



International Journal of Veterinary Sciences and Animal Husbandry



ISSN Online: 2456-2912
NAAS Rating (2026): 4.61
IJVSAH 2026; 11(10): 97-102
www.veterinarypaper.com
Received: 22-08-2026
Accepted: 28-09-2026
Published: 10-10-2026

Tembhurne Meena Charandas

ICAR-Central Institute of
Fisheries Education, Mumbai-
400061I, Maharashtra, India

Vanshita Tandel

College of Fisheries Science,
Kamdhenu University, Veraval,
Gujarat, 3622652, India

Kisun Soren

ICAR-Central Institute of
Fisheries Education, Mumbai-
400061I, Maharashtra, India

Mayur Tandel

College of Fisheries,
Mangalore, KVAFSU, Bidar-
5854013, Karnataka, India

Emerging non-thermal preservation technologies for fish and seafood: Mechanisms, quality effects, safety, sustainability and industrial prospects

Tembhurne Meena Charandas¹, Vanshita Tandel², Kisun Soren³, Mayur Tandel⁴

DOI: <https://www.doi.org/10.22271/veterinary.2026.v11.i10b.3842>

ABSTRACT

Fish and seafood are highly perishable products that rapidly lose quality because of microbial activity, enzymatic reactions, and lipid oxidation. Although conventional preservation methods help extend shelf life, they may negatively affect the nutritional, sensory, and physical properties of seafood. This review examines five emerging non-thermal technologies high-pressure processing (HPP), pulsed electric fields (PEF), cold plasma, ultrasound, and ozone for improving the safety, quality, and shelf life of fish and seafood. Their working principles, preservation effects, applications, benefits, and limitations are discussed. These technologies show considerable potential for maintaining fresh-like quality while minimising heat-related damage. However, challenges related to cost, process optimisation, scale-up, oxidation, and regulatory approval still need to be addressed. Future research should emphasise integrated approaches combining non-thermal technologies with refrigeration, smart packaging, and effective cold-chain management for sustainable and practical seafood preservation.

Keywords: Fish and seafood, Non-thermal preservation, HPP, PEF, Cold plasma, Ultrasound, Ozone, Shelf life

Introduction

Fish and seafood are important parts of the global food system because they contribute to food security, human nutrition, employment, and economic development. Fisheries and aquaculture support a wide range of activities, including harvesting, farming, processing, transportation, distribution, and marketing. These activities provide income and employment to millions of people around the world (Farmery *et al.*, 2021; Mohanty *et al.*, 2019) [1, 2]. Fish and seafood are considered highly nutritious foods because they provide high-quality protein and essential amino acids. They are also important sources of long-chain omega-3 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), along with several vitamins and minerals. Because of this nutrient-rich composition, fish can play an important role in maintaining human health and improving nutritional security (Mohanty *et al.*, 2019) [2]. Fisheries and aquaculture contribute to the seafood industry through several stages, from harvesting and farming to processing, preservation, transportation, and marketing. Therefore, aquaculture is becoming an increasingly important source of seafood for meeting future food and nutritional needs (Béné *et al.*, 2024).

Why does fish deteriorate rapidly?

Fish deteriorates quickly after death because its muscle contains a high amount of moisture and nutrients, while its water activity provides favourable conditions for microbial growth and biochemical reactions. Three major processes are mainly responsible for quality deterioration: microbial activity, enzymatic degradation, and chemical oxidation (Nie *et al.*, 2022) [3].

- **Microbial deterioration:** Microorganisms grow during storage and produce various metabolites that can cause unpleasant odours and flavours, slime formation, discolouration, and other signs of spoilage.
- **Chemical deterioration:** Oxidation of the polyunsaturated fatty acids present in fish can produce undesirable compounds responsible for rancid flavours. These reactions may also affect the colour, texture, and nutritional quality of the product.
- **Enzymatic deterioration:** Naturally occurring enzymes in fish muscle continue to act after death and break down proteins and lipids. This can lead to muscle softening, drip loss, and a gradual decline in freshness (Nie *et al.*, 2022; Speranza *et al.*, 2021) [3, 4].

