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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.

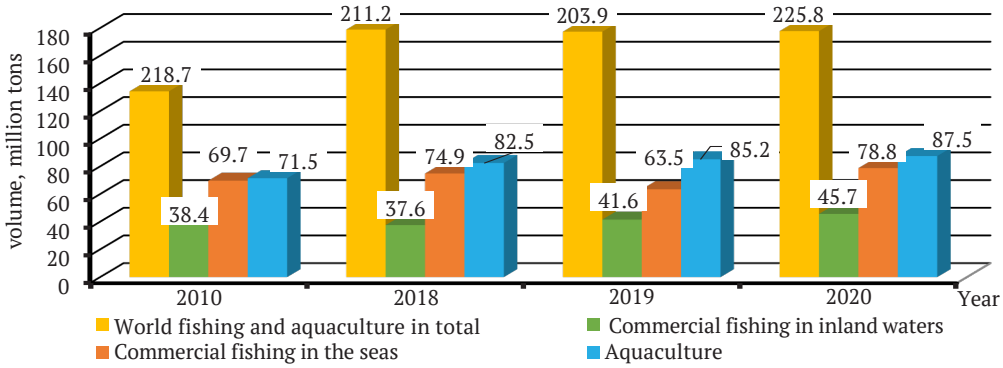

Figure 1. The volume of extraction of aquatic bioresources in the world

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).

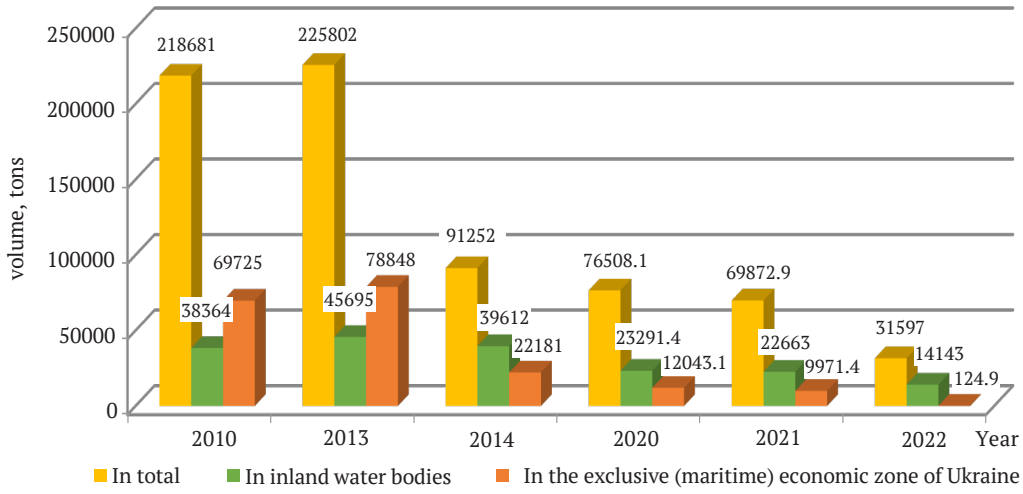

Figure 2. The volume of extraction of aquatic bioresources in Ukraine
Source: Extraction of aquatic bioresources ... (2023)

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.

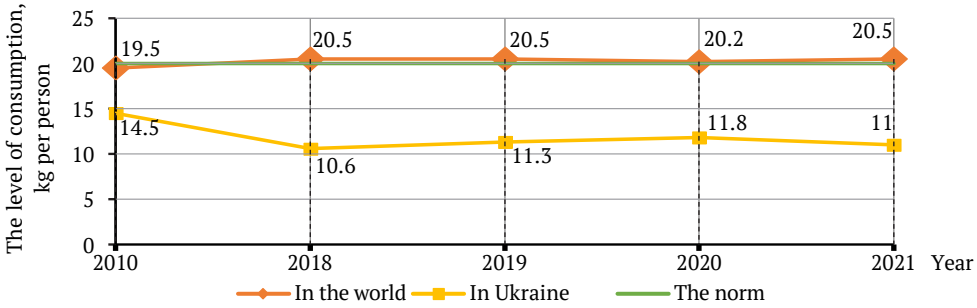

Figure 3. The consumption of fish and fish products in the world and in Ukraine
Source: T. Yaroshevych & O. Pakholiuk (2020); The State of World Fisheries and Aquaculture (2022)

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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Conflict of Interest

None.

