Ciencia Latina Revista Científica Multidisciplinar, Ciudad de México, México.
ISSN 2707-2207 / ISSN 2707-2215 (en línea), mayo-junio 2026,
Volumen 10, Número 3.

https://doi.org/10.37811/cl_rcm.v10i3

FISHERY PRODUCTS, NUTRITIONAL VALUE, EMERGING MICROBIOLOGICAL RISKS, AND CHALLENGES IN FOOD SAFETY: A LITERATURE REVIEW

PRODUCTOS PESQUEROS, VALOR NUTRICIONAL, RIESGOS MICROBIOLÓGICOS EMERGENTES Y DESAFÍOS EN LA SEGURIDAD ALIMENTARIA: UNA REVISIÓN DE LA LITERATURA

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DOI: https://doi.org/10.37811/cl_rcm.v10i3.24181

Fishery Products, Nutritional Value, Emerging Microbiological Risks, and Challenges in Food Safety: A Literature Review

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ABSTRACT

Fishery products represent a key source of essential nutrients and play a strategic role in global food security, particularly in the context of increasing demand and the rapid expansion of aquaculture. This review provides an integrated analysis of fish nutritional composition and the main challenges related to food safety, with emphasis on emerging microbiological risks under current environmental changes. Fish muscle is characterised by a high content of proteins of high biological value, long-chain omega-3 polyunsaturated fatty acids (EPA and DHA), and essential micronutrients with high bioavailability. However, these properties also increase susceptibility to microbiological and oxidative spoilage, posing challenges for preservation and safety. Along the supply chain, fishery products are exposed to multiple contamination sources, including environmental chemicals and microorganisms from aquatic ecosystems and processing environments. Intrinsic factors such as pH and water activity, together with extrinsic conditions like temperature and handling, significantly influence microbial growth. Emerging pathogens such as *Vibrio* spp., alongside persistent pathogens including *Listeria monocytogenes* and opportunistic species such as *Aeromonas* spp., are of increasing concern. Additionally, antimicrobial resistance in aquatic environments represents a critical public health issue, highlighting the need for integrated control strategies based on surveillance and advanced monitoring tools.

Keywords: fishery products, food safety, emerging pathogens, nutritional value, aquaculture

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Productos Pesqueros, Valor Nutricional, Riesgos Microbiológicos Emergentes y Desafíos en la Seguridad Alimentaria: Una Revisión de la Literatura

RESUMEN

Los productos pesqueros representan una fuente clave de nutrientes esenciales y desempeñan un papel estratégico en la seguridad alimentaria mundial, especialmente en el contexto de la creciente demanda y la rápida expansión de la acuicultura. Esta revisión ofrece un análisis integral de la composición nutricional del pescado y los principales desafíos relacionados con la inocuidad alimentaria, con énfasis en los riesgos microbiológicos emergentes en el marco de los cambios ambientales actuales. El músculo de pescado se caracteriza por un alto contenido de proteínas de alto valor biológico, ácidos grasos poliinsaturados omega-3 de cadena larga (EPA y DHA) y micronutrientes esenciales con alta biodisponibilidad. Sin embargo, estas propiedades también aumentan la susceptibilidad al deterioro microbiológico y oxidativo, lo que plantea desafíos para la conservación y la inocuidad. A lo largo de la cadena de suministro, los productos pesqueros están expuestos a múltiples fuentes de contaminación, incluyendo sustancias químicas ambientales y microorganismos de los ecosistemas acuáticos y los entornos de procesamiento. Factores intrínsecos como el pH y la actividad del agua, junto con condiciones extrínsecas como la temperatura y la manipulación, influyen significativamente en el crecimiento microbiano. Los patógenos emergentes como Vibrio spp., junto con patógenos persistentes como Listeria monocytogenes y especies oportunistas como Aeromonas spp., son motivo de creciente preocupación. Además, la resistencia a los antimicrobianos en ambientes acuáticos representa un problema crítico de salud pública, lo que subraya la necesidad de estrategias de control integradas basadas en la vigilancia y herramientas de monitoreo avanzadas.

