SILESIAN UNIVERSITY OF TECHNOLOGYPUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2024
ORGANIZATION AND MANAGEMENT SERIESNO. 203

QUALITY AND RISK MANAGEMENT IN AQUACULTURE: A CASE STUDY OF TROUT PRODUCTION IN THE "SLUPIA VALLEY" LANDSCAPE PARK

Anita KUKUŁOWICZ[1*], Izabela STEINKA[2], Maciej MACHETA[3]

[1] Gdynia Maritime University; a.kukulowicz@wznj.umg.edu.pl, ORCID: 0000-0002-7520-7992
[2] Gdynia Maritime University; i.steinka@wznj.umg.edu.pl, ORCID: 0000-0002-7520-7992
[3] Gdynia Maritime University, maczo112233445@wp.pl
* Correspondence author

Purpose: The purpose of this paper is to assess the microbiological quality of rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) from aquaculture farms located within the "Dolina Słupi" (Slupia Valley) Landscape Park, with a focus on regional sustainability practices. The research aims to evaluate water hygiene, the microbiological quality of feed, the prevalence of antibiotic-resistant bacteria, and their impact on the final quality of the farmed trout. This study seeks to contribute to the broader discourse on sustainable aquaculture by highlighting the importance of quality and risk management practices in maintaining food safety and environmental stewardship.
Design/methodology/approach: The research employed a comprehensive microbiological analysis of samples collected from trout farms, including external and internal parts of trout, viscera, water, and feed. The study focused on identifying the presence of specific pathogens, such as *Staphylococcus aureus, Escherichia coli, Salmonella* spp., methicillin-resistant *S. aureus*, and vancomycin-resistant *Enterococcus* spp. The approach combined field sampling with laboratory testing to assess the hygienic conditions of the aquaculture environment and the quality of the final fish products. The research focuses on evaluating the microbiological quality of trout from aquaculture farms, with particular attention to local practices and their alignment with sustainability goals.
Findings: The study revealed that the trout from the examined farms generally met good microbiological quality standards. Specifically, no methicillin-resistant *S. aureus* or vancomycin-resistant *E. faecium* and *E. faecalis* were detected, indicating effective risk management. However, *Salmonella* spp. were present in 30.5% of water samples, yet their presence did not significantly affect the contamination levels in fish samples. The highest *S. aureus* count was found on the skin of rainbow trout (1.5±101 cfu/g), while *E. coli* was detected on brook trout skin and viscera (11%). *Enterococcus* spp. were found in 17% of feed samples, but at low concentrations (<10 cfu/g). These results suggest that while overall microbiological quality is satisfactory, ongoing monitoring and adherence to good management practices are crucial for maintaining safety and quality in aquaculture.
Research limitations/implications: One limitation of the research is the geographical focus on aquaculture farms within the "Dolina Słupi" Landscape Park, which may limit the generalizability of the findings to other regions or types of aquaculture systems. Future research

could expand the scope to include a broader range of aquaculture environments and examine the long-term impact of sustainability practices on fish quality.
Practical implications: The research underscores the critical role of continuous monitoring and rigorous quality management practices in aquaculture. The findings indicate that by implementing effective hygiene protocols and risk management strategies, aquaculture farms can achieve high safety standards for their fish products. These practices not only ensure product quality and consumer safety but also support the sustainability and economic viability of the aquaculture industry.
Social implications: The study demonstrates that sustainable aquaculture enhances food security and environmental conservation. By promoting effective practices, it builds public trust in farmed fish, potentially influencing consumer behavior and supporting more sustainable industry practices.
Originality/value: This paper contributes to the existing body of knowledge on sustainable aquaculture by providing empirical evidence on the microbiological quality of trout from farms in a specific regional context. It offers practical insights for industry professionals and consumers on optimizing quality and risk management to ensure safe and sustainable fish production.
Keywords: quality management, risk management, aquaculture, trout, food safety.
Category of the paper: research paper.