References

[1] Baker, M.T., Lu, P., Parrella, J.A., & Leggette, H.R. (2022). Consumer acceptance toward functional foods: A scoping review. *International Journal of Environmental Research and Public Health*, 19(3), article number 1217. doi: 10.3390/ijerph19031217.

[2] Bespyatov, T. (2022). *Fish catch in Ukraine in 2022 radically fell due to the war: What are the indicators in each segment*. Retrieved from https://delo.ua/agro/vilov-ribi-v-ukrayini-v-2022-roci-radikalno-vpav-cerez-viinu-yaki-pokazniki-v-koznomu-segmenti-411999/.

[3] Bozhko, N., Tischenko, V., Pasichnyi, V., Polumbryk, M., & Haschuk, O. (2018). Development of meat-containing minced semi-finished products based on the locally produced raw materials. *Eastern European Journal of Enterprise Technologies*, 4(11), 49-54. doi: 10.15587/1729-4061.2018.140052.

[4] Bozhko, N., Tischenko, V., Pasichnyi, V., Shubina, Y., Kyselov, O., Marynin, A., & Strashynskyi, I. (2021). The quality characteristics of sausage prepared from different ratios of fish and duck meat. *Potravinarstvo Slovak Journal of Food Sciences*, 15, 26-32. doi: 10.5219/1482.

[5] Brandhorst, S., & Longo, V.D. (2019). Protein quantity and source, fasting-mimicking diets, and longevity. *Advances in Nutrition*, 10(4), 340-350. doi: 10.1093/advances/nmz079.

[6] Chen, Y.T., Chen, S.J., Hu, C.Y., Dong, C.D., Chen, C.W., Singhania, R.R., & Hsieh, S.L. (2023). Exploring the anti-cancer effects of fish bone fermented using *Monascus Purpureus*: Induction of apoptosis and autophagy in human colorectal cancer cells. *Molecules*, 28(15), article number 5679. doi: 10.3390/molecules28155679.

[7] Dhanabalan, V., Marimuthu, M., Don, S., Sarojini, A., Vinoth, K.L., & Chattopadhyay, K. (2023). Modern fish preservation methods enhancing the quality and safety of fish and fishery products . *Chronicle of Aquatic Science*, 1(3), 1-8.

[8] Extraction of aquatic bioresources. (2023). Retrieved from https://ukrstat.gov.ua/operativ/operativ2007/rg/rg_e/rg_rik_96-19e.htm.

[9] Fasuan, A.A., Akin-Obasola, B., & Abiodun, B.O. (2022). Water activity relations of spoilage fungi associated with smoke-dried catfish (*Clarias gariepinus*) sold in some open markets in Nigeria. *Journal of Food Science and Technology*, 59, 2168-2176. doi: 10.1007/s13197-021-05229-8.

[10] Golovko, N., Golovko, T., Gelikh, A., & Prymenko, V. (2019). Research of quality indicators of dishes and culinary products based on semi-finished products of freshwater mussel and their changes during storage. *Scientific Works NUKHT*, 5(25), 100-108.

[11] Helikh, A. (2019). The research of quality indicators of minced products based on freshwater mussel and ginko biloba powder. *Scientific Messenger of Lviv National University of Veterinary Medicine and Biotechnologies. Series: Food Technologies*, 21(92), 36-41. doi: 10.32718/nvlvet-f920.

