Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 30(2): 3981 – 3999 (2026)
www.ejabf.journals.ekb.eg

A Review of Biopreservation in Fish and Seafood by Lactic Acid Bacteria

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ARTICLE INFO
Article History:
Received: Jan. 10, 2026
Accepted: April 13, 2026
Online: April 30, 2026

Keywords:
Biofermentation,
Biopreservation,
Lactic acid bacteria,
Marine,
Peptides,
Sustainability

ABSTRACT
This study aims to review and analyze studies on the role of lactic acid bacteria in biopreservation to extend shelf life and to enhance the safety of seafood and fish products. This review focuses on the biological classification and functional difference of lactic acid bacteria strains and mechanisms of inhibiting bacteria, such as bacteriocins, complementary compounds, and production of organic acids. It also reviews practical applications in different marine products (cooked, chilled, and fermented), and highlights the resulting sensory and microbial benefits. This review explains the actual challenges facing the commercial use of lactic acid bacteria, such as the induced antimicrobial spectrum, sensitivity of the environment, differences between breeds, and consumer behavior. The present review provides a multidimensional comparison between biopreservation techniques and traditional methods (such as chemicals, drying, and refrigeration), and explains the significant efficiency of lactic acid bacteria, their effect on the environment, and acceptance of societal. The review concludes with a future vision for the development of genetically modified starter crops and their integration with smart packaging within food security and circular economy systems.

INTRODUCTION

Seafood and fish are a highly valuable food source, since they contain excellent minerals, fatty acids, vitamins, and proteins **(Noreen *et al*., 2025)**. Additonally, they contain a beneficial medium for the growth of microorganisms, which causes spoilage during production and circulation **(Onyeaka & Nwabor, 2022)**. The availability of different preservation techniques, such as smoking, salting, drying, freezing, refrigeration, irradiation, and the use of preservatives, many of them suffer from limitations related to efficiency, cost, or a negative effect on organoleptic properties. The chemicals have also raised health and environmental concerns, prompting manufacturers and researchers to look for safe and natural alternatives **(Rathod *et al*., 2021)**.

Lactic acid bacteria (LAB), characterized by the ability to inhibit spoilage organisms during the production of organic acids and bacteriocins with improvement of organoleptic properties during production of volatile compounds and desirable flavors, offer a promising biological strategy for inhibiting spoilage and pathogenic microorganisms **(Cortés-Sánchez *et al*., 2024b; Fabián *et al*., 2025)**. The Food and Drug Administration classified LAB as food-safe organisms (GRAS), with the possibility of genetically modifying them to enhance their effectiveness using modern technology such as CRISPR **(Wu *et al*., 2021)**.

This study seeks to review and analyze studies on the role of lactic acid bacteria in the biopreservation to extend shelf life and to enhance the safety of products of seafood and fish by reviewing the biosynthesis, mechanisms of microbial inhibition, industrial applications, challenges, and future opportunities within sustainable food security systems.

1. Biological Classification and Types of Lactic Acid Bacteria

1.1 Lactic Acid Bacteria's Current Taxonomy and Genetic Development

Enterococcus, Carnobacterium, Streptococcus, Pediococcus, Leuconostoc, Lactococcus, and *Lactobacillus* represent the genera in the LAB. Lactic Acid Bacteria are classified under the Bacillota phylum, Bacilli class, and Lactobacillales order **(Panda, *et al*., 2022; Rama, *et al*., 2024)**. Most *Lactobacillus* species have also been assigned to other genera, such as *Limosilactobacillus* and others within the order Lactobacillales, in consideration of their exclusive genetic and functional properties, according to recent genomic studies **(Zheng *et al*., 2020)**. Other potential species in these genera, unlike *Lactobacillus*, include *Weissella* and *Tetragenococcus*, which have a higher ability to grow under high saline or low-temperature conditions, making them suitable for use in biopreservation applied in fermented and aquatics products (**Fusco *et al*., 2023; Zhang, *et al*., 2023)**. Other species, such as *Lactiplantibacillus plantarum*, *Pediococcus acidilactici*, and *Carnobacterium divergens*, are well known to produce antimicrobial compounds such as plantaricin and pediocin. In addition, they have long demonstrated the potential to resist challenging conditions in the environment **(Garcia-Gonzalez *et al*., 2022; Zhang *et al*., 2023; Nguyen *et al*., 2024; Bhattacharya *et al*., 2025)**, with high genetic diversity observed, especially in genes responsible for biocompound production and tolerance to saline or cold storage environments.