Corresponding Author:

Tembhurne Meena Charandas

ICAR-Central Institute of
Fisheries Education,
Mumbai-400061I,
Maharashtra, India

Limitations of conventional preservation

Traditional preservation methods such as chilling, freezing, salting, drying, smoking, and heat processing have been widely used to slow deterioration and extend the shelf life of fish products. For example, freezing can result in ice-crystal formation, which may damage muscle structure and cause protein denaturation, drip loss, and changes in texture after thawing (Speranza *et al.*, 2021; Kato *et al.*, 2022) [4].

Why emerging technologies?

The increasing demand for seafood that is safe, nutritious, minimally processed and similar to fresh products has encouraged researchers and the food industry to explore alternative preservation approaches. Non-thermal technologies such as high-pressure processing (HPP), pulsed electric fields (PEF), ultrasound, cold plasma, and pulsed light

have attracted considerable attention because they can help reduce microorganisms and extend shelf life with less exposure to heat. Nevertheless, factors such as high equipment costs, processing requirements, energy consumption, scale-up, and regulatory approval can limit their wider commercial application (Speranza *et al.*, 2021) [4].

Objective of the review

This review examines emerging non-thermal preservation technologies used for fish and seafood, with particular attention to their working mechanisms, effects on product quality and safety, sustainability, industrial applications, current limitations and future prospects.

Conventional vs emerging preservation technologies

Technology	Classification	Primary objective	Key benefit	Main constraint	Reference
Chilling	Conventional, non-thermal	Slow down microbial growth	Simple, practical and widely used	Provides only a limited extension of shelf life	Zhao <i>et al.</i> (2019)
Freezing	Conventional, non-thermal	Slow microbial and enzymatic activity	Allows fish products to be stored for longer periods	Ice-crystal formation can damage muscle structure and affect texture	Zhao <i>et al.</i> (2019)
High-pressure processing (HPP)	Emerging, non-thermal	Reduce pathogenic and spoilage microorganisms	Can retain many characteristics of fresh products	Requires expensive, high-pressure equipment	Rathod <i>et al.</i> (2022)
Pulsed electric fields (PEF)	Emerging, non-thermal	Inactivate microbial cells	Rapid treatment with limited heat generation	Mainly suitable for liquid or pumpable food products	Rathod <i>et al.</i> (2022)
Cold plasma	Emerging, non-thermal	Reduce microorganisms on product surfaces	Effective surface decontamination	Reactive species may promote oxidation under certain conditions	Kulawik <i>et al.</i> (2023)
Ultrasound	Emerging, non-thermal	Control microorganisms and enzyme activity	Can improve mass transfer and support processing efficiency	Effectiveness may decrease when treatment penetration is limited	Zhao <i>et al.</i> (2019)
Ozone	Emerging, non-thermal	Reduce microbial contamination	Decomposes without leaving persistent chemical residues	Excessive exposure may cause undesirable oxidation	Zhao <i>et al.</i> (2019)

High-pressure processing (HPP)

Principle

HPP is a non-thermal preservation method in which seafood is treated with high hydrostatic pressure using water as the pressure medium. It helps reduce microorganisms while retaining nutritional and sensory quality. Typical pressures are 400-600 MPa for microbial inactivation and 200-350 MPa for shellfish shucking (Roobab *et al.*, 2022) [5].

Mechanism

High pressure damages microbial cell membranes, proteins and enzymes, disturbing essential cellular functions and causing microbial inactivation. Its effectiveness depends on pressure, time, temperature and microorganism type (Roobab *et al.*, 2022) [5].

Processing Parameters

HPP generally operates at about 100-600 MPa, with treatment times ranging from seconds to several minutes. Pressure, holding time, temperature, seafood composition and initial microbial load influence its effectiveness (Oliveira *et al.*, 2017) [6].