Palabras clave: productos pesqueros, inocuidad alimentaria, patógenos emergentes, valor nutricional, acuicultura

Artículo recibido 25 marzo 2026
Aceptado para publicación: 25 abril 2026

INTRODUCTION

Fishery products constitute a strategic component of global food security; however, their growing relevance is not only driven by their nutritional value but also by profound transformations in food production and consumption systems at a global scale. In 2016, approximately 35% of fishery production was destined for international trade, and by 2022, total production reached 223.2 million tonnes, with aquaculture increasingly dominating as the primary source of aquatic foods for human consumption (FAO, 2018). This structural shift reflects not only an increase in supply but also a transition towards more intensified food systems, with direct implications for the quality, sustainability, and safety of fishery products.

The sustained increase in per capita consumption from 9.1 kg in 1961 to 20.7 kg in 2021, together with projections of continued growth, highlights a reconfiguration of consumption patterns, in which foods are valued not only for their energy contribution but also for their functional benefits (FAO, 2024). In this context, fishery products stand out due to their content of high biological value proteins and long-chain omega-3 polyunsaturated fatty acids (EPA and DHA), which are associated with cardioprotective and anti-inflammatory effects (Calder, 2017; Golden et al., 2021; Hicks et al., 2019). Nevertheless, increasing demand and the diversification of production systems raise concerns regarding the consistency of their nutritional quality and the implications associated with their intensification.

Concurrently, the high perishability of fish and the expansion of globalised supply chains have increased the complexity of handling and preservation, generating new challenges in terms of sanitary control (Mao & Lu, 2023). Within this scenario, anthropogenic environmental factors, particularly climate change, have altered the dynamics of aquatic ecosystems, favouring the proliferation of emerging pathogens and the dissemination of antimicrobial resistance. The geographical expansion of bacteria of the genus *Vibrio* into previously non-endemic regions, together with the role of aquatic systems as reservoirs of resistance genes, evidences a reconfiguration of microbiological risk in fishery products (Baker-Austin et al., 2018; Cabello et al., 2016; Trinanes & Martinez-Urtaza, 2021).

Furthermore, the quality of water used in food production and processing has emerged as a critical determinant of safety, particularly in intensive aquaculture systems, where the interaction between environmental variables and production practices may amplify health risks (FAO, 2018).

In the European context, the increasing relevance of *Vibrio* as an emerging risk reinforces the need to reassess traditional approaches to food safety evaluation (ECDC-EFSA, 2023).

Despite the extensive literature available on fishery production, nutritional value, and microbiological risks, these aspects have often been addressed in a fragmented manner. This limitation is particularly critical in the context of global environmental change, where the interaction between production, nutritional, and sanitary factors becomes increasingly complex. Consequently, there is a need to adopt integrative approaches that enable a holistic understanding of the challenges associated with fishery products.

Within this framework, the present review aims to provide an integrated analysis of current production trends, the nutritional value of fishery products, and emerging challenges in food safety, with particular emphasis on microbiological risks and their potential impact on public health.

METHODOLOGY

The present study was conducted under a qualitative approach, with a descriptive, documentary design based on a literature review, aimed at providing a comprehensive analysis of the available scientific evidence on fishery products, their nutritional value, emerging microbiological risks, and the challenges associated with food safety in the current context.

The study population consisted of scientific articles published in English and Spanish, primarily between 2015 and 2025, retrieved from high-impact indexed databases, including Web of Science, Scopus, PubMed, and ScienceDirect, complemented by Google Scholar. Priority was given to recent publications from indexed journals in order to ensure the quality, relevance, and timeliness of the information.

The search strategy employed terms such as: “fishery products”, “seafood safety”, “foodborne pathogens”, “*Vibrio* spp.”, “*Listeria monocytogenes*”, “*Aeromonas* spp.”, “antimicrobial resistance”, and “aquaculture”, as well as their Spanish equivalents. These terms were combined using Boolean operators (AND, OR) to optimise the retrieval of relevant information.