Recent genomic insight into LAB showed functional traits, including the production of bacteriocin and environmental resilience, which can support the classification of LAB as biotechnologically valuable strains. These functional properties would enable the development of more targeted and sustainable conservation strategies independent of conventional chemicals **(Ibrahim, 2024)**.

1.2 Environmental Sources and Isolation

Lactic acid bacteria are widely distributed in nutrient-rich habitats associated with human hosts, soil, food, plants, and animals **(Miranda *et al*., 2021)**. Also, LAB are naturally present in fermentation plant-based products and gastrointestinal tracts of animals and humans, contributing to gut health and microbial balance **(Akpoghelie *et al*., 2025)**. Moreover, they are also present in aquatic environments, where they play a key role in sustainable aquaculture systems during disease control and probiotic activity **(Figueras *et al*., 2023)**. In terms of preservation applications for seafood and fish, the genera *Tetragenococcus*, *Lactobacillus*, *Carnobacterium* are the most suitable species due to their ability to grow and survive in higher salinity and lower temperature conditions, which are commonly found in stored or fermented marine products **(Čanak *et al*., 2024)**.

1.3 Functional Characteristics, Biological Classification, and Their Role in Biopreservation

Lactic acid bacteria produce important antimicrobial compounds which are peptides that are synthesized by ribosomes and are characterized by a selective impact against spoilage and disease-causing microorganisms. This compound enhances the ability of LAB to biorevitalization, which makes them effective tools in the biopreservation of food products, including products of marine **(Gálvez *et al*., 2021; Cortés-Sánchez *et al*., 2024a)**.

Table 1. Lactic acid-producing species used in the preservation of marine products, with application examples highlighting their functional characteristics.

Lactic acid-producing species	Main use	Examples of associated marine products
Lactobacillus	Production of acids and bacteriocins	Traditional pickling and fermentation of fish
Carnobacterium	Inhibition of spoilage pathogens in chilled fish	Smoked salmon, tilapia fillets
Weissella	Production of compounds that influence sensory properties (flavor and texture)	Marinated or fermented shrimp
Tetragenococcus	High salinity tolerance, bioactivity against fungi and bacteria	Fish sauces, fermented products
Enterococcus	Probiotic activity and inhibition of Gram-positive bacteria	Semi-cooked seafood

1.4 Developments in Genetic Taxonomy

Recent studies in the fields of genomics and Functional Food Science, published between 2020 and 2025, have revealed wide possibilities for the use of several genera of LAB in fish and seafood biopreservation technologies. Apart from their ability to withstand cold and salinity, the *Carnobacterium divergens*, *Pediococcus acidilactici*, and *Lactiplantibacillus plantarum* species showed an enhanced ability to secrete antifungals such as pediocin and plantaricin, making these species useful for fermentation and storage within the marine environment **(Garcia-Gonzalez *et al*., 2022; Zhou *et al*., 2023a; Nguyen *et al*., 2024)**.

An important genetic variation is observed within these genera, which is significantly expressed within genes coding for biocompound synthesis and adaptation to harsh environmental conditions, using whole pangenome and genome studies **(Min *et al*., 2020; Fusco *et al*., 2023)**. The observed findings will help develop a precise and sustainable approach toward the preservation of food using biotechnology, resuling in a less dependence on the traditional use of chemical preservatives **(Elidrissi *et al*., 2023)**.

Table 2. The relationship between species, morphological form, isolation environment, and genetic and functional characteristics.

