

Fermentation biotechnology applied to by-products of the fish processing industry: nutrition and functionality information

Olga Krotova^{1*}, *Olga Tyulumdjieva*², *Natalia Vertiy*³, *Aleksandr Ushakov*⁴, *Natalya Isaeva*⁵, and *Vyacheslav Lodyanov*¹

¹ Don State Technical University, 1, Gagarin Sq., 344003, Rostov-on-Don, Russia

² Kalmyk State University named after B.B. Gorodovikov, Pushkin str., 11, 358000, Elista, Republic of Kalmykia, Russia

³ Rostov State Medical University" of the Ministry of Health of the Russian Federation, 29, Nakhichevansky Lane, Rostov-on-Don, 344022, Russia

⁴ Don State Agrarian University, Novochoerkassk Engineering and Reclamation Institute named after A.K. Kortunov, Novochoerkassk, 111 Pushkinskaya str., 346428, Novochoerkassk, Russia

⁵ Dagestan State Agrarian University named after M.M. Dzhambulatov, 367032, RD, Makhachkala, Magomed Hajiyev str., 180, Russia

Abstract. The article examines the importance of fermentation in the biotechnology of processing fish processing industry waste for the purpose of food production. In the context of the growing interest in sustainable development and food waste management, fermentation represents a promising approach to improving the efficiency of raw materials and creating added value. The article discusses various aspects of fermentation, including the selection of optimal enzymes, optimization of feedstock processes, as well as technological and economic aspects of food production from fish processing industry waste. The presented review of research and practical examples highlights the importance of fermentation in creating innovative and sustainable solutions in the field of food production from fish waste. The role of using microorganisms, such as lactic acid bacteria, for fish fermentation is invaluable. This process not only reduces the risk of spoilage due to competition for nutrients with pathogenic microorganisms, but also promotes the formation of beneficial metabolites such as organic acids, which improves the safety of the product and its organoleptic properties. Fermentation of fish by-products is an urgent and promising direction in the context of the development of sustainable methods of processing and using fish processing waste. The efficient use of fish by-products not only reduces waste in industry, but also creates additional resources for various industries, contributing to sustainable development and economic growth.

* Corresponding author: alb9652@yandex.ru

1 Introduction

Fermentation plays a key role in the food industry, representing an important raw material processing process aimed at improving the nutritional properties and extending the shelf life of various products. One of the important applications of fermentation is the production of fish and seafood products. Fish and seafood are a valuable source of protein, essential fatty acids, vitamins and minerals, but their excessive consumption in raw form may be associated with certain health risks such as infections and intoxication, as well as insufficient shelf life.

Fermentation in the production of fish products is a process in which enzymes or microorganisms decompose proteins, fats and carbohydrates, which leads to a change in the structure and properties of raw materials, as well as an improvement in its storage and consumer characteristics. This process can be carried out both naturally and using added enzymes or microorganisms.

Fermentation is a traditional method of food preservation and is widely used to improve food safety, shelf life, organoleptic and nutritional properties. Fermented fish is produced and consumed in different parts of the world and is an integral part of many food crops. In addition, fermented fish is a source of interesting microbes and an important industry in many countries, including the Russian Federation [1].

The theoretical aspects of the influence of microorganisms on the quality of fish meat are key in the study of this topic. Microorganisms play an important role in the decomposition of fish meat and can have both positive and negative effects on its quality. The influence of microorganisms on the quality of fish meat can manifest itself through various processes such as fermentation, oxidation, decomposition of proteins and fats. Some microorganisms contribute to improving the taste, aroma and texture of fish meat, while others can cause an unpleasant odor, discoloration and texture, as well as deterioration in the nutritional value of the product. To control the quality and safety of fish meat, it is necessary to take into account the influence of various types of microorganisms, their conditions of reproduction and decomposition, as well as methods of preventing and destroying pathogenic microorganisms. Studying the theoretical aspects of the influence of microorganisms on the quality of fish meat will allow a deeper understanding of the processes occurring in the product, and develop effective methods to control and improve its quality.