1. Introduction

Fish, whether produced through aquaculture or caught from wild marine or freshwater stocks, are a major source of protein and essential nutrients (HLPE, 2014). The nutrients found in fish (protein, lipids containing omega-3 acids, vitamins: D, A, E, B and minerals: calcium, phosphorus, iron, copper, selenium) are essential for the proper functioning of the body, as they provide energy and are involved in repair and regulatory processes (Mishra, Pradesh, 2020; Pandey, Upadhyay, 2022). Vitamins play pivotal roles in energy metabolism, nervous system function, and red blood cell formation (Brancaccio et al., 2022). Fish consumption lowers glucose levels and reduces the risk of cardiovascular diseases. Fish protein is consumed as a substitute for animal protein in many regions of the world. Literature data reports that approximately 16-17% of animal protein comes from fish consumed by humans at a global level (Pandey, Upadhyay, 2022). The global population is expected to reach 9.7 billion by 2050 (López-Mas et al., 2023) and thus the demand for food, including fishery products, will increase. Projections indicate that fish consumption in 2031 will reach 21.4 kg per capita, approximately 1 kg more than in 2019-2021 (Oecd, FAO, 2022). In Poland, there is also an upward trend in fish consumption which is currently around 14 kg per person (Kowalska, 2022). Farmed fish, a pivotal component of global aquaculture, refers to fish species cultivated in controlled environments for commercial purposes. This practice addresses the increasing demand for seafood while helping to alleviate pressure on wild fish populations. Effective management of production processes in aquaculture, including the implementation of modern technologies and sustainable practices, is essential for meeting this growing demand. Farmed fish production involves various species, including salmon, tilapia, and catfish, and employs diverse aquaculture methods ranging from pond and cage systems to recirculating aquaculture systems (Sustainable seafood…, 2023).

1.1. Sustainable aquaculture

Overexploitation of global marine resources has been observed in recent years due to unsustainable fishing practices. As a result of years of intensive fishing, wild stocks are threatened with depletion, so farmed fish from aquaculture can provide an alternative to these raw materials (Forleo, Palmieri, 2023; López-Mas et al., 2023). According to data, global aquaculture production was 57,3% in 2020 (The State of World Fisheries and Aquaculture, 2022). In line with the principles of sustainable development, environmentally friendly and socially acceptable aquaculture practices should be pursued, ensuring high-quality production (Biegała, 2014). Quality management in aquaculture involves careful monitoring and control of environmental factors, ensuring that production processes not only meet consumer demand but also adhere to sustainability standards (Firlej et al., 2005). By adopting practices that prioritize resource efficiency, biodiversity conservation, and ethical treatment of aquatic ecosystems, sustainable aquaculture aims to meet the growing global demand for seafood while safeguarding the health of our oceans and supporting resilient coastal communities. In 2020, Poland was the sixth-largest producer of fishery products and the fifth in terms of sourcing aquaculture products. In Poland, the production of consumer fish in the fishery economy in 2020 was about 252 thousand tonnes, of which aquaculture accounted for 46 thousand tonnes (more than 18%). This consisted mainly of carp (47%), and trout (43%) production. The main production methods in 2020 were pond farming (52%) and pool and fairway farming (40%) (https://www.eumofa.eu/…). Fish farms are increasingly focusing on quality management and environmental issues by implementing modern farming technologies and improving fish nutrition, which are critical for the sustainability of their operations and product safety.

1.2. Factors leading to reduced safety of farmed fish

Although aquaculture now plays a significant role in global sustainability, a significant proportion of consumers have a negative perception of farmed fish compared to their wild counterparts. Consumers perceive wild-caught fish to be superior to farmed fish in terms of better quality, fewer antibiotics, freshness, nutritional value, and better taste (López-Mas et al., 2023). This perception underlines the importance of rigorous quality management in aquaculture, ensuring that farmed fish meet or exceed the safety and quality standards expected by consumers. The conditions in which fish are kept are conducive to their exposure to pathogens, which can affect both the health of the fish themselves and potential consumers, leading to food poisoning. Various species of bacteria are found in fish, some of which are pathogenic to humans, such as: *Vibrio parahaemolyticus*, *Vibrio cholerae*, *Escherichia coli*, *Aeromonas* spp., *Salmonella* spp., *Staphylococcus aureus, Listeria monocytogenes, Clostridium botulinum, Clostridium perfringens, Campylobacter jejuni*, which may be related to direct contact with contaminated water, sediment or contaminated feed (Külahci, Gündoğan, 2021; Sheng, Wang, 2021). Furthermore, a fairly common practice in aquaculture is the use of antibiotics, which are most often used for prophylactic, therapeutic, metaphylactic purposes, and as growth stimulants. This practice may affect the spread of resistance in the environment and in humans (Pepi, Focardi, 2021). The management of antibiotic use in aquaculture is a critical component of risk management, as improper use can lead to significant public health risks. Moreover, the quality of feed plays a crucial role, as poor formulations can compromise fish health and contribute to the presence of contaminants in the final products. Ensuring high-quality feed is an essential part of the quality management process, as it directly impacts the safety and quality of the final fish products. From the point of view of the idea of sustainability, the quality of products (and thus fisheries products) is of great importance. Products that are of limited quality become less valuable to the consumer (Maik, 2021).