Species	**Morphological form**	**Isolation environment**	**Genetic and functional characteristics**	**Reference**
Lacticaseibacillus casei	Rod	Dairy, digestive system	Lactic acid production, bacteriocins, high genomic diversity	**Ibrahim (2024)**
Lactiplantibacillus plantarum	Rod	Fermented vegetables, fish	Flexible genome (open pangenome), plantaricin production	**Garcia-Gonzalez *et al*. (2022)**
Weissella cibaria	Short rod	Plants, fermented foods	Modern genetic diversity, production of antimicrobial compounds	**Fusco *et al*. (2023)**
Carnobacterium divergens	Rod	Fish, cold environments	Bacteriocin production, cold resistance	**Nguyen *et al*. (2024)**
Pediococcus acidilactici	Cocci (Tetrads)	Meat, fish	Pediocin synthesis, salt tolerance and heat	**Zhou *et al*. (2023b)**
Enterococcus faecium	Cocci	Human and animal guts	Probiotic/pathogenic strains, flexible genome	**Min *et al.* (2020)**
Leuconostoc spp.	Cocci/ Short rod	vegetables, dairy products	Dextran and bacteriocin production, cold tolerance	**Pujato *et al.* (2024)**

2. Antimicrobial Biomechanics of LAB

Lactic acid bacteria are characterized by their ability to carry out a set of complex biological processes that contribute to prolonging the life of marine products and improve their sensory quality during several function pathways, including the production of organic acids, bacteriocins, and complementary compounds and the modification of the internal environment of the food products **(Sharma *et al*., 2022)**.

2.1 Organic Acid Production and pH Lowering

LAB are characterized by their ability to carry out a set of complex biologically processes that contribute to prolong life of marine products and improve their sensory quality during several function pathways organic acids such as lactic, acetic, and propionic are among the most important vital compounds produced by LAB during fermentation processes, since they contribute to lower the pH to levels unsuitable for growth of spoilage-cause organisms such as *Shewanella putrefaciens, Vibrio* spp. and *Pseudomonas* spp. **(Siqhny & Irfandy, 2024)**.

Undissociated organic acids diffuse across the bacterial membrane. Once inside the cell, the higher intracellular pH environment, they dissociate into protons and anions. This process causes intracellular acidification, disruption of enzyme activity, and collapse of proton motive force. This mechanism also contributes to the improvement of flavor and texture and is one of the most prominent advantages of biopreservation compared to chemical preservatives **(Sorathiya *et al*., 2025)**.

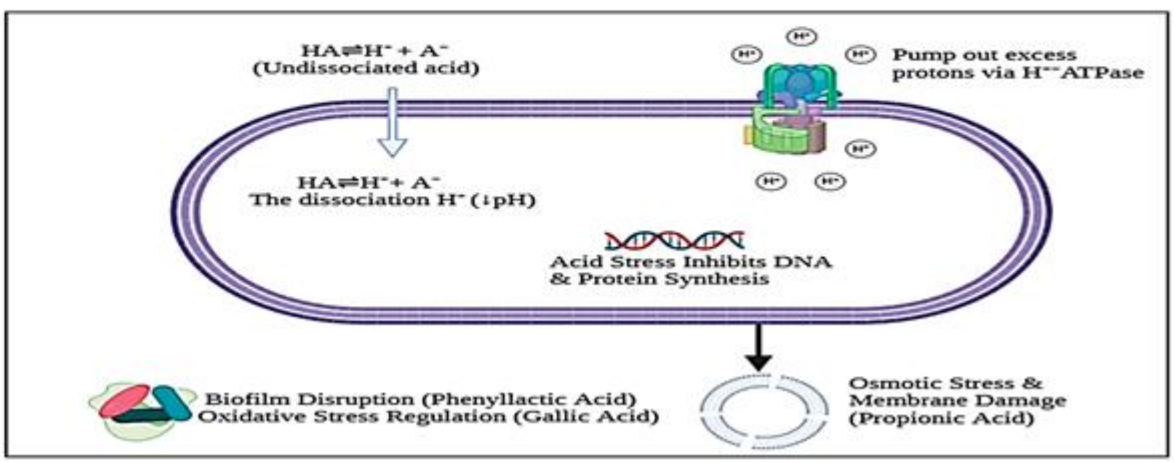

Fig. 1. Action mechanism of organic acid on microbial cells. The undissociated acid form diffuses through the microbial membrane when the intracellular pH is higher than the surrounding environment of the cell. Once inside, the intracellular pH of acid causes cell damage **(Sorathiya *et al*., 2025)**.

