat (protein) products, which are essential for a healthy diet, constantly requires scientists and manufacturers to search for alternative protein analogues, which is actively pursued in their research activities by S. Smetana *et al.* (2021) and L. Bal-Prylypko *et al*. (2022). Recently, there has been a significant expansion of the market for "artificial" meat of plant origin, which is increasingly used by consumers around the world and in Ukraine (Bakhsh *et al*., 2022). According to O. Huk (2022), the plant-based meat industry is expected to reach USD 20.7 billion with a total annual growth rate of about 8.6 % and by 2040 could account for up to 60 % of the global meat market, while meat, poultry, and seafood production will amount to USD 7.3 trillion. Meat analogues are defined as food products that mimic traditional meat products in terms of consistency, organoleptic, aesthetic, and chemical characteristics. Meat substitutes include many products that are not necessarily based only on plant material, but may contain animal protein, milk, eggs, fish, or insect components (Yang *et al.*, 2023). There is a diverse range of vegetable meat analogues that is constantly being improved and is widely available

in grocery chains in the form of cutlets, burgers, fillets, minced meat and nuggets. Plant-based proteins derived from wheat, lentils, soybeans, peas, and beans are widely consumed by different population groups around the world and are one of the key structure-forming and nutritional components in meat analogues (Kyriakopoulou *et al.*, 2021).

According to the existing paradigm of recent decades, animal proteins have been considered the main dietary source of protein, but changing food consumption patterns and culture among the world's population has led to the significant use of plant proteins and, as a result, its production has increased dramatically in the agricultural and food industries. There has also been a long-standing and justified debate about the health benefits of eating plant-based foods as opposed to meat products, but the research is heterogeneous and, in many cases, highly controversial (O'Keefe *et al.*, 2022). Scientific review by L.P. Penkert *et al*. (2021) generally suggests that meat is a source of high-quality protein, but its amino acid composition is very different from plant protein, which affects liver metabolism. On the one hand, the consumption of plant-based foods is generally considered healthy and modern, but studies by A. Kaleda *et al*. (2021) confirmed that most plant-based proteins, which come from legumes and grains, are lower in fat and protein compared to meat products. The macro- and micro-nutrient composition of meat analogue products often coincides with that of traditional meat products, but the research by S.R. Hertzler *et al*. (2020) studying the amino acid composition of plant proteins provides insight into the low content of lysine, cysteine and methionine in meat substitutes.

In arguing for the benefits of a plant-based diet, J.F. O'Keefe *et al*. (2022) highlight the negative impact on human health of high meat consumption, especially red and processed meat, and link excessive meat consumption to higher rates of coronary heart disease, type 2 diabetes, and certain gastrointestinal cancers. In addition to quality indicators, products must be safe and provide the body with a full range of nutrients and have a positive impact on its development and vitality.

The study aimed to investigate the impact of long-term consumption of plant-based and meat-based food on reproductive function, pre- and postnatal development of offspring.

The main objectives of the study were:

1. To systematically summarize scientific data on the impact of semifinished products made from vegetable and meat raw materials on the body.

2. To simulate and perform an experiment during normal pregnancy in white rats with consumption of semifinished products from vegetable and meat raw materials.

3. To conduct a meta-analysis to assess the total effect of semifinished products from vegetable and meat raw materials on the body weight of pregnant females, the weight of rats at birth, the weight of rats on the 7^{th}, 14^{th} and 30^{th} days of life, the general physical development of offspring, the rate of appearance of basic sensory and motor reflexes during the feeding period, emotional and motor behaviour, the appearance of hair and eye-opening.