1.3. Research problem and aim of the study

Monitoring the quality of water, feed and also the health surveillance of fishery products are important elements in the marketing of aquaculture products. In the context of quality management and risk management, it is crucial to verify how these factors impact the overall safety and quality of aquaculture products. Therefore, the objectives of this study were (i) to assess the hygienic status of the water in which the trouts were housed, (ii) to assess the microbiological quality of the feed used to feed the fish, (iii) to assess the prevalence of antibiotic-resistant bacteria and (iv) to determine whether the above factors affected the final quality of the studied trouts.

2. Material and Methods

2.1. Research materials

The study material (n = 84) consisted of rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*), the water in which they lived and the feed they were fed. Both fish species originated from farms located in the buffer zone of the "Dolina Słupi"(Slupia Valley) Landscape Park (Pomeranian Voivodeship). The brook trout farm takes its water from the River Skotawa, which is the longest tributary of the River Slupia and exhibits the characteristics of a foothill river, i.e. it has a steep gradient and a hard bottom strewn with pebbles and gravel. The rainbow trout farm takes its water from the Brodek stream (a tributary of the River Slupia), which is characterized by a sandy bottom. Both farms raise fish from eggs to adults. The owners raise trouts and sturgeons in concrete pools with flow-through fresh water circulation. They also use 'baths' to prevent the development of parasites in the fish. Fish were transported to the microbiology laboratory in ice-filled isothermal containers (EPS styrobox) to protect the fish from temperature changes and ensure safe transport. Water and feed samples were taken in sterile containers. Water was transported in thermal bags. Transport took approximately 2 hours. Immediately upon arrival at the laboratory, the samples were analyzed.

2.2. Microbiological analyses

In a chamber with laminar air flow, samples were taken for testing, which were, respectively: the external part of the trout including the skin, the internal part (muscles), the fish's viscera (mainly intestines, liver, gonads), feed and water.

Microbiological tests were carried out to determine the number of:

- *Staphylococcus aureus* on Merck's Baird-Parker+RPF medium (incubation at 37°C for 48 h),
- *Escherichia coli* on Coli ID medium from bioMerieux (incubation at 37°C for 48 h),
- *Enterococcus* spp. on D-coccosel medium from bioMerieux (incubation at 37°C for 48 h)

and the presence of *Salmonella* spp. on Chromogenic Salmonella LAB-AGAR Biomaxima medium. (incubation at 37°C for 24 h).

In addition, to assess the prevalence of methicillin-resistant *S. aureus* (MRSA) and *E. faecium* and *E. faecalis* showing acquired vancomycin resistance, surface cultures were performed on CHROMagar MRSA plates (Graso Biotech) (incubated for 24-48 h at 37ºC) and chromID™ VRE plates (bioMerieux) (incubated for 24-48 h at 37ºC), respectively. Tests were performed in six replicates.

2.3. Statistical analysis

In the analysis of the results obtained, elements of descriptive statistics were used, i.e.: mean value and standard deviation. As only a proportion of the samples were found to contain microorganisms, the data were recoded and analyzed using tools for qualitative data. The significance level was set at 0.05. The relationship between microbial prevalence and trout species from different cultures was estimated using Yates' chi2 test(χ2Y). The data were processed using Statistica software (StatSoft, Inc.).

3. Results and Discussions

No *Salmonella* spp. were found in the tested samples of rainbow trout and brook trout (Table 1). Approximately 22% of water samples taken from brook trout (*Salvelinus fontinalis*) farms and approximately 39% of water samples taken from rainbow trout (*Oncorhynchus mykiss*) farms showed the presence of *Salmonella* spp. However, there was no effect of the prevalence of these bacteria on the degree of contamination of the tested fish samples. Only in the feed of brook trout (*Salvelinus fontinalis*) were *Enterococcus* spp. found in two samples. The presence of these bacteria was also detected in the viscera of trouts that had been fed the tested feed, but the numbers were at low levels (Table 1).