2.2 Bacteriocin Production

LAB produces a group of antimicrobial peptides known as bacteriocins, classified into three main categories by molecular weight and manufacturing method:

- Class I: small modified peptides such as nisin and mersacidin, effective against Gram-positive bacteria **(Shrestha & Aryal, 2024)**.

- Class II: unmodified peptides such as pediocin, produced efficiently in food environments **(Baptista *et al*., 2020)**.

- Class III: proteins of large size (>10 KDa), with multiple inhibition mechanisms **(Aguirre-Garcia *et al*., 2024)**.

Bacteriocins act via two main mechanisms:

1- Making holes in the membrane of the target cell, leading to leakage of internal content and cell death.

2- Disruption of cell wall construction by binding to carrier molecules such as Lipid II **(Negash & Tsehai, 2020)**.

Compounds such as nisin and pediocin have shown high efficacy in reducing spoilage organisms in raw fish, without affecting organoleptic properties **(Sharma *et al*., 2022)**.

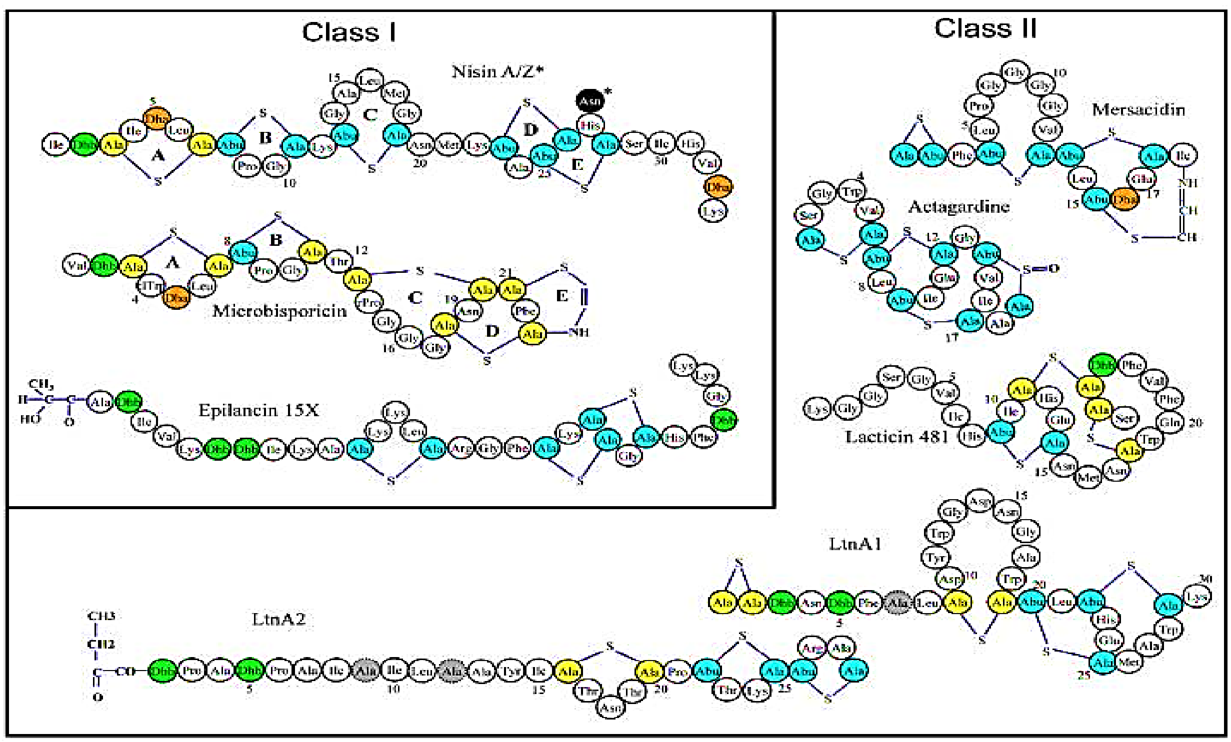

Fig. 2. Structure of class I bacteriocins; Nisin of type A (1) and mersacidin of type B (2) **(Field *et al*., 2015)**