[12] Huang, C.Y., Kuo, C.H., Wu, C.H., Ku, M.W., & Chen, P.W. (2018). Extraction of crude chitosans from squid (Illex argentinus) pen by a compressional puffing-pretreatment process and evaluation of their antibacterial activity. *Food Chemistry*, 254, 217-223. doi: 10.1016/j.foodchem.2018.02.018.

[13] Kim, J.B. (2021). A development framework of processed fishery products using regional specialization. *The Journal of Fisheries Business Administration*, 52(3), 1-14. doi: 10.12939/FBA.2021.52.3.001.

[14] Kupinets, L., & Shershun, O. (2022). The capacity of the fisheries and fisheries products market on the basis of determining the ratio of supply and demand. *Eastern Europe: Economy, Business and Management*, 4(37), 23-32. doi: 10.32782/easterneurope.37-4.

[15] Lebska, T., Bal-Prylypko, L., Kovalinska, T., Sakhno, V., Bondarenko, Ye., Mikhneva, E., Kravchenko, O., & Bondarenko, V. (2021). Preservation of rapana meat by the irradiation technology. *Food Science and Technology*, 15(3), 120-132. doi: 10.15673/fst.v15i3.2123.

[16] Lebsky, S. (2022). Quality of lipid-carotenoid concentrate from the Black Sea shrimp Palaemon adspersus Rathke, 1837. *Commodities and Markets*, 2(42), 79-87. doi: 10.31617/2.2022(42)07.

[17] Marques, C., Lise, C.C., Lima, V.A.D., & Daltoe, M.L.M. (2020). Survival analysis and cut-off point to estimate the shelf life of refrigerated fish burgers. *Food Science and Technology*, 40(1), 171-177. doi: 10.1590/fst.36918.

[18] Menchynska, A., Manoli, T., Tyshchenko, L., Pylypchuk, O., Ivanyuta, A., Holembovska, N., & Nikolaenko, M. (2021). Biological value and consumer properties of fish pastes. *Journal of Food Science and Technology*, 15(3), 52-62. doi: 10.15673/fst.v15i3.2121.

[19] Mukojima, K., Yoshii, M., Nakashio, A., Mabuchi, R., Furuta A., & Tanimoto, S. (2023). Effect of vacuum packing on the odor of yellowtail Seriola quinqueradiata flesh stored after heating. *Fisheries Science*, 89, 709-721. doi: 10.1007/s12562-023-01702-9.

[20] Mykhalchyshyna, L., & Sinenok, I. (2020). Strategic directions of aquaculture development in Ukraine. *Bioeconomics and Agrarian Business*, 11(2), 72-85. doi: 10.31548/bioeconomy2020.02.072.

[21] Myskovets, N.P. (2020). Analysis of the current state and prospects for the development of fisheries in Ukraine. *Business Inform*, 3, 104-111. doi: 10.32983/2222-4459-2020-3-104-111.

[22] Production of aquaculture products for 2022. State agency of recreation and fisheries of Ukraine. (2022). Retrieved from https://darg.gov.ua/files/23/03_08_aqua22.pdf/.

[23] Public report of the acting head of the State Agency for Reclamation and Fisheries of Ukraine Ihor Klymenko for 2022. (2022). Retrieved from https://darg.gov.ua/files/23/02_23_zvit.pdf.

[24] Pylypenko, I.O., Bal-Prylypko, L.V., Slobodyaniuk, N.M., & Israyelyan, V.M. (2021). Improvement of the technology of cooked sausage products with the addition of proteins of plant origin and seafood. In *The IX International scientific and practical conference of scientists, graduate students and students: "Scientific achievements in solving actual problems of production and processing of raw materials, standardization and food safety"* (pp. 132-133). Kyiv: National University of Life and Environmental Sciences of Ukraine.