Effects on Fish Quality

HPP can improve microbial quality and shelf life and reduce spoilage indicators such as TVB-N and TMA-N. However, excessive pressure may cause protein denaturation, whitening, increased hardness, lipid oxidation and reduced water-holding capacity (Kumar *et al.*, 2019; Oliveira *et al.*, 2017; Aubourg, 2018) [8, 6, 7].

Applications in Seafood

HPP is used or investigated for fish fillets, shrimp, salmon, tuna, oysters, lobster, crab, mussels, clams and scallops. It is particularly useful for shellfish shucking, meat recovery and ready-to-eat seafood preservation (Roobab *et al.*, 2022) [5].

Pulsed electric field (PEF)

Principle and Mechanism

Pulsed electric field (PEF) is a promising non-thermal processing technique in which food is exposed to short, high-voltage electrical pulses between two electrodes. At an appropriate treatment intensity, this damage becomes irreversible, causing leakage of cellular components and ultimately microbial inactivation. Because the treatment is extremely rapid, PEF can achieve microbial reduction while minimising prolonged heat exposure (Gómez *et al.*, 2019; Peng *et al.*, 2025) [9, 10].

Processing Parameters and Effects on Fish Quality

PEF performance is influenced by several factors, including electric-field strength, pulse duration, pulse number, frequency, temperature and electrical conductivity of the product. Increasing field strength and pulse exposure generally enhances electroporation, whereas conductivity and temperature affect current flow and heat generation. It may also improve tissue permeability and mass transfer, thereby affecting texture and water-holding capacity. Conversely, excessive treatment intensity or temperature may cause protein denaturation,

lipid oxidation and undesirable changes in colour and texture (Peng *et al.*, 2025) [10].

Applications, Advantages and Limitations

PEF has been explored for fish preservation, microbial control, tenderization, drying, salting, marination, thawing and recovery of valuable compounds from fish-processing by-products. Nevertheless, high equipment costs, uneven electric-field distribution, variations in product conductivity, electrode-related issues, temperature development and difficulties in scaling laboratory systems to industrial production remain important challenges (Gómez *et al.*, 2019; Tomasevic *et al.*, 2025) [9, 11].

Future Directions

Further research should establish species and product-specific processing conditions and develop standardized protocols for PEF treatment. Greater attention is also needed toward long-term storage stability, microbial community changes, protein and lipid oxidation, continuous-flow systems, energy efficiency and techno-economic feasibility. Integration of PEF with HPP, refrigeration, intelligent process monitoring and other hurdle technologies, together with industrial validation and consumer studies, could support its wider application in seafood processing (Peng *et al.*, 2025; Tomasevic *et al.*, 2025) [10, 11].

Cold plasma

Cold plasma is an emerging non-thermal technology that uses a partially ionized gas containing electrons, ions, reactive radicals and excited species. It is often described as the fourth state of matter and can be generated at relatively low bulk temperatures, making it attractive for processing heat-sensitive foods such as fish and seafood (Misra *et al.*, 2019) [12].

Types and Reactive Species

Common plasma-generation systems include atmospheric-pressure plasma, dielectric barrier discharge (DBD), plasma jets and corona discharge. During plasma generation, reactive oxygen species (ROS), reactive nitrogen species (RNS), ozone, hydroxyl radicals and other excited species are formed. These highly reactive compounds play a central role in the antimicrobial action of plasma (Thirumdas *et al.*, 2018) [13].

Antimicrobial Mechanism

The antimicrobial action of cold plasma occurs through several simultaneous reactions. Reactive species first interact with the microbial cell membrane, causing membrane oxidation and loss of integrity. They can subsequently oxidize cellular proteins and enzymes and damage nucleic acids, eventually preventing normal cellular functions and causing microbial death. Thus, the overall process can be represented

as

ROS/RNS → membrane disruption → protein and enzyme damage → DNA damage → microbial inactivation (Gavahian *et al.*, 2021) [14].