Table 1.
Average degree of contamination of the analyzed samples (X±SD)

Type of sample/ number of samples (n)		*E.coli*	*S.aureus*	*Enterococcus* spp.	*Salmonella spp.*
As/n = 6	cfu/g	< 10	$10^1 \pm 1{,}5x10^1$	nb	nb
Am/n = 6		nb	< 10	nb	nb
Ag/n = 6		< 10	nb	< 10	nb
Af/n = 6		nb	nb	< 10	nb
Aw/n = 18	cfu/100 ml	< 10	< 10	< 10	ob
Bs/n = 6	cfu/g	nb	$1{,}5x10^1 \pm 1{,}7x10^1$	< 10	nb
Bm/n = 6		nb	< 10	nb	nb
Bg/n = 6		nb	< 10	nb	nb
Bf/n = 6		nb	nb	nb	nb
Bw/n = 18	cfu/100 ml	< 10	< 10	< 10	ob

A – brook trout, B – rainbow trout, s – external part of trout with skin, m – internal part (muscles), g – fish viscera, f – feed, w – water, nb – not present.

Source: own studies.

Microbiological contamination of tested water samples taken from brook trout (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*) cultures with *E. coli* and *Enterococcus* spp. bacteria met the requirements (<1000 and <400 cfu/100 ml, respectively) to be met by the quality of bathing water (Journal of Laws of 2019, item 255). In addition to contaminated water samples from both farms, *E. coli* was also detected in brook trout samples from the skin surface and viscera (about 11%). The highest level of *E.coli* ($4x10^1$ cfu/g) was found in samples from the skin surfaces, which may have been affected by the quality of the water. In the current study, the highest mean number of *S. aureus* ($\geq 10^1$ cfu/g) was found on the skin of the tested trout (Table 1). However, in none of the tested samples, the number of *S. aureus* exceeded the acceptable limit 10^3cfu/g (Rondón-Espinoza et al., 2022) (maximum value of $1{,}5x10^1$cfu/g obtained in one sample). The samples of rainbow trout (*Oncorhynchus mykiss*) were characterized by higher and more frequent microbiological contamination than brook trout (*Salvelinus fontinalis*), 50% and 27.8%, respectively. Although *S.aureus* was more likely to contaminate rainbow trout, no significant relationship ($p = 0.3050$) was observed between the presence of these bacteria and the species in question (Table 2). Approximately 11% of the water samples collected from the brook trout (*Salvelinus fontinalis*) farms and 33.3% of the water samples collected from the rainbow trout (*Oncorhynchus mykiss*) farms showed the presence of *S. aureus* at levels <10 cfu/ml. The same result was obtained by Joseph et al. (2017) for the water samples analyzed from different farms. The study showed the absence of methicillin-resistant *S. aureus* and *E. faecium* and *E. faecalis* showing acquired vancomycin resistance in any of the tested samples (trout/water/feed).