Inclusion criteria

- Original research articles and review papers published in English or Spanish.
- Publications between 2015 and 2025.

- Studies with full-text availability.
- Research indexed in recognised databases (Web of Science, Scopus, PubMed, SciELO, ScienceDirect).
- Studies with direct thematic relevance to the microbiology of fishery products, food safety, emerging pathogens, or antimicrobial resistance.

Exclusion criteria

- Publications outside the established time frame.
- Documents without full-text access.
- Conference abstracts, letters to the editor, or opinion pieces lacking methodological support.
- Studies not directly addressing the core themes of the review.

The selection of studies was carried out through purposive (criterion-based) sampling, prioritising scientific relevance, methodological quality, and contribution to the research topic. Subsequently, the selected articles were critically analysed and organised into thematic categories, allowing for an integrative synthesis of the evidence.

For data management and organisation, bibliographic management tools (EndNote) were used, facilitating the storage, classification, and citation of the consulted sources.

Ethical considerations

This study was based on the review of scientific literature, adhering to the principles of academic integrity, proper citation of sources, and plagiarism prevention. No human or animal subjects were involved; therefore, ethical committee approval was not required.

Limitations

Among the main limitations is the potential exclusion of non-indexed literature and the methodological heterogeneity of the analysed studies, which may affect the comparability of results. Nevertheless, high-quality scientific evidence was prioritised to strengthen the validity of the analysis.

RESULTS

Nutritional Composition and Food Safety Considerations of Fishery Products

In the context of the sustained growth of aquaculture production and the global consumption of fishery products described previously, it is essential to understand the composition of fish muscle not only from a nutritional perspective, but also as a determining factor in its stability, quality, and safety throughout the supply chain.

Fish, defined as the muscle tissue of fish intended for human consumption, exhibits a highly variable chemical composition influenced by biological factors (species, age, sex), environmental factors (habitat, temperature, seasonality), and production-related factors (farming systems and feeding practices) (Fernandes, 2009; Fitri et al., 2022; Mohamed & El Lahamy, 2020). This variability is particularly relevant in the current context of aquaculture expansion, where production conditions may significantly alter the nutritional profile of the final product.

From a compositional standpoint, fish muscle is characterised by a high content of proteins of high biological value, with a complete profile of essential amino acids, as well as by the presence of non-protein nitrogenous compounds that contribute to its sensory and technological properties. In contrast, the carbohydrate fraction is virtually absent, distinguishing this food matrix from other terrestrial protein sources (Noreen et al., 2025).

Lipid content shows marked interspecific variability, ranging from lean species (<1%) to fatty species (>20%), which directly impacts nutritional quality. In particular, fish represents one of the main dietary sources of long-chain omega-3 polyunsaturated fatty acids (LC-PUFAs), notably EPA and DHA (Omidvar et al., 2024; Selamoglu & Naeem, 2023). These compounds play a central role in the prevention of cardiovascular diseases, modulation of inflammatory responses, and neurological development, which explains their increasing prominence in global nutritional recommendations (Calder, 2018).

Table 1 presents the average composition of various fish species as a percentage of the edible portion, together with the grams of omega-3 per 100 g of fillet. This variability has been widely documented in recent studies assessing the proximate composition and nutritional quality of fish (Mao & Lu, 2023).

Table 1. Average composition of selected fish species as a percentage of the edible portion and omega-3 content (g/100 g of fillet)

Species	Moisture (%)	Protein (%)	Fat (%)	Minerals (%)	Omega-3 (g/100 g)
Salmon	66	20	14	1	0.79
Tuna	62	22	16	1.1	2.33
Cod	82	17	0.64	1.2	0.23

Source: (Omidvar et al., 2024)

Table 2 shows the average composition of fish muscle.