2.3 Complementary Compounds with Antimicrobial Activity

Along with acids and bacteriocins, LAB produce complementary compounds such as hydrogen peroxide (H_2O_2), carbon dioxide, proteolytic and lipolytic enzymes, and volatile compounds such as acetaldehyde and diacetyl. H_2O_2 contributes to the oxidation of sensitive cell components, while carbon dioxide helps create an unsuitable environment for aerobic organisms, especially in modified atmospheric encapsulation (MAP) **(Negash**

& Tsehai, 2020; Gálvez *et al*., 2021). Enzymes such as protease and lipase also reduce spoilage-causing compounds such as biogenic amines, improving the organoleptic and microbial quality of the product **(Sharma *et al*., 2022; Aguirre-Garcia *et al*., 2024)**.

2.4 Inhibiting the Formation of Biogenic Amines and Harmful Volatile Compounds

LAB contribute to reducing the formation of harmful compounds such as histamine, cadaverine, and putrescine, as well as volatile compounds such as ammonia and sulfur, which adversely affect taste and smell. The mechanisms of inhibition are represented by:

- Lowering the pH, which reduces the activity of decarboxylation enzymes **(Cortés-Sánchez *et al*., 2024b)**.
- The production of hydrolyzed enzymes that reduce the availability of substrates necessary for the formation of harmful compounds **(Ma *et al*., 2024)**.
- Direct inhibition of histamine-producing bacteria using bacteriocins and complementary compounds produced by LAB; this process has been demonstrated in fermented seafood systems **(Thuy *et al*., 2024)**.

Practical applications using *Lactiplantibacillus plantarum* and *Carnobacterium divergens* have shown a significant decrease in histamine levels and an improvement in the organoleptic properties of chilled fish **(Negash & Tsehai, 2020)**.

3. Applications of LAB in Fish and Seafood Preservation

LAB are used in several industrial applications aimed at improving the quality and safety of marine products through well-studied microbial and enzymatic inhibition mechanisms. The following are the most prominent of these applications:

3.1 Traditional Fermented Fish

A study on the Suanyu product (fermented carp in China) showed that co-fermentation using *Lactiplantibacillus plantarum* and *Saccharomyces cerevisiae* resulted in a marked decrease in pH and spoilage compounds such as TVB-N and TBA, while improving flavor via an increase in amino acids and aromatic compounds **(Wang *et al*., 2022)**. Another study using HPLC-MS/MS on *Siniperca chuatsi* also revealed the production of 62 flavor-related compounds, of which amino acids such as glutamic and aspartic contributed to the fresh taste, according to the KEGG analysis **(Zhang *et al*., 2022)**. In the Korean gajami-sikhae product, fermentation at 20°C accelerated the production of organic acids and improved organoleptic quality compared to 5°C **(Kim *et al*., 2022** In Iranian fish sauce, the use of starter cultures has improved organoleptic properties and acid balance after 30–45 days of fermentation, particularly with *Lactobacillus plantarum* and *Paenibacillus polymyxa* **(Nazari *et al*., 2021)**. In Asia, strains such as *Tetragenococcus halophilus* have shown efficacy in reducing biogenic amines and improving organoleptic properties in products such as dried shrimp and fish sauce **(Ahn *et al*., 2021)**.