The microorganisms that populate freshly caught fish usually reflect the microflora of the water they were in, and the more polluted the water, the more diverse the microflora (Vasemägi, Visse, 2017). Mitiku et al. (2023) found the presence of *Salmonella* in 6% of the analyzed fish, respectively, while Elhadi (2014) found them at the level ranging from 26.6-64% depending on the fish species farmed. *Salmonella* spp. is not a natural microflora of fish, but can infect them through contact with contaminated water, improper farming or improper hygiene practices (Fernandes, 2018; Sheng, Wang, 2021). Differences in the prevalence of *Salmonella* spp. in the above studies may have been due, among other things, to water quality and husbandry practices (feed quality) (Fernandes, 2018; Mitiku, 2023). Providing animals with wholesome feed has a significant environmental impact (creation of greenhouse gases, cause of global warming) throughout the intensive aquaculture supply chain (Sarker, 2023). Poor quality feed used in aquaculture can result in poor fish growth, emerging infectious diseases, and low fish survival rates (Rey et al., 2019). The composition of the analyzed feed is based on high-quality raw materials, which influence the minimization of water contamination. Külahci and Gündoğan (2021) isolated *Enterococcus* spp. in about 22% of the fish samples they analyzed. This was higher than the result obtained in our own study (8.3%). The occurrence of *E. coli* is indicative of faecal origin contamination and represents a public health risk. In an aquaculture system, the source of *E. coli* is mainly surface terrestrial waters where contamination has occurred as a result of human, industrial, or agricultural activities in the area (Rondón-Espinoza et al., 2022). In the present study, *E. coli* counts were consistent with the results obtained by Joseph et al. (2017), who showed contamination with these bacteria in fish culture tanks at a level of <10 cfu/ml. Mitiku et al. (2023) found the presence of *E. coli* in the analyzed fish at the level of 14.4%, while Ayenadis and Aweke (2019) found that 23.3% of the samples were contaminated with *E. coli*, of which 32.5% came from the skin and 8.4% from the muscles of the fish. Higher microbiological contamination of the skin than of the muscles is associated with the fact that the skin has direct contact with the environment and is therefore exposed to contact with various microorganisms (Ayenadis, Aweke, 2019). *S. aureus* does not belong to the natural microflora of fish, and contamination of meat with these bacteria is much more often caused by poor hygiene of staff or fish disease than by the natural environment (Külahci, Gündoğan, 2021). The result obtained in the current studies for *S. aureus* was higher than the results obtained by Mitiku et al. (2023) (4.8%) and Külahci and Gündoğan (2021) (8%). Murugadas et al. (2016) found that 36.5% of the samples were contaminated with *S. aureus*, which was approximately 5% higher than the result obtained by Oniyide et al. (2022). Current studies have also attempted to detect the presence of methicillin-resistant *S. aureus* and *E. faecium* and *E. faecalis* showing acquired resistance to vancomycin. Antibiotics are of great importance in the treatment, control and prevention of diseases in both animals and humans. They are often used prophylactically in aquaculture to eliminate bacterial infections that occur under poor hygienic conditions in the aquatic environment (Tilahun, Engdawork, 2020). Antibiotic residues in food can cause allergies and toxicities that are difficult to diagnose due to lack of knowledge about the source of their consumption (Fernandes et al., 2018). Araújo et al. (2020) based their study on the characterization of the resistance and virulence profile of enterococci isolated from aquaculture dug ponds and masonry tanks in southern Brazil, identified a total of 79 enterococcal strains, of which the most frequently isolated species were *E. faecalis* (44.3%). Kukułowicz et al. (2021) found methicillin-resistant *S. aureus* in 65% of the tested fishery products. Vazquez-Sanchez et al. (2012) detected methicillin-resistant *S. aureus* in ca. 25% of fishery products, of which the largest number of contaminated samples were fresh products (43%). The results of the above studies show that aquatic products may be a reservoir of potentially pathogenic bacteria *S. aureus* and *Enterococcus* spp. with antibiotic resistance. Continuous monitoring of water and feed quality becomes a strategic tool for the proper functioning of aquaculture farms, addressing challenges related to regionalization and semi-globalization. Furthermore, the emphasis on preventing cross-contamination through good farm management practices aligns with the innovation of the regional economy, fostering a resilient and sustainable approach to fish production.

4. Summary and Conclusions

The conducted studies indicate good microbiological quality of rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) from farms located in the enclosure of the “Dolina Słupi” (Slupia Valley) Landscape Park. No significant relationship was found between the degree of contamination of the tested fish and their species. The farming facilities are strategically located in areas that minimize the risk of water pollution, highlighting the importance of risk management in site selection. The aquaculture farm owners from which the research material originated feed their fish with high-quality feed, demonstrating effective quality management practices. The results also indicate the absence of methicillin-resistant *S. aureus* and *E. faecium* and *E. faecalis* showing acquired resistance to vancomycin, reflecting robust health and safety standards. Although Salmonella spp. were detected in the water, no effect of their presence on the degree of contamination of the fish samples was found, underscoring the effectiveness of risk management strategies in preventing cross-contamination. Continuous monitoring of water and feed quality is deemed essential for the proper functioning of aquaculture farms, as inadequate hygiene practices may lead to cross-contamination of fish products. Implementing various preventive measures and good farm management practices can help to prevent or reduce the entry of pathogenic microorganisms into the fish habitat. This, in turn, could increase consumer confidence in farmed fish by demonstrating that aquaculture is a critical component of global sustainability.

In conclusion, this study not only enhances our understanding of the microbiological quality of aquaculture products but also emphasizes the crucial interplay between sustainability, food safety, and regional practices. The findings contribute to the ongoing discourse on sustainable aquaculture, encouraging the adoption of best practices that prioritize both environmental health and the production of safe, high-quality fishery products.

Acknowledgements

The research was financed via the funds allocated to the UMG departments for research activities under project number WZNJ/2024/PZ/01.