Materials and Methods

To systematically summarize scientific data on the effects of semifinished products made from vegetable and meat raw materials on the body, experiments were conducted using the method of group analogues at the vivarium of the National University of Life and Environmental Sciences of Ukraine on 30 pregnant female white laboratory rats aged six to twelve months and their offspring (30 rats). The experimental animals were housed in a room with a controlled temperature (20-23°C) and humidity (approximately 50%) according to a 12:12 light:dark schedule. To facilitate the measurement of food intake, rats were housed in individual suspended stainless steel mesh cages. The food was pre-weighed (in grams) and fed

into the cages to the animals. After 24 hours, the rats were briefly removed from the cages and weighed, and the amount of food remaining at the bottom of the cages or poured onto plastic sheets placed under each cage was recorded and the weight of the food consumed was calculated. The animals were cared for in vivarium conditions in accordance with the regulations: "European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes" (1986), as well as Law of Ukraine No. 3447-IV "On the Protection of Animals from Cruel Treatment" (2006, February).

The animals were divided into the following groups:

Group I – animals of the control group, which received drinking water and commercial standard food (18 % protein) in the form of dry granular feed containing all the substances necessary for normal life throughout the experiment.

Group II – rats of the experimental group received frozen chopped meat cutlets and drinking water. The nutritional value per 100 g of product was: energy value – 264 kcal, proteins – 22.4 g, fats – 19.0 g, of which saturated fats – 18.7 g, carbohydrates – 0.8 g, salt – 0.63 g. After defrosting, the semifinished product was cooked in a frying pan over high heat for 4-5 minutes on each side.

Group III – animals of the experimental group received quick-frozen vegetable semifinished products using soya-wheat texture and drinking water. Their nutritional value per 100 g of product was: energy value –159.50 kcal, proteins – 14.77 g, fats – 11.76 g, carbohydrates – 5.10 g, salt – 1.52 g. After defrosting, the semifinished product was cooked in a frying pan over high heat for 4-5 minutes on each side.

Animals began receiving the specified feed 2 weeks before pregnancy, during pregnancy and one month after the birth of the offspring. The weight of pregnant and newborn rats was determined using electronic scales ACOM JW (Germany) with an accuracy of 0.01 g. In the experiment, the following parameters were determined in pregnant females: duration of pregnancy, days; average number of rats born per female of this group, pcs; weight of females before pregnancy, g; weight of females on the 7^{th}, 14^{th} and 21^{st} day of pregnancy, g.

Statistical data processing was performed using a package of applied statistical computer programs — MS Excel 2016 and SPSS-17. The mean values between the three groups of rats were compared by one-factor analysis of variance (ANOVA) followed by the Bonferroni post hoc test. Comparison of the frequencies of distribution of various parameters in subgroups was performed using the Pearson's test. The value of $p < 0.05$ was considered significant. The approaches of observation, comparison, analysis, and generalization of data were used to conduct general scientific research. Observation included recording important indicators that characterize the nature of ontogenesis. The methods of comparison and analysis were used to record the results that were in the array of data obtained. The approach of generalization was used to describe the research results, their logical and consistent presentation, and to formulate the author's conclusions.

Results and Discussion

During the experiment, pregnant females of all groups showed no signs of toxicosis, visible disorders of pregnancy and physiological functions. The duration of pregnancy in group 3 was the highest — 22.5 days, which is 5.8% more than in group 2 and 1.3% more than in the control. In general, there was no statistical difference between the groups in terms of pregnancy duration. In a pairwise comparison between the groups, no significant difference was found (Table 1). The average number of rats born from females of each group was almost the same between the groups. The difference ranged from 0.2 to 0.4 ($p = 0.716$). There was no statistically significant difference between the comparison groups when analysing the weight of females during pregnancy

(Table 1). The weight of females before pregnancy and on the 7th day of pregnancy was the highest in the group, where semifinished products from soya-wheat texture were consumed. On the 7th day of pregnancy, the difference was 0.7 % compared to the group that consumed meat cutlets and the control group. From the 14th day of pregnancy until the end of the experiment, females of the control group had the highest weight. The difference in weight of females on the 21st day of pregnancy ranged from 0.8-3.6 %.