It is important to note that microorganisms can be both beneficial and harmful to fish meat. Beneficial microorganisms can improve the taste and aroma of the product, as well as contribute to its longer storage. For example, lactic acid bacteria can be used to produce fermented fish products such as smoked fish or fish paste. However, the uncontrolled proliferation of harmful microorganisms, such as pathogenic bacteria or fungi, can lead to spoilage of the product and deterioration of its quality. To prevent the negative impact of microorganisms on the quality of fish meat, various conservation and processing methods are used. These include heat treatment, cold storage, the addition of preservatives and antioxidants, as well as the use of special packaging materials. These methods can reduce the risk of reproduction of harmful microorganisms and preserve the quality of fish meat for a long time. It should be borne in mind that the study of the interaction of microorganisms with fish meat is a key aspect in the development of new technologies for the production and storage of fish products. Understanding the theoretical aspects of the influence of microorganisms on the quality of fish meat will help to develop effective strategies for controlling the quality and safety of the product in the food industry.

An important aspect of the influence of microorganisms on the quality of fish meat is also their ability to cause diseases in humans when eating contaminated products. Some microorganisms, such as salmonella or E. coli, can be dangerous to human health and cause

serious infectious diseases. Therefore, monitoring the microbiological safety of fish products is a priority task for the food industry and state control bodies.

In addition, it is important to take into account factors affecting the reproduction of microorganisms in fish meat, such as storage temperature, humidity, pH level, oxygen content and others. Understanding these factors makes it possible to develop optimal conditions for the storage and transportation of fish products in order to minimize the risk of pathogenic microorganisms.

Thus, the study of the theoretical aspects of the influence of microorganisms on the quality of fish meat is an important task for ensuring food safety and quality. Scientific research in this area allows the development of new production methods and technologies that contribute to the preservation of freshness, taste and nutritional qualities of fish products and ensure their safety for consumers.

Geosmin and mib (2-methylisoborneol) are substances that are produced by certain types of bacteria and can affect the quality of fish meat. Geosmin has a specific mushroom smell, which can give the product an unpleasant taste and aroma. This substance is usually formed during the decomposition of organic substances under the influence of bacteria, for example, in aquatic ecosystems, including reservoirs inhabited by fish. The presence of geosmin in fish meat may be a consequence of poor-quality processing and storage of the product, as well as unfavorable production conditions. Mib, in turn, has an earthy smell and can also negatively affect the taste characteristics of fish meat. This substance is also formed as a result of the activity of certain types of bacteria and may be present in fish products, especially those that have been improperly processed or stored.

The control of the reproduction and activity of bacteria producing geosmin and mib is an important aspect of ensuring the quality and safety of fish meat. Methods of preventing and destroying these bacteria, such as proper heat treatment, cold storage and the use of preservatives, can help prevent the appearance of undesirable substances in fish products. Thus, the study of the effect of bacteria producing geosmin and mib on the quality of fish meat is an important aspect of research in the field of food microbiology and food safety.

Fish production by main species in the Russian Federation is shown in Figure 1.

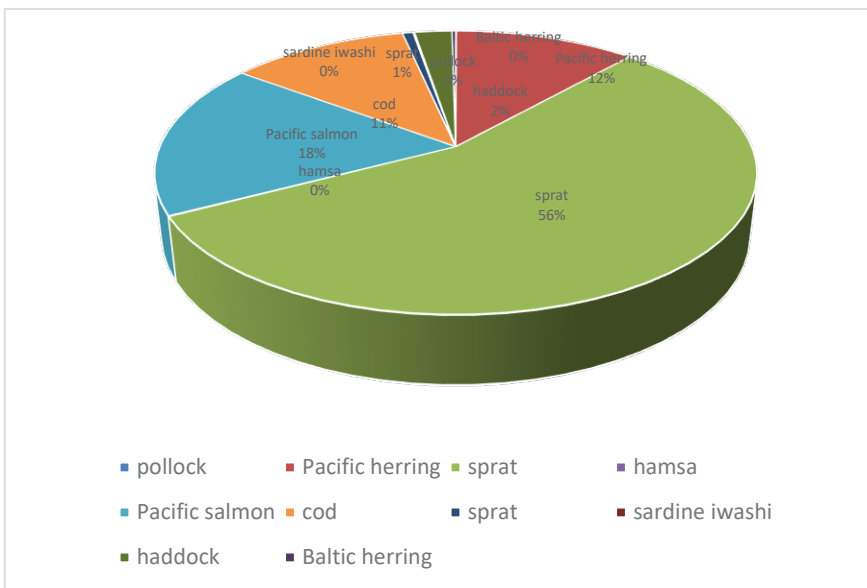


Fig. 1. Fish production by species in the Russian Federation in 2023 (thousand tons)