References

1. Araújo, A.J.G.D., Grassotti, T.T., Frazzon, A.P.G. (2020). Characterization of *Enterococcus* spp. isolated from a fish farming environment in southern Brazil. *Brazilian Journal of Biology*, *81*, 954-961. doi:10.1590/1519-6984.232503
2. Ayenadis, T., Aweke, E. (2019). Isolation, Identifi cation and antimicrobial susceptibility profi le of *E. coli* (O157:H7) from fish in Lake Hawassa, Southern Ethiopia. *International Journal of Veterinary Science & Technology*, *3*(1), 13-19. doi:10.7537/marslsj170220.10
3. Biegała, Z. (2014). Zrównoważony rozwój akwakultury przyszłością sektora przetwórstwa rybnego. *Rocznik Samorządowy, 3*, 12-25.
4. Brancaccio, M., Mennitti, C., Cesaro, A., Fimiani, F., Vano, M., Gargiulo, B., Caiazza, M., Amodio, F., Coto, I., D'Alicandro et al. (2022). The biological role of vitamins in athletes' muscle, heart and microbiota. *International Journal of Environmental Research and Public Health, 19*(3), 1249. doi:10.3390/ijerph19031249

5. Elhadi, N. (2014). Prevalence and antimicrobial resistance of Salmonella spp. in raw retail frozen imported freshwater fish to Eastern Province of Saudi Arabia. *Asian Pacific Journal of Tropical Biomedicine, 4,* 234-238. doi:10.1016/S2221-1691(14)60237-9
6. Fernandes, D.V.G.S., Castro, V.S., Cunha Neto, A.D., Figueiredo, E.E.D.S. (2018). *Salmonella* spp. in the fish production chain: a review. *Ciência Rural, 48, 8,* e20180141. doi:10.1590/0103-8478cr20180141
7. Firlej, K., Sikorska, D., Wielewska, I., Jeleń, B. (2005). *Rola i miejsce zrównoważonego rozwoju w działalności polskich przedsiębiorstw. Integracja problemów środowiskowych i teorii zrównoważonego rozwoju w systemie zarządzania przedsiębiorstwem*. Białystok: Politechnika Białostocka, Centrum Zrównoważonego Rozwoju i Zarządzania Środowiskiem, 263-269.
8. Forleo, M.B., Palmieri, N. (2023). Environmental Attributes of wild versus farmed tuna: beliefs, knowledge and purchasing choices of Italian consumers of canned tuna. *Sustainability,15(9),* 7149. doi:10.3390/su15097149
9. *HLPE, Sustainable fisheries and aquaculture for food security and nutrition* (2014). A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
10. Joseph, G., Kharnaior, E., Remyakumari, K. (2017). Physicochemical and microbiological quality of aquaculture farms of Chellanam Panchayath, Ernakulam. *International Journal of Fisheries and Aquatic Studies, 5*(5), 428-437.
11. Kowalska, J. (2022). *Spożycie ryb na świecie – jak wypada spożycie ryb w Polsce na tle świata?* https://wiadomoscispozywcze.pl/artykuly/11328/spozycie-ryb-na-swiecie-jak-wypada-spozycie-ryb-w-polsce-na-tle-swiata/, 9.08.2023.
12. Kukułowicz, A., Steinka, I., Siwek, A. (2021). Aquatic products of different processing levels as a source of methicillin-resistant *Staphylococcus aureus*. *Żywność Nauka Technologia Jakość, 28, 3(128),* 55-62. doi:10.15193/zntj/2021/128/388
13. Külahci, M.B., Gündoğan, N. (2021). Occurrence and characteristics of staphylococci and enterococci in retail fish used for human consumption in Turkey. *Avrupa Bilim ve Teknoloji Dergisi, 28*, 911-916.
14. López-Mas, L., Claret, A., Arvisenet, G., del Castillo, R.R., Kallas, Z., Zuccaro, M., Guerrero, L. (2023). European consumers' beliefs about the main pillars of the sustainability: a comparison between wild and farmed Fish. *Aquaculture International*, 1-21. doi:10.1007/s10499-023-01070-2
15. Maik, R. (2017). Jakość produktów w świetle idei zrównoważonego rozwoju. *Marketing i Zarządzanie, 2*(48), 373-385. doi:10.18276/miz.2017.48-34
16. Mishra, S.P., Pradesh, U. (2020). Significance of fish nutrients for human health. International *Journal of Fisheries and Aquatic Research, 5*(3), 47-49.
17. Mitiku, B.A., Mitiku, M.A., Ayalew, G.G., Alemu, H.Y., Geremew, U.M., Wubayehu, M. T. (2023). Microbiological quality assessment of fish origin food along the production chain

in upper Blue Nile watershed, Ethiopia. *Food Science & Nutrition, 11*(2), 1096-1103. doi:10.1002/fsn3.3147