Table 1. *Massometric indicators of pregnant females (n = 10)*

	I group, control	II group, meat cutlet	III group, semifinishedproducts from soy-wheat texture	p
Duration of pregnancy, day	22.2 ± 1.55	21.2 ± 2.09	22.5 ± 1.72	0.258
		p = 0.676*	p > 0.05**	
			p = 0.355***	
The average number of rats born from a female of this group, pcs	7.3 ± 1.06	6.9 ± 0.99	7.1 ± 1.19	0.716
		p > 0.05*	p > 0.05**	
			p > 0.05***	
Weight of females before pregnancy, g	224.90 ± 20.18	227.65 ± 20.91	226.99 ± 17.71	0.948
		p > 0.05*	p > 0.05**	
			p > 0.05***	
Weight of females on the 7th day of pregnancy, g	238.78 ± 19.08	239.01 ± 19.29	240.58 ± 14.09	0.970
		p > 0.05*	p > 0.05**	
			p > 0.05***	
Weight of females on the 14th day of pregnancy, g	264.12 ± 14.87	261.06 ± 18.95	263.97 ± 18.02	0.907
		p > 0.05*	p > 0.05**	
			p > 0.05***	
Weight of females on the 21st day of pregnancy, g	303.53 ± 15.45	293.11 ± 19.37	301.07 ± 14.16	0.349
		p = 0.506*	p > 0.05**	
			p = 0.867***	

Note: n is the number of rats in the group; p – difference between groups; * – difference between the control group and the group of animals that consumed meat cutlets; ** – difference between the control group and the group of animals that used semifinished products; *** – difference between the group of animals that used meat cutlets and semifinished products

Source: developed by the authors

Comparative characteristics of postnatal development of rats of all study groups are presented in Table 2. No significant difference between the comparison groups was found in the analysis of the adhesion of the auricles (p = 0.766), craniocaudal size at birth (p = 0.891) and on day 5 (p = 0.882), and the appearance of the coat (p = 0.318).

Table 2. *Indicators of postnatal development of rats (n = 10)*

	I group, control	II group, meat cutlet	III group, semifinishedproducts from soy-wheat texture	p
Detachment of auricles, day	3.9 ± 0.88	4.1 ± 0.88	3.8 ± 1.03	0.766
		p > 0.05*	p > 0.05**	
		p > 0.05***		
Craniocaudal size at birth, cm	5.03 ± 0.21	4.97 ± 0.29	5.02 ± 0.32	0.891
		p > 0.05*	p > 0.05**	
		p > 0.05***		
Craniocaudal size on the 5th day, cm	5.32 ± 0.08	5.29 ± 0.11	5.34 ± 0.29	0.882
		p > 0.05*	p > 0.05**	
		p > 0.05***		
The appearance of a woolen coat, day	6.1 ± 0.31	5.7 ± 0.3	6.3 ± 0.21	0.318
		p = 0.962*	p > 0.05**	
		p = 0.422***		
Opening eyes, day	12.6 ± 0.52	14.2 ± 0.51	12.4 ± 0.48	0.034
		p = 0.099*	p > 0.05**	
		p = 0.053***		
Weight of rats at birth, g	5.99 ± 0.39	5.41 ± 0.29	5.76 ± 0.34	0.003
		p = 0.002*	p = 0.451**	
		p = 0.09***		
Weight of rats on the 7th day of life, g	8.49 ± 0.43	7.83 ± 0.39	8.12 ± 0.46	0.006
		p = 0.005*	p = 0.178**	
		p = 0.421***		
Weight of rats on the 14th day of life, g	16.32 ± 1.32	15.69 ± 1.29	16.18 ± 0.71	0.45
		p = 0.701*	p > 0.05**	
		p > 0.05***		
Weight of rats on the 30th day of life, g	59.77 ± 7.31	53.71 ± 2.73	58.13 ± 4.19	0.036
		p = 0.04*	p > 0.05**	
		p = 0.191***		

Note: n is the number of rats in the group; p – difference between groups; * – difference between the control group and the group of animals that consumed meat cutlets; ** – difference between the control group and the group of animals that used semifinished products; *** – difference between the group of animals that used meat cutlets and semifinished products