It is worth noting that almost all the fish produced is used for canning. The volume of fish production in 2023 increased by 10.4% compared to the same period last year – up to 3.4 million tons, according to Rosstat [2]. Moreover, the share of canned fish production in the Russian Federation ranks second in 2023, as evidenced by the graph in Figure 2.

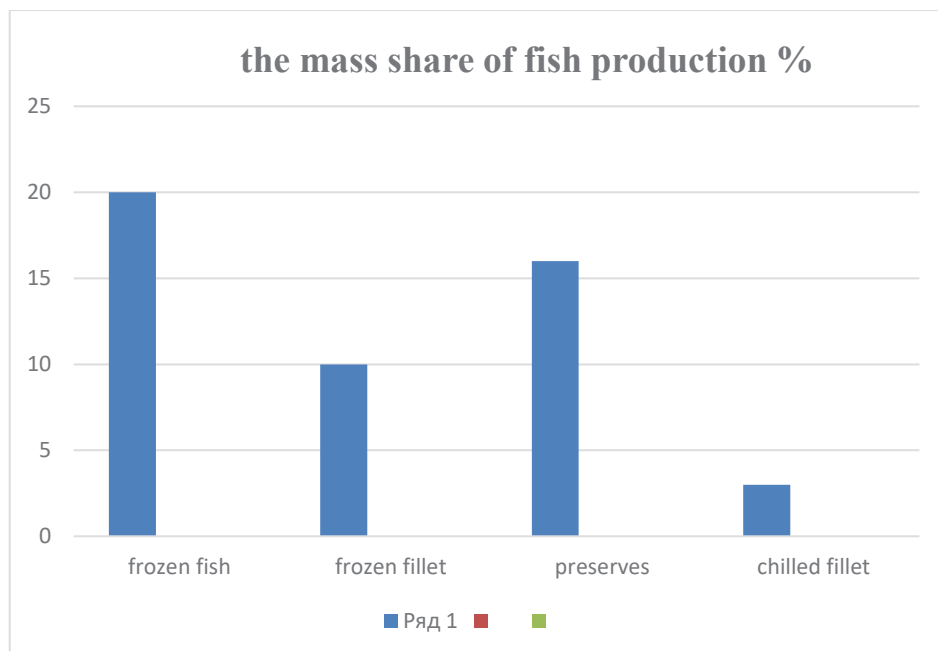


Fig. 2. Production dynamics by market segments

2 Materials and methods

In the process of processing fish, waste (by-product) is obtained, which is no less expensive than the fish itself. By-products can make up a significant part of the total weight of fish, which implies that with the growth of global demand for fish, the production of these by-products also increases. Extraction from these by-products obtained after processing fish offers a diverse range of high-quality compounds suitable for human consumption. Among these compounds, proteins, amino acids, oil, collagen and gelatin stand out, having significant added value due to their potential to increase the value of fish waste.

Fish by-products such as fish bones, stomachs, intestines and heads are also a significant resource that requires efficient processing to minimize waste in the fish processing industry. Since a significant part goes to the production of fishmeal, protein feed concentrates, dietary supplements (omega-3 fatty acids, vitamins and minerals), fertilizers and even biofuels, and is obtained by fermentation. Another important use of fish by-products is the production of enzymes. The main group of marine enzymes are proteases, which have important commercial applications. The efficient use of fish by-products not only reduces waste in industry, but also creates additional resources for various industries, contributing to sustainable development and economic growth.

Fermentation of fish by-products is an urgent and promising direction in the context of the development of sustainable methods of processing and using fish processing waste.