3.2 Raw or Chilled Fish

The *Leuconostoc pseudomesenteroides* strain isolated from the intestines of fresh fish has proven its ability to coexist with other probiotic strains and withstand gastrointestinal conditions, along with its inhibitory activity when applied to fresh fish products **(Sarmah *et al*., 2025)**. The addition of *Carnobacterium divergens* to smoked salmon also contributed to the inhibition of *Listeria monocytogenes* and prolonged shelf life **(Heir *et al*., 2023)**. In another experiment, treating raw tilapia fillets with *Lactobacillus sakei* reduced the number of intestinal bacteria and yeasts during 9 days of storage at 4 °C **(Masoumi *et al*., 2022)**. Some strains have shown efficacy in preserving cooked and chilled shrimp by delaying protein degradation and reducing volatile compounds with an unpleasant odor **(Kontominas *et al*., 2021)**.

3.3 Heat-Treated or Canned Fish

Although research is limited, a study has shown that biopreservation using LAB is an effective strategy in thermally treated or canned fish products, as these strains produce organic acids and bacteriocins that reduce the growth of pathogens such as *Listeria monocytogenes* and *Clostridium botulinum*. This application has contributed to enhancing microbial safety, extending shelf life, preserving the nutritional and organoleptic properties of fish, making it a promising alternative to conventional chemical preservatives **(Courchez-Schimenches *et al*., 2024a)**. Previous studies have also shown the possibility of using LAB as biostimulants before sterilization or within smart packaging layers that release anti-compounds when needed, reducing thermal stress and preserving the nutritional value of marine products **(Cortés-Sánchez *et al*., 2024a)**.

3.4 Application of LAB with Plant Extracts

To increase the effectiveness, LAB is sometimes used in combination with plant extracts possessing antimicrobial activity. In an experiment on fermented tilapia fillets, the combination of *L. plantarum* and turmeric extract or black pepper reduced the growth of *Salmonella enterica* and *Staphylococcus aureus* by more than 90%, while improving the color and flavor **(Ismail *et al*., 2021)**.

4. Challenges and Limitations of Using LAB in Biopreservation

Despite the unique properties of LAB in biopreservation, their commercial application faces several challenges related to the microbial environment, storage conditions, and variation between strains, as well as legislative obstacles and consumer behavior. Table (3) shows the most prominent of these challenges with proposed solutions and scientific support.

Table 3. Prominent challenges and proposed solutions.

Challenges	Scientific or technical reason	Proposed solutions	Scientific support
Poor LAB effectiveness in salty or cold environments	Some strains do not grow well in high salinity or at 4 °C	Use of genera such as *Tetragenococcus* and *Carnobacterium*	**Huang *et al*. (2023)** demonstrated that *Carnobacterium divergens* is effective in inhibiting Listeria in chilled salmon.
			Choudhary *et al*. (2024) discussed the ability of *Tetragenococcus* to adapt to high salinity
Resistance of Gram-negative bacteria to bacteriocins	The presence of a protective outer membrane.	Combining LAB with plant extracts or natural compounds to improve the antibacterial spectrum.	**Cortés-Sánchez *et al*. (2024a)** Recommended combining bacteriocins with natural compounds to enhance the antimicrobial spectrum.
			Conz *et al*. (2024) reported the effectiveness of chitosan and bacteriocins together.
Variability in performance among strains.	Genome variation even within the same species.	Design of customized starter cultures and testing of strains under actual marine product conditions.	**Zheng *et al*. (2020)** reclassified *Lactobacillus* into 23 new genera based on genomic variation.
			Mejía - Caballero *et al*. (2025) discussed the importance of whole-genome analysis for selecting appropriate strains.

Instability of biocomposites during storage	Disintegration of peptides or their interaction with fish lipids	Active packaging, smart packaging, humidity, and temperature control during transportation and storage	**Kerry *et al*. (2020)** and **Zhao *et al.* (2023b)** reviewed smart packaging and active packaging technologies to increase the stability of biocomposites.
Low consumer acceptance of the presence of "live" bacteria.	Concerns about "food safety."	Consumer education and the use of clear labeling.	**Binda *et al*. (2020)** discussed the importance of raising awareness of the concept of probiotics.
			FAO (2022) recommended the inclusion of simplified information on labels to enhance confidence.