Source: developed by the authors

However, it is worth noting that the adhesion of the ears was faster by 2.6-7.9 % in the group whose mothers consumed vegetable-based semifinished products (3.8 days), the craniocaudal size of rats at birth was larger in the control group (5.03 cm); however, on the 5th day of life, the representatives of the group whose mothers consumed semifinished products from soya-wheat texture were larger – 5.34 cm, which is 0.9% more than in the 2nd group, whose mothers consumed meat cutlets, and 0.4% more than in the control group. The

hair coat appeared faster in rats whose mothers consumed meat cutlets – 5.7 days, which is 7.0% faster than the control and 10.5% faster than the group whose mothers consumed semifinished products from soya-wheat texture. A statistical difference between the comparison groups was noted in eye-opening ($p = 0.034$). This sign of development was fastest in offspring whose mothers received semifinished products with soya-wheat texture – 12.4 days, which is 14.5% faster than in group 2, whose mothers consumed meat cutlets, and 1.6% faster than in the control group. At the same time, no significant difference was found in the groups after pairwise comparison. The study of the weight of newborn rats showed a significant difference between the comparison groups at birth ($p = 0.003$), on the 7th ($p = 0.006$) and 30th day of postnatal development ($p = 0.036$). In general, during the experiment, the weight of rats at birth was the highest in the control group. The difference in the mass parameters of newborn rats was 0.23-0.58 g or 3.8-9.7%, at 7 days of age – 0.37-0.66 g or 4.4-7.8%, at 14 days of age – 0.14-0.63 g or 0.9-3.7%, at 30 days of age – 1.64-6.06 g or 2.7-10.1%. At the same time, a posteriori analysis by the Bonferroni method showed that the weight of newborn rats from mothers who received semifinished meat products was statistically lower than in the control group ($p = 0.002$). There was no statistically significant difference in birth weight between the groups of rats whose mothers consumed semifinished products and the control group ($p = 0.451$). There was also no significant difference in birth weight between the 2nd and 3rd experimental groups ($p = 0.09$). On the 7th day of life, the situation between the comparison groups was like that at birth. On the 14th day of the study, there was no statistical difference in weight between the groups. On day 30, it was found that the weight of newborn rats whose mothers received semifinished products did not differ from the control group ($p > 0.05$). On day 30, the weight of animals whose mothers ate meat cutlets was statistically different from the control group ($p = 0.04$).

Thus, the results obtained indicate that there is no negative effect of the vegetable semifinished product using soya-wheat texture and meat cutlet on the reproductive functions of rats and the development of offspring. During the experiment, female rats showed no signs of toxicosis, visible pregnancy disorders, or physiological disorders. During the dynamic observation of the weight of experimental females in all experimental groups, no decrease in weight gain was recorded compared to control animals. The weight and postnatal dimensions of newborn rats of the experimental groups did not differ from those of the control. At the same time, there was a difference in weight between the control and experimental groups of newborn rats.

N. Omelchenko & G. Dronik (2018) showed in their study no negative effect of heat-treated genetically modified soybeans in the feed on the reproductive functions of rats and the physical development of their offspring. All the studied parameters were within the physiological norm. The authors did not observe a decrease in the weight of the animals during the experiment, which received heat-treated soya beans. However, the researchers did find a decrease in the number of newborn rats in the group that consumed genetically modified soybeans. They suggest that this may be due to the influence of phytoestrogens and other biologically active substances in genetically modified soybeans, which cause disruption of embryonic development and, as a result, the birth of physiologically weak and non-viable offspring. The results of the author's research are not consistent with those presented in the publication, where no reduction in the number of newborn pups was observed in the group of females who consumed vegetable semifinished products using soy-wheat texture.

I.V. Chorna & G. Dronik (2018) also showed in their research that when soybean was added to the diet of female rats, the number of

offspring was within the range of the control group, which is consistent with the presented studies. The authors observed an increase in the weight of newborn pups whose mothers received soybean feed compared to the control. At the same time, from day 3 to day 20, the researchers noted a decrease in the weight of the offspring, which may be due to the residual effect of soy bioflavonoids. The weight of 2-month-old rats was higher than that of the control group, which proves the positive impact of soy on offspring growth, the high level of soy protein absorption by animals and its biological value.