3 Results

The fermentation process promotes the formation of more digestible proteins due to their hydrolysis and decomposition into shorter peptides and amino acids [3]. Some of the main benefits of fermentation include increasing the effectiveness of antioxidant peptides that interact with glutathione (GSH), providing protection against damage associated with the use of fermentation. Fermentation is a safe, environmentally friendly and profitable method that allows you to obtain a wide range of compounds, including bioactive peptides or aromatic compounds. Until now, the preferred method of producing peptides in industry has been the use of acids or alkalis to accelerate protein hydrolysis, mainly due to their simplicity and low cost, therefore fermentation can be a significant tool for improving the nutritional characteristics of fish products used as a source of protein in feed [4]. In addition, due to fermentation, the quality of the oil obtained from fish waste improves compared to treatment with formic acid [5]. Various ways of using fermentation to increase the value of fish offal are presented in table 1.

Table 1. Compounds obtained as a result of fermentation of fish by-products and microorganisms used in the processing process

Raw materials (fish)	Microorganisms for fermentation	High-value-added connections
Fish sauce (minnows / carp)	<i>Lactobacillus acidophilus</i>	Peptide inhibitor of HMG-CoA reductase
Sirloin (sea bass)	<i>Lactobacillus reuteri</i>	Reuterin (preservative)
Muscles (cod)	<i>Lactobacillus curvatus</i> и <i>Enterococcus faecium</i>	Preservative compounds
Fish sauce (offal)	<i>Aspergillus oryzae</i>	Antioxidant peptides (preservatives)
Leather (turbot)		Antioxidant peptides (preservatives)
Heads (carps)	Lactic acid bacteria	Antioxidant peptides (preservatives)
Head, skin, insides, fins (freshwater fish)	<i>A. oryzae</i> и <i>Aspergillus niger</i>	Glutamic acid, 2-methylbutanol, 3-methylbutanol (flavoring compounds)
Fish sauce (with anchovies)	<i>A. oryzae</i>	Flavoring additives

Fish sauce (silver carp)	<i>A. oryzae</i>	Flavoring additives
Skin, internal organs and muscles (sardine, perch, rainbow trout, Atlantic salmon)	Lactic acid bacteria	Bacteriocins
Skin, head, carcass and giblets of a sea bass	<i>Lb. plantarum</i> , <i>Pediococcus acidilactici</i> , <i>Lactobacillus brevis</i> , <i>Enterococcus gallinarum</i> и <i>Streptococcus spp.</i>	Oil
Thorns (white cupid)	<i>Leuconostoc mesenteroides</i>	Calcium
Scales and intestines	<i>Bacillus subtilis</i>	Bioplastics
Fish waste (catfish and tilapia)	<i>Lactobacillus pentosus</i>	Lactic acid

It is also worth noting that in the production of fermented fish products such as pickled trout or smoked trout, lactic acid bacteria can be used to give the product a characteristic taste and aroma.

Fermentation is an effective method of obtaining bioactive peptides from fish by-products. Biologically active peptides, consisting of 2 to 20 amino acid residues, have a specific function and can bring health benefits, including antihypertensive, antitumor and antioxidant properties.

Although these peptides do not show activity in the original protein, they can perform various physiological functions after hydrolysis. The physiological activity of bioactive peptides depends on their amino acid sequence, type and chain length, and they can exhibit a variety of biological effects [6]. As evidenced by the research conducted by Yu. Fu, M. Thorkildsen, R.E. Aluko, R. Lamet in 2018 at the University of Copenhagen. In this work, the main approaches to the production of collagen peptides with a wide range of bioactivity, including antihypertensive, antioxidant and antidiabetic activity, as well as beneficial effects on bone, joint and skin health, were summarized. The biological possibilities of collagen peptides and their bioavailability were considered.

4 Discussion of the results

Studies show that fermentation of tuna insides leads to the formation of peptides-inhibitors of angiotensin-converting enzyme, which may be useful for blood pressure control [7,8]. Other studies demonstrate that peptides derived from fermented fish sauce can help lower blood cholesterol levels [9,10]. The biological activity of bioactive peptides obtained from fish by-products by fermentation is often associated with both their antioxidant and biocidal functions.