Component	Typical Range (%)	Description	Reference
Moisture	60–80	Predominantly water; it influences texture and preservation.	(Mohamed & El Lahamy, 2020)
Proteins	16–24	High biological value proteins, essential for human nutrition	(Mohamed & El Lahamy, 2020)
Total lipids	0.5–20+	Depends on species, diet, and habitat; source of omega-3 fatty acids	(Mao & Lu, 2023; Omidvar et al., 2024)
Ash	1.0–2.5	Total minerals present in the muscle.	(Fitri et al., 2022; Mohamed & El Lahamy, 2020)
Carbohydrates	~0	Virtually absent in fish flesh.	(Mao & Lu, 2023; Mohamed & El Lahamy, 2020)
Omega-3 fatty acids ω-3 (EPA + DHA)	0.5–3.0*	Bioactive compounds mainly present in marine species.	(Omidvar et al., 2024; Selamoglu & Naeem, 2023)

*Approximate values; may vary depending on species and analytical method

Additionally, fish muscle provides a wide range of essential micronutrients, including minerals such as iron, phosphorus, selenium, and iodine, as well as fat-soluble vitamins (A, D, E, and K) and B-complex vitamins. The high bioavailability of these nutrients reinforces the role of fish as a functional food within the context of healthy diets (Kandyliari et al., 2020; Selamoglu & Naeem, 2023; Toppe et al., 2007).

However, these same compositional characteristics, particularly their high water content and unsaturated lipids, also render fish highly susceptible to microbiological and oxidative spoilage. In this regard, muscle composition not only determines its nutritional value but also its stability and associated health risks.

Micronutrients present in fish muscle not only provide nutritional value but also actively participate in key metabolic processes through synergistic interactions. Table 3 summarises the biological functionality of minerals and vitamins, emphasising their role as enzymatic cofactors, metabolic modulators, and essential components of antioxidant systems. This integrative perspective allows for a better understanding of how these compounds contribute to physiological homeostasis and reinforces the relevance of fish as a nutrient-dense food matrix (Kandyliari et al., 2020; Selamoglu & Naeem, 2023).

Table 3. Functionality and Synergy of Micronutrients in Fish Muscle

Category	Key Nutrient	Biological Function / Metabolic Impact	Reference
Minerals	Selenium (Se)	Cofactor of glutathione peroxidase; protection against oxidative stress	(Kandyliari et al., 2020)
	Iodine (I)	Precursor of thyroid hormones (T3 and T4); metabolic regulation	(Toppe et al., 2007)
	Iron (Fe)	Present as haem iron with high bioavailability for haematopoiesis	(FAO, 2024)
Vitamins	Vitamin D	Calcium homeostasis and maintenance of bone integrity	(Selamoglu & Naeem, 2023)
	Vitamin E	Lipophilic antioxidant that prevents peroxidation of long-chain polyunsaturated fatty acids (LC-PUFAs).	(Calder, 2017)
	B-complex	Essential coenzymes in cellular oxidative metabolism (B1, B2, B3)	(Kandyliari et al., 2020)

Sources and mechanisms of contamination along the fishery products supply chain

In the context of increasingly extensive and globalised supply chains, fishery products are exposed to multiple sources of contamination that may compromise their safety. Contamination is defined as the presence of biological, chemical, or physical agents at levels capable of affecting food safety or quality (FAO, 2024).

Aquatic ecosystems act as recipients of contaminants of anthropogenic origin, including heavy metals, microplastics, and persistent organic pollutants (POPs), which may bioaccumulate along the trophic chain (Forster et al., 2023). This phenomenon is particularly relevant in high-trophic-level species, where the risk of exposure for consumers is increased.

From a microbiological perspective, the microbial load of fishery products results from a complex interaction between environmental and operational factors. Two main sources of contamination can be distinguished:

Primary sources, associated with the aquatic environment and the organism itself;

Secondary sources, linked to processing stages, include ice, surfaces, equipment, and food handlers (Soon et al., 2021).

Microbial growth is regulated by intrinsic factors of the muscle, such as pH, water activity (aw), and redox potential, as well as by extrinsic factors, particularly storage temperature and atmospheric conditions (Ramesh et al., 2023).