The timing of the ear flaps and the appearance of a woolly coat in newborn rats in the presented studies coincided with the results of N. Omelchenko & G. Dronik (2018). However, the opening of eyes in the authors' experimental pups was observed earlier compared to the researcher's data. An analysis of this year's research has shown that the scientific community has focused on the role of diets in high fat. And although their research is consistent with the authors' study of the reactions of pregnant females and their offspring, in general, the results of the experiments are incomparable due to the difference in the objects and partially in the subjects of the studies. C.C. Lapa Neto *et al*. (2023) studied the effect of a high-fat diet on the body of pregnant and lactating females and changes in the liver of their offspring, which is in stark contrast to the studies presented here, given the additional difference in the observed indicators. Although T.L. He *et al*. (2023), like the authors, observed fetal growth, the rest of the indicators and the study as a whole are not consistent.

Also, over the past year, there have been scientific papers on the study of reproductive functions and body development, which is consistent with the authors' research. However, the factors of influence that interest the authors differ. Scientists from the United States of America, England, the Kingdom of Belgium, the People's Republic of China, and the Republic of Kazakhstan focused their research on the impact of trace elements: W. Ali *et al.* (2023) – Cadmium, and F.J. Murray *et al.* (2023) – Copper. The scientific search has shown the interest of the scientific community in alternative factors of influence on reproductive function and fetal development, which allows comparing the authors' studies. However, the mechanism of action of the exposure factors (*Chrysobalanus icaco* leaf extract (Rodrigues *et al*., 2023), *Agaricus bisporus* mushroom (Ng, 2020; Caetano *et al*., 2023) is not consistent and the comparison of results in such conditions is incorrect. The current array of scientific publications shows the interest of researchers in the reproductive function of females, which is consistent with the presented studies, but mostly there is a desire to improve pathological diabetic manifestations in pregnancy, which is not consistent with the objectives of the presented studies. E. Klöppel *et al.* (2023) investigated the role of calcium and vitamin D supplementation on tolerance to diabetic symptoms during pregnancy.

There are studies that agree on the main objectives of the researchers, but there are discrepancies in the results of the experiments. S.D. Simons and P.V. Johnston (1976) confirmed the negative effects of limiting animal protein (casein) in the diet of rats. The researchers recorded a slowdown in brain development and a disruption in the composition of the myelin sheath of nerve fibres, indicating a general delay in the development of offspring in the postnatal period, which was not observed in the authors' studies of plant-based semifinished products, which were also deficient in animal proteins. There is an assumption that the delayed development of rats in the US researchers was caused specifically by a deficiency of casein (a protein in dairy products), and the studies are quite outdated and require clarifying experiments using modern methods. This inconsistency in results suggests that studies should be repeated with the addition of casein control in females and their offspring.

Current research confirms the importance of protein control in the diet of pregnant females and their offspring. V.S. Moullé *et al*. (2023) experimentally demonstrated that groups with lower protein content during pregnancy and lactation were characterized by lower weight parameters compared to groups with a balanced diet. These studies are consistent with the authors' in the context of the overall goal, but do not agree on the results, since V.S. Moullé *et al*. (2023) fed the study group a limited level of protein, and the authors of the presented studies did not bring the level of protein to a deficiency in any of the groups, but its origin was different.

Thus, there are similar studies on the effect of different diets on the pre- and postnatal development of rats among modern scientific works, but there was no complete agreement on the specifics of diets. This confirmed the scientific novelty of the studies conducted by the authors and provided many grounds for further research in this area.