4.1 Sensitivity to Environmental and Product Compositional Conditions

The effectiveness of the LAB largely depends on the surrounding environment. The composition of fish meat (high humidity, biodegradable proteins, trans fats) is an ideal environment for the growth of spoilage organisms. Moreover, some species of LAB do not tolerate low temperatures or high salinity, which necessitates the selection of adapted strains such as *Carnobacterium* and *Tetragenococcus* **(Gökoğlu, 2021; Cortés-Sánchez *et al.*, 2024b)**.

4.2 Microbiological Challenges (Resistance of Gram-Negative Bacteria)

Gram-negative bacteria, such as *Vibrio parahaemolyticus* and *Pseudomonas* spp., represent a major challenge, as most bacteriocins target Gram-positive bacteria due to the presence of an outer membrane that blocks the entry of antibody compounds. However, recent studies have shown that combining bacteriocins with plant extracts or natural essential oils can expand the spectrum of their effectiveness, as some formulations have proven effective in inhibiting the growth of spoilage pathogens in marine products **(Thuy *et al*., 2024)**.

4.3 Poor Cohesion Between Strains

LAB strains show great variability in performance due to genetic differences, even within a single species, which affects the production of biocompounds and their adaptability. It is therefore recommended to design custom prefix implants based on whole genome analysis and to test them in application conditions **(Zheng *et al*., 2020; Mejía- Caballero *et al*., 2025)**.

4.4 Impact of Storage and Logistical Conditions

Peptides and bacteriocins are biocompounds that may undergo degradation or interaction with marine lipids during storage, reducing their effectiveness. This can be overcome by using intelligent and active package technologies and humidity and temperature control during transport and storage **(Kerry *et al*., 2020; Mkhari *et al*., 2023)**.

4.5 Legislative Challenges and Consumer Acceptance

Consumer acceptance of the idea of the presence of "live bacteria" in food is a marketing challenge, especially in marine products. International organizations recommend strengthening community education and using simplified explanatory labels to explain the benefits and safety of probiotics **(Binda *et al*., 2020; FAO, 2022)**.

5. Future Prospects for Biopreservation Using LAB

The food business continues to prioritize sustainable, health-promoting, and environmentally friendly solutions in view of the increasing environmental and legal issues. Bacteriocin-producing LAB will play an increasingly important role in contemporary food processing and preservation **(Perez *et al*., 2022)**.

5.1 Genetic Modification and Bioengineering of Strains

Without compromising their nutritional integrity, LAB strains can be altered to produce more bacteriocins or increase their resistance to salinity and cold thanks to technologies like CRISPR. Initial research has demonstrated that these methods are effective in enhancing LAB's characteristics without compromising its environmental equilibrium or sensory qualities **(Zhou *et al*., 2019)**.

5.2 Development of customized co-cultures

Analyses of the entire genome and pangenome have revealed that the strains' capacities to generate biocompounds and adjust to their surroundings vary. Therefore, it is expected that the next stage will witness the design of custom starter implants, selected based on their genetic and functional characteristics, in accordance with the type of marine products and conditions of storage **(An *et al*., 2022; Comunian & Chessa, 2024)**.

5.3 Integration with Smart and Active Packaging

A potential innovation in food preservation is smart packaging, especially for delicate items like seafood. **Kerry *et al*. (2020)** have drawn attention to the possibility of including antimicrobial agents into package layers that react to external stimuli. Concurrently, **Mkhari *et al*. (2023)** showed that bioactive substances may be released as needed by embedding LAB into intelligent package systems. Additionally, **Abdullahi *et***

***al*. (2025)** highlighted that active encapsulation methods minimize the need for heat processing by successfully shielding these compounds from deterioration.

5.4 Sustainability and Reducing Food Loss

By lowering food losses, using fewer chemicals, and increasing cold chain efficiency, LAB bioconservative technologies align with the circular economy's tenets. Additionally, these technologies improve food security, particularly in coastal regions where marine goods are the primary source of food **(FAO, 2022)**.