18. Murugadas, V., Toms, C., Joseph, K., Reshmi, K., Lalitha, K.V. (2016). Prevalence of methicillin resistant *Staphylococcus aureus* in selected seafood markets and aquaculture farms in Kerala, south-west coast of India. *Indian Journal of Fisheries, 63*(4), 150-153. doi:10.21077/ijf.2016.63.4.59010-25
19. OECD, F.A.O. (2022). *OECD-FAO agricultural outlook 2022-2031*. https://www.agri-outlook.org/commodities/oecd-fao-agricultural-outlook-fish.pdf, 9.08.2023.
20. Oniyide, T.J, Ogidi, C.O., Akinyele, B.J. (2022). Microbiological quality and organoleptic property of meat and fish preserved with oil from dacryodes edulis seed. *Acta Universitatis Cibiniensis Series E: Food Technology, XXVI(1),* 55-68. doi:10.2478/aucft-2022-0005
21. Pandey, S., Upadhyay, R.K. (2022). Dietary and nutritional value of fish oil, and fermented products. *Journal of Fisheries Science, 4(1),* 26-45. doi:10.30564/jfs.v4i1.4311
22. Pepi, M., Focardi, S. (2021). Antibiotic-resistant bacteria in aquaculture and climate change: a challenge for health in the Mediterranean area. *International Journal of Environmental Research and Public Health, 18*(11), 5723. doi:10.3390/ijerph18115723
23. *Polska na świecie i w UE*. https://www.eumofa.eu/documents/20178/61322/Poland_pl.pdf, 10.08.2023.
24. Rey, S., Little, D.C., Ellis, M.A. (2019). Farmed fish welfare practices: salmon farming as a case study. *GAA publications*.
25. Rondón-Espinoza, J., Gavidia, C.M., González, R., Ramos, D. (2022). Water quality and microbiological contamination across the fish marketing chain: a case study in the Peruvian Amazon (Lagoon Yarinacocha). *Water*, *14*(9), 1465. doi:10.3390/w14091465
26. Rozporządzenie Ministra Zdrowia z dnia 17 stycznia 2019 r. w sprawie nadzoru nad jakością wody w kąpielisku i miejscu okazjonalnie wykorzystywanym do kąpieli (Dz.U. z 2019 r., poz. 255). https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190000255
27. Sarker, P.K. (2023). Microorganisms in Fish Feeds, Technological innovations, and key strategies for sustainable aquaculture. *Microorganisms*, *11*(2), 439. doi:10.3390/microorganisms11020439
28. Sheng, L., Wang, L. (2021). The microbial safety of fish and fish products: Recent advances in understanding its significance, contamination sources, and control strategies. *Comprehensive Reviews in Food Science and Food Safety*, 20, 738-786. doi:10.1111/1541-4337.12671
29. *Sustainable seafood: discover the eco-friendly benefits of fish farming* (2023), https://www.kohinoorrope.com/sustainable-seafood-discover-the-eco-friendly-benefits-of-fish-farming/, 21.08.2023.
30. *The State of World Fisheries and Aquaculture* (2022). https://reliefweb.int/report/world/state-world-fisheries-and-aquaculture-2022-enarruzh, 9.08.2023.

31. Tilahun, A., Engdawork, A. (2020). Isolation, identification and antimicrobial susceptibility profile of E. coli (O157: H7) from fish in lake Hawassa, southern Ethiopia. *Life Science Journal, 17,* 64-72. doi:10.7537/marslsj170220.10
32. Vasemägi, A., Visse, M., Kisand, V. (2017). Effect of environmental factors and an emerging parasitic disease on gut microbiome of wild salmonid fish. *MSphere, 2*(6), e00418-17. doi:10.1128/msphere.00418-17
33. Vázquez-Sánchez, D., López-Cabo, M., Saá-Ibusquiza, P., Rodríguez-Herrera, J.J. (2012). Incidence and characterization of *Staphylococcus aureus* in fishery products marketed in Galicia (Northwest Spain). *International Journal of Food Microbiology, 157*(2), 286-296.