Conclusions

Thus, analysing the results of the study, there was no negative effect of adding soya-wheat texture to animal feed on reproduction, pre- and postnatal development of rats. Pregnancy of female rats was without signs of toxicosis, visible disorders of pregnancy and physiological functions. The duration of pregnancy in group 3 was the highest, 5.8 % longer than in group 2 and 1.3 % longer than in the control group. However, the difference was not statistically significant. In general, no significant differences were found in the average number of newborn rats and the weight of pregnant females during the experiment. The difference in the average number of newborn rats ranged from 0.2 to 0.4 ($p = 0.716$). The weight of females before pregnancy and on the 7th day of pregnancy was the highest in the group, where semifinished products from soya-wheat texture were consumed. From the 14th day of pregnancy until the end of the experiment, females of the control group had the highest weight. The postnatal parameters of the rats were within the physiological norm. The adhesion of the auricles was faster in the group whose mothers consumed vegetable-based semifinished products, the craniocaudal size of rats at birth was larger in the control group, but on the 5th day of life of the offspring, an increase in the weight of newborn animals whose mothers consumed soy-wheat texture semifinished products was noted. The hair coat appeared faster in rats whose mothers consumed meat cutlets. The opening of the eyes started the fastest in offspring whose mothers received semifinished products with soya-wheat texture (12.4 days), the difference between the groups was statistically significant ($p = 0.034$). The study of mass parameters of offspring showed a significant difference between the comparison groups, respectively at birth – $p = 0.003$, on the 7th day of postnatal development – $p = 0.006$ and on the 30th day – $p = 0.036$. A posteriori analysis by the Bonferroni method showed a statistically significant difference in the weight of newborn rats whose mothers received semifinished meat products with the control group, and a similar situation was observed at the end of the experiment.

The results obtained can serve as a basis for further studying the effect of soy-wheat texture on organ morphology and will help solve the current problem of plant-based nutrition. Another prospect for further research is to study the morphology of organs in laboratory pregnant rats and their offspring after consumption of soy-wheat, pea, and soy texture by adult animals.

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Conflict of Interest

None.

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Вплив раціону на основі напівфабрикатів з рослинної і тваринної сировини на відтворювальну здатність, ріст і розвиток організму

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Анотація. Актуальним питаннями сьогодення є попит серед населення на білкові продукти, які необхідні для здорового харчування людини, що постійно вимагає від науковців та виробників займатися пошуком альтернативних аналогів білка. Саме тому метою наукової роботи було дослідження впливу раціону на рослинній і тваринній сировині на відтворювальну здатність ріст і розвиток організму. В експерименті у вагітних самок визначали тривалість вагітності; середню кількість народжених щурів від самки відповідної групи; вагу самок до вагітності; вагу самок на 7-му, 14-ту та 21-шу добу вагітності. Проведено порівняння постнатального розвитку щурів контрольної та дослідних груп. У новонароджених щурів визначали: вік відлипання вушних раковин; краніокаудальний розмір при народженні; краніокаудальний розмір на 5-ту добу; вік появи шерстяного покриву; вік відкривання очей; вага щурів при народженні; вага щурів на 7-му, 14-ту та 30-ту добу життя. Отримані результати свідчать про відсутність негативного впливу рослинного напівфабрикату з використанням соєво-пшеничного текстурату та м'ясної котлети на репродуктивні функції щурів та розвиток потомства. Протягом експерименту у щурів-самок не було ознак токсикозу, видимих порушень вагітності, порушення фізіологічних функцій. Під час динамічного спостереження за вагою дослідних самок у всіх експериментальних групах не зареєстровано зниження приросту ваги порівняно з контрольними тваринами. Вага та постнатальні розміри новонароджених щурів експериментальних груп не відрізнялись від контролю. Вперше на лабораторних тваринах, на основі комплексного підходу з використанням сучасних методів дослідження проведено вивчення впливу тривалого споживання їжі на основі напівфабрикатів із соєво-пшеничного текстурату та м'ясної котлети на репродуктивні функції щурів та розвиток потомства, що має практичну цінність у контексті здоров'я самок і потомства ссавців під дією альтернативного аліментарного чинника

Ключові слова: вагітність; розвиток до народження та під час народження; соєво-пшеничний текстурат; сировинні матеріали м'яса

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