6. A Comparison of Biopreservation Using LAB with Traditional Preservation Methods in the Food Sector

More specifically, in the current industrial and commercial sector, biopreservation methods using lactic acid bacteria (LAB) are an increasingly promising biological alternative to traditional preservation methods such as refrigeration and chemical preservation. The ability of LAB to produce inhibitory compounds to bacterial pathogens, such as bacteriocins and organic acids, makes it possible to preserve marine products without the use of synthetic chemical preservation and heat treatment **(Gálvez *et al*., 2021; Cortés-Sánchez *et al*., 2024b)**.

There are sustainable overtones in the application of this technology because it consumes less energy compared to the cooling or drying methods **(Chen *et al*., 2022)**. Further, the use of eco-friendly or sustainable approaches to the advancement of customer interests in the acquisition of natural and quality products, especially in the "clean label" product group **(Mintel, 2025)**, supports the sustainability of the proposed technology. To the negative, a possible concern in certain conventional methods might pertain to the modification of the organoleptic or the chemical residues developed in the final product **(Cortés-Sánchez *et al*., 2024a)**. A multi-dimensional difference between the technology of bioconservation through the employment of the proposed method and conventional approaches shall is presented in Table (4).

Table 4. Multidimensional comparison between the use of LAB bacteria and traditional preservation methods.

Preservation Methods	**Characters or the Effects**						**Reference**
	Microbial effectiveness	**Operational cost**	**Environmental impact**	**Consumer acceptance**	**Marketing value**	**Flexibility of use**	
LAB	Multi-target activity against gram-positive and gram-negative bacteria and fungi	Relatively low – no cooling or heat energy required	Very low – no emissions or hazardous waste	High – seen as normal and healthy	High – supported by the “Clean Label” trend and the demand for additive-free products	Blendable with active coatings and natural extracts	**(Cortés-Sánchez *et al*., 2024b; Ibrahim *et al*., 2021)**
Refrigeration and freezing	Temporarily effective – restricts growth without	Medium to high, depending on storage type	High due to continuous energy consumption	Acceptable but does not provide added market value	Moderate – depends on cold chain	Limited – requires a complete cold chain	**(FAO, 2022)**

	preventing it						
Drying	Effective in removing moisture, but may allow oxidation	High in freeze drying and energy saving	Medium to high, depending on the energy source	Uneven - change in flavor and texture	Marketable in dry products only	Not suitable for some wet or greasy products	**(Nowacka *et al.*, 2023)**
Chemical preservatives	Effective but may contribute to worrying microbial resistance	Low in the short term, but may impose a regulatory cost later	High - Chemical residues and limited biodegradability	Low – Concerns related to toxicity or chemical buildup	Low – often used in cheaper products	Limited to narrow contexts and restricted by legislation in some markets	**(Cortés-Sánchez *et al.*, 2024b)**

CONCLUSION

This review emphasizes the critical role that lactic acid bacteria play in the preservation of fish and seafood through efficient processes that enhance the organoleptic qualities of the goods and produce bacteriocins, organic acids, and complementary chemicals. With a multifaceted comparison to conventional conservation techniques, the study addressed the contemporary genetic classification of laboratories, their environmental features, mechanisms of microbial suppression, and various industrial uses.

Proposed solutions include the intergration of unique starter cultures, integration with natural extracts, and clever packaging, open up numerous opportunities for LAB applications in the secure and long-term preservation of marine products, despite the difficulties brought on by genetic variations, resistance to specific microorganisms, and storage sensitivity.

This research recommends the need to strengthen applied studies linking the functional genome of lab strains and actual storage conditions, as well as the development of genetic modification techniques and active packaging, to achieve integration between food safety, environmental sustainability, and market trends toward natural products.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Food Sciences, College of Agriculture, University of Basrah, Basrah, Iraq and the Department of Marine

Vertebrates, Marine Science Center, Basra University, Basra, Iraq, for their support and for providing the necessary tools.

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