Although the internal muscle of fish is sterile under physiological conditions, external surfaces harbour a diverse microbiota that reflects the conditions of the aquatic environment. The final microbial load depends on variables such as geographical location, seasonality, capture method, and the efficiency of the post-harvest cold chain (Bondad-Reantaso et al., 2023; Selamoglu & Naeem, 2023).

Compliance with food safety standards established by international bodies such as the Codex Alimentarius is imperative for the commercialisation of fishery products. As shown in Table 4, limits for heavy metals and pathogens act as the final control barrier against the anthropogenic contamination described. Monitoring these parameters, together with strict control of the intrinsic and extrinsic factors of the muscle, ensures that the high nutritional value of fish is not compromised by chemical or biological risks during processing (Forster et al., 2023; Ramesh et al., 2023).

Table 4. Maximum limits for heavy metals and pathogens

Contaminant	**Maximum Limit (mg/Kg fresh weight)**	**Regulatory Body**	**Reference**
Mercury (Hg)	0.5 - 1.0*	Codex Alimentarius	(193-1995, 1995)
Cadmium (Cd)	0.05 - 0.25	EFSA / Codex	(2023/915, 2023)
Lead (Pb)	0.3	Codex Alimentarius	(193-1995, 1995)
Salmonella spp.	Absences in 25 g	ICMSF / Codex	(21-1997, 1997; FDA, 2011)
Histamine	< 100 - 200**	FDA / EFSA	(Food & Administration, 2011)

Note: *The limit of 1.0 mg/Kg applies to large predatory species (e.g., shark and swordfish).
**Histamine is a critical indicator of spoilage in scombroid species (e.g., tuna).

Emerging Pathogens and Antimicrobial Resistance

Fishery products may harbour a wide diversity of microorganisms; however, in recent years, increasing attention has been directed towards bacterial pathogens whose public health relevance has intensified as a consequence of climate change, globalised trade, and the rise of antimicrobial resistance (AMR). Unlike pathogens associated with terrestrial foods, many microorganisms present in marine products are native to aquatic ecosystems; therefore, their abundance, distribution, and pathogenic potential are closely dependent on environmental variables, particularly temperature and salinity, which are currently being altered by climate change (Baker-Austin et al., 2018; FAO-WHO, 2019; Trinanes & Martinez-Urtaza, 2021).

In this context, the genus *Vibrio* represents one of the principal emerging pathogens of public health concern. Species such as *Vibrio parahaemolyticus*, *Vibrio vulnificus*, and *Vibrio cholerae* are frequently associated with fishery products and exhibit high sensitivity to environmental fluctuations. Rising sea surface temperatures have promoted their proliferation and geographical expansion into previously non-endemic regions, thereby increasing the risk of infection associated with the consumption of seafood (Baker-Austin et al., 2018; EFSA, 2024). In addition, an increase in multidrug resistance among *Vibrio* spp. to clinically relevant antimicrobials has been documented, reinforcing their significance as emerging pathogens in aquatic ecosystems.

In contrast, *Listeria monocytogenes* represents a predominantly post-harvest risk due to its ability to persist in industrial environments, form biofilms, and adapt to refrigeration conditions. These characteristics favour its persistence in processing facilities and explain its recurrence in ready-to-eat fishery products. The identification of persistent clonal lineages of *Listeria monocytogenes*, such as sequence type ST155 (serogroup IIa), implicated in prolonged outbreaks in Europe, highlights the critical role of genomic surveillance in tracking the persistence and dissemination of this pathogen within the food chain (ECDC-EFSA, 2023; Kandyliari et al., 2020).

The genus *Aeromonas,* in turn, has emerged as a relevant opportunistic pathogen in fishery products and aquaculture systems. Its importance lies in its frequent isolation from fresh fish and its capacity to express virulence factors, form biofilms, and develop resistance to multiple antimicrobials.

Species such as *Aeromonas hydrophila*, *Aeromonas caviae*, and *Aeromonas veronii* have been widely recognised for their pathogenic potential in humans (Fernández-Bravo & Figueras, 2020). Unlike *Vibrio* and *Listeria*, *Aeromonas* spp. occupies an intermediate position within the production chain, being associated with both aquatic ecosystems and intensive production systems.