For centuries, fermentation using lactic acid bacteria has been widely used in the preparation of fish and other seafood in order to improve their preservation. This method has become one of the main ways to improve the quality of food products, allowing to prevent the proliferation of microbes and, consequently, prolong their shelf life. Lactic acid bacteria play an important role in this process, as they produce antimicrobial substances that prevent the spread of pathogenic microorganisms or microorganisms that cause spoilage of food products.

For example, an antimicrobial substance isolated from an enzyme of the *Lactobacillus plantarum* strain is used as a food additive to improve food safety. Another example is the fermentation of glycerin on the surface of fish fillets to produce reuterin, which has antibacterial properties and prevents infection by microorganisms [11].

However, in the case of fish offal, they are more often used to produce antioxidant compounds. For example, bioactive peptides have been obtained from fermented fish offal sauce. In the studies of a number of scientists [12], antioxidant peptides were obtained after fermentation of fish heads using lactic acid bacteria.

Fermented fish products often have a characteristic «umami» flavor, which is associated with a high content of glutamic and aspartic acids. The study [13,14,15] showed that after fermentation of fish sauce made from freshwater fish by-products, the content of glutamic acid increases, and the presence of other volatile flavoring compounds such as aldehydes 2-methylbutanal and 3-methylbutanal is also detected. These ingredients contribute to the characteristic taste and aroma of fermented fish sauces.

Studies conducted by a number of scientists over the past 5 years indicate that fish, especially large carnivorous species, can effectively absorb environmental pollutants such as mercury and DDT. However, fish raised in inland fish ponds tend to contain lower levels of pollutants due to less complex trophic levels and shorter growing periods. Despite this, the consumption of infected fish is becoming a public health problem.

In the field of fermentation of fish offal, there are several recent trends and innovations aimed at improving processes and obtaining more valuable products. For example, research on the introduction of new enzymes and enzyme combinations for a more efficient and controlled protein hydrolysis process. Scientists from the University of Technology of Malaysia investigated the use of a combination of proteases for protein hydrolysis in fish offal in order to obtain more valuable peptides.

The introduction of new technologies, such as ultrasound or plasma treatment, to accelerate the fermentation process and improve the quality of the products obtained, has been investigated to obtain more active antioxidant peptides from fish offal. Ultrasound demonstrates various key characteristics, such as increased process efficiency, effective inactivation of microorganisms, improved quality, minimization of technological steps, preservation of desired quality indicators such as texture, nutrition, organoleptic properties, unchanged along with an extended shelf life.

Although fermentation of fish products can be an effective method to improve their quality and functionality, it can also face problems such as:

- Contamination and deterioration of the quality of raw materials;
- Unpredictability of the process;
- Risk of microbial contamination;
- Loss of biologically active substances;
- Technological limitations.

Solving these problems requires careful control of the fermentation process, the use of high-quality raw materials, optimization of fermentation conditions and the development of technological methods to overcome technical limitations.

Over the past five years, there have been significant prospects for the development of research in the field of fermentation of fish products, especially given the growing interest

in healthy nutrition and innovative technologies in the food industry. The key areas of research are the use of probiotics and prebiotics. Researchers are actively exploring the potential of probiotic and prebiotic cultures for the fermentation of fish products. For example, a study by Michael Box and co-authors showed that the use of probiotic cultures can improve the quality of fish products and enhance their functional properties.

In addition, research has been conducted on the study of metagenomics and microbiome. Using modern methods of metagenomics and microbiome analysis, researchers are discovering new microorganisms capable of fermenting fish products. The study by Kim and co-authors discusses the microbiota of marine fish and its potential in the fermentation process.

Nanotechnology research also offers new approaches to the fermentation of fish products. For example, a study by Zhang and co-authors describes the use of nanoparticles to improve the fermentation efficiency of fish meat. These works explore various aspects of fish product fermentation, from new technologies and enzymes to the use of microbiomes, which allows us to expand our knowledge and optimize the production processes of healthier and more functional fish products.

5 Conclusions

Fermentation plays an essential role in improving the nutritional properties of fish and seafood due to various biochemical processes. Such as proteolysis, lipid decomposition and ammonia reduction. The role of using microorganisms, such as lactic acid bacteria, for fish fermentation is invaluable. This process not only reduces the risk of spoilage due to competition for nutrients with pathogenic microorganisms, but also promotes the formation of beneficial metabolites such as organic acids, which improves the safety of the product and its organoleptic properties.