[25] Qi, Z., Zhang, X.H., Boon, N., & Bossier, P. (2021). Probiotics in aquaculture of China – Current state, problems and prospect. *Aquaculture*, 290(1-2), 15-21. doi: 10.1016/j.aquaculture.2009.02.012.

[26] Racioppo, A., Speranza, B., Campaniello, D., Sinigaglia, M., Corbo, M.R., & Bevilacqua, A. (2021). Fish loss/waste and low-value fish challenges: State of art, advances, and perspectives. *Foods*, 10(11), article number 2725. doi: 10.3390/foods10112725.

[27] Rocha, C.P., Pacheco, D., Cotas, J., Marques, J.C., Pereira, L., & Gonçalves, A.M. (2021). Seaweeds as valuable sources of essential fatty acids for human nutrition. *International Journal of Environmental Research and Public Health*, 18(9), article number 4968. doi: 10.3390/ijerph18094968.

[28] State agency of recreation and fisheries of Ukraine. (2023). Retrieved from https://darg.gov.ua/.

[29] Sydorenko, O., & Petrova, O. (2021). Areas of use of Palaemon adspersus shrimp in food technology. *International Journal of Food Science and Biotechnology,* 6(2), 30-35. doi: 10.11648/j.ijfsb.20210602.12.

[30] Sydorenko, O., Bolila, N., & Forostyana, N. (2021). Spiny dogfish (*Squalus acanthias*): Changes in structural and mechanical properties under storage. *International Journal of Food Science and Biotechnology*, 6(1), 1-7. doi: 10.11648/j.ijfsb.20210601.11.

[31] Takahashi, K., Narisawa, Y., Morii, T., Morii, S., & Nakamura, Y. (2023). Aging of greater amberjack seriola dumerili meat promoted by low-temperature heating. *Food and Bioprocess Technology*, 16(12), 1-10. doi: 10.1007/s11947-023-03124-y.

[32] The State of World Fisheries and Aquaculture. (2022). *Towards blue transformation*. Retrieved from https://www.fao.org/3/cc0461en/online/sofia/2022/world-fisheries-aquaculture.html.

[33] Trofymchuk, A., Grinevich, N., Trofymchuk, M., Kunovsky, Y., Bondar, O., Tkachenko, O., & Savchuk, O. (2021) The state of the fish farming industry and its development trends in Ukraine and the world. *Animal Husbandry Products Production and Processing*, 2, 123-133. doi: 10.33245/2310-9289-2021-166-2-123-133.

[34] Valenti, W.C., Barros, H.P., Moraes-Valenti, P., Bueno, G.W., & Cavalli, R.O. (2021). Aquaculture in Brazil: Past, present and future. *Aquaculture Reports*, 19, article number 100611. doi: 10.1016/j.aqrep.2021.100611.

[35] Volkhova, T.V., & Holembovska, N.V. (2021). State and prospects of fish market development in Ukraine. *SWorld Journal,* 1(7), 44-50. doi: 10.30888/2663-5712.2021-07-01-013.

[36] Wang, C., Li, Z., Wang, T., Xu, X., Zhang, X., & Li, D. (2021). Intelligent fish farm – the future of aquaculture. *Aquaculture International*, 29(6), 2681-2711. doi: 10.1007%2Fs10499-021-00773-8.

[37] Yaroshevych, T., & Pakholiuk, O. (2020). Ukrainian fish and seafood market: Problems and prospects. *Commodity Bulletin*, 1(13), 40-51. doi: 10.36910/6775-2310-5283-2020-13-04.

[38] Zhao, X., Zhang, Z., Cui, Z., Manoli, T., Yan, H., Zhang, H., Shlapak, G., Menchynska, A., Ivaniuta, A., & Holembovska, N. (2022). Quality changes of sous-vide cooked and blue light sterilized Argentine squid (Illex argentinus). *Potravinarstvo Slovak Journal of Food Sciences*, 16, 175-186. doi: 10.5219/1731.

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