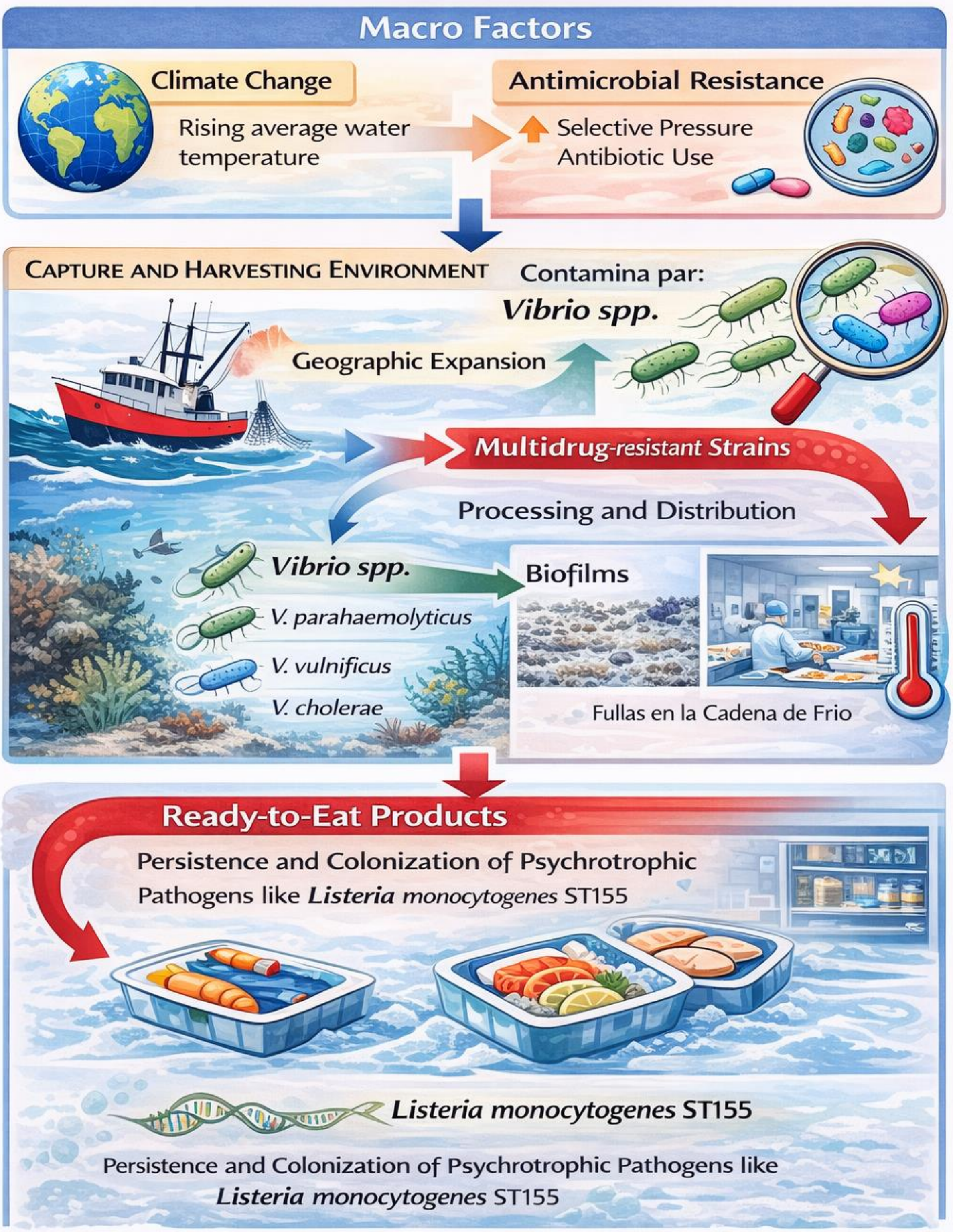
In this scenario, antimicrobial resistance acts as a cross-cutting factor that amplifies the complexity of microbiological risk in fishery products. Selective pressure resulting from the use of antimicrobials in aquaculture, together with the discharge of anthropogenic effluents, promotes the emergence and dissemination of multidrug-resistant bacteria in aquatic ecosystems. These environments function as reservoirs of resistance genes, facilitating horizontal gene transfer and limiting available therapeutic options (Cabello et al., 2016; EFSA, 2024).