However, challenges include the need to optimize fermentation conditions for each type of fish and seafood, as well as research on the effects of fermentation on food safety. For example, uncontrolled fermentation can lead to the formation of toxic compounds such as biogenic amines, which can endanger the health of consumers. Therefore, future research should focus on the development of methods for controlling fermentation processes, as well as on optimizing fermentation conditions in order to maximize the improvement of nutritional properties of products with minimal risk to health.

References

1. J. Zang, Y. Xu, W. Xia, & J. M. Regenstein, *Critical Reviews in Food Science and Nutrition*, **60(7)**, pp. 1228–1242, (2020). DOI: 10.1080/10408398.2019.1565491
2. A. Alekseev, O. Krotova, T. Tupolskikh, V. Onkaev, O. Kedeeva, N. Gucheva, *Fundamental and Applied Scientific Research in the Development of Agriculture in the Far East (AFE-2022)* Vol. **733-1**. – Zug: Springer Cham, P. 1119-1129, (2024). DOI: 10.1007/978-3-031-37978-9_108.
3. A.L. Alekseev, T.V. Alekseeva, L.F. Obrushnikova, O.A. Knyazhechenko, Y.V. Starodubova, M.I. Slozhenkina,
4. IOP Conference Series: Earth and Environmental Science "AgroINNOVATION: Innovative Solutions in the Agro-Industrial Complex, AgroINNOVATION 2021", pp. 012038, (2022) DOI: 10.1088/1755-1315/965/1/012038
5. G. Amagliani, E. Omiccioli, G. Brandi, I.J. Bruce, M. Magnani, *Food Microbiology*.- V. **27**.- Issue5.-2010.- pp. 580-585. DOI:10.1016/j.fm.2010.01.007.

6. O. E. Krotova, S. M. Chelbin, M. Krotova, O.S.Sangadzhieva, K.E.Khalgaeva, BIO Web of Conferences : Sustainable Development of Traditional and Organic Agriculture in the Concept of Green Economy (SDGE 2021), Vol. **42**, P. 01018, (2022). DOI 10.1051 /bioconf/20224201018
7. M. Kaltenbrunner, R. Hocegger, M. Cichna-Markl, Food Control, 89, 157 - 166 (2018). DOI: 10.1016/j.foodcont.2018.01.021
8. K. Manikandan, N. Felix, Aquaculture Nutrition, 27(6), 2240-2250 (2021). DOI: 10.1111/anu.13359
9. S. Mazinani, A. Motamedzadegan, S. Nghizadeh Raeisi, M. Alimi, Journal of Food Measurement and Characterization, 15(6), 5515-5527 (2021). DOI: 10.1007/s11694-021-00973-z
10. X. Zhuang, S. Clark, N. Acevedo, Journal of Food Science, 86(11), 4892-4900 (2021). DOI: 10.1111/1750-3841.15928.
11. M. Khalesi, R.J. Fitzgerald, Catalysts, 11(7), 787 (2021). DOI: 10.3390/catal11070787
12. R. Li, J.-T. Teng, C.-T. Chang, Annals of Operations Research, 307(1-2), 303-328 (2021). DOI: 10.1007/s10479-021-04272-0
13. Y. Wang, Y.-H. Bai, F. Ma, K. Li., H. Zhou, C.-G. Chen, International Journal of Food Science and Technology, 56(12), 6322-6334 (2021). DOI: 10.1111/ijfs.15346
14. Y. Gao, W. Wang, J. Wang, Shipin Kexue/Food Science, 42(1), 197-207 (2021). DOI: 10.7506/spkx1002-6630-20191210-104
15. A. Alekseev, O. Krotova, T.Tupolskikh, N.Gucheva, T. Skoba, I. Trofimenko, E3S Web of Conferences. XVI International Scientific and Practical Conference “State and Prospects for the Development of Agribusiness - INTERAGROMASH 2023”. Rostov-on-Don, Russia, pp. 01012 (2023) DOI: 10.1051/e3sconf/202341301012