Overall, the evidence indicates that microbiological risks in fishery products exhibit a differentiated epidemiological organisation, involving environmental, industrial, and anthropogenic factors. While *Vibrio* spp. is primarily associated with pre-harvest conditions influenced by the environment, *Listeria monocytogenes* predominates in post-harvest stages due to its persistence in processing environments, and *Aeromonas* spp. occupies an intermediate position linked to both aquatic environments and intensive aquaculture. The convergence of these pathogens, together with AMR, underscores the need to implement integrated surveillance strategies that include environmental monitoring, genomic sequencing, and predictive risk models.

The risk analysis presented in Figure 1 highlights a dichotomy in the food safety of fishery products: while the risk posed by *Vibrio* spp. is strongly influenced by pre-harvest and environmental factors (climate change), the threat from *L. monocytogenes* is predominantly post-harvest, linked to genomic persistence in industrial settings.

The convergence of antibiotic multiresistance in both genera complicates the clinical outlook, requiring a shift from conventional surveillance methods towards genomic sequencing approaches and predictive environmental monitoring.

Figure 1. Integrated risk framework for emerging pathogens in the fishery product **value chain**



Knowledge Gaps, Challenges and Future Research Directions

Fishery products are positioned at the intersection of nutrition, food safety, and environmental change; however, the available knowledge remains fragmented. The lack of integrative approaches limits understanding of how environmental conditions, production intensification, and post-harvest handling jointly influence nutritional quality and health risks.

One of the main knowledge gaps concerns the impact of climate change on aquatic pathogens. Although the expansion of *Vibrio* spp. has been documented, uncertainty persists regarding the influence of variables such as temperature and salinity on their dynamics, hindering the development of reliable predictive models.

Similarly, antimicrobial resistance in aquatic ecosystems represents a critical challenge. While aquaculture is recognised as a potential reservoir of resistance genes, the mechanisms underlying their persistence and transfer are not yet fully understood, requiring multidisciplinary approaches within the "One Health" framework.

From a nutritional perspective, further research is needed to better understand how production systems affect the biochemical composition of fish. Variability in fatty acids and micronutrients raises questions regarding the consistency of the health benefits associated with fish consumption.

In this context, future research should focus on the development of integrated predictive models, the application of omics-based tools for pathogen detection and antimicrobial resistance characterisation, and the implementation of innovative preservation technologies.

CONCLUSIONS

The evidence reviewed demonstrates that microbiological hazards in fishery products arise from a dynamic interaction between environmental conditions, production practices, and post-harvest handling. Emerging pathogens such as *Vibrio* spp., whose proliferation is closely linked to climate change and ocean warming, coexist with persistent contaminants such as *Listeria monocytogenes*, associated with processing environments and ready-to-eat products, and opportunistic bacteria such as *Aeromonas* spp., which occupy an intermediate ecological niche between aquatic systems and aquaculture.

In addition, antimicrobial resistance represents a critical cross-cutting challenge, as aquatic ecosystems act as reservoirs and transmission pathways for resistance genes, complicating risk management and therapeutic interventions. Addressing these challenges requires moving beyond conventional, fragmented approaches toward integrated and preventive strategies. Strengthening environmental monitoring, ensuring strict hygienic practices, maintaining cold-chain integrity, and incorporating advanced tools such as genomic surveillance and predictive modeling are essential to mitigate risks effectively and sustainably. Ultimately, ensuring the safety and quality of fishery products demands a systemic perspective under the One Health framework, integrating environmental sustainability, food safety, and public health to support resilient and safe aquatic food systems globally.

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