Effects on Fish and Applications

Cold plasma has considerable potential for reducing surface micro-organisms and extending the refrigerated shelf life of fish. It has been investigated for surface decontamination, seafood packaging, microbial control and shelf-life extension. However, prolonged or intensive treatment may also accelerate lipid and protein oxidation and produce changes in colour, texture and sensory characteristics.

Advantages, Limitations and Future Directions

The technology offers low-temperature processing, short treatment times, limited water consumption and reduced dependence on chemical preservatives. Its limitations include shallow penetration, non-uniform treatment of irregular fish surfaces, possible oxidative deterioration and challenges in scaling up treatment systems. Future work should concentrate on optimizing plasma conditions, controlling oxidation, developing continuous systems, studying plasma packaging

interactions and evaluating long-term storage performance. Combining cold plasma with refrigeration, HPP and other hurdle technologies may further improve its effectiveness (Misra *et al.*, 2019; Gavahian *et al.*, 2021) [12, 14].

Ultrasound

Principle, Types and Mechanism

Ultrasound (US) is a non-thermal processing approach in which high-frequency sound waves travel through a medium and produce acoustic cavitation. During cavitation, microscopic bubbles form, grow and rapidly collapse, generating localized pressure, temperature and shear forces. These physical effects can disrupt microbial cells and increase tissue permeability. Low-frequency ultrasound generally produces more intense cavitation, whereas high-frequency treatment tends to provide milder effects (Yi *et al.*, 2025).

Processing Parameters and Applications

The performance of ultrasound depends mainly on frequency, acoustic power, intensity, treatment duration and temperature. In fish and other aquatic products, ultrasound has been investigated for microbial decontamination, marination, drying, freezing and thawing, extraction and enhancement of mass transfer. Appropriate treatment conditions can improve processing efficiency and modify tissue structure without excessive quality deterioration (Yi *et al.*, 2025).

Effects, Advantages, Limitations and Future Directions

Properly controlled ultrasound can contribute to microbial reduction and improve mass transfer, texture and processing efficiency. However, excessive acoustic intensity or prolonged exposure may damage tissue structure and increase undesirable oxidation. The main advantages are rapid treatment and improved processing efficiency, whereas limitations include non-uniform energy distribution, equipment and energy requirements and the absence of universally applicable treatment conditions. Future studies should emphasize process standardization, industrial scale-up, energy optimization, storage stability and integration with other preservation methods (Yi *et al.*, 2025).

Ozone technology

Chemistry, Generation and Antimicrobial Mechanism: Ozone (O₃) is a highly reactive oxidizing agent that can decompose and participate in reactions producing reactive oxygen species. It can be generated through corona discharge, ultraviolet radiation and electrochemical processes. Ozone and its reactive products attack microbial cell membranes and can oxidize cellular proteins, enzymes and nucleic acids, thereby disrupt essential cellular functions and cause microbial inactivation.

Application and Effects on Fish: In seafood processing, ozone can be delivered through ozonated water, gaseous ozone, ozonated ice or slurry ice, and direct surface treatment. Its principal benefit is the reduction of microbial contamination, which may contribute to extended refrigerated shelf life. However, the strong oxidative nature of ozone presents an important quality concern. A recent systematic review reported reductions in mesophilic and psychrotrophic bacteria in aquatic products following ozone treatment, although the magnitude of microbial reduction varied considerably between studies (de Arruda *et al.*, 2025) [15]. Similarly, treatment of *Gadus morhua* with gaseous ozone reduced microbial contamination but increased lipid oxidation with longer exposure (Antos *et al.*, 2025) [16].

Advantages, Limitations and Future directions

Ozone offers rapid antimicrobial action and leaves relatively little chemical residue, while also allowing treatment through different application methods. However, its strong oxidative activity can become detrimental to fish quality when treatment is excessive. Important research priorities include determining optimum ozone concentration and exposure time, minimizing lipid and protein oxidation, improving treatment uniformity, evaluating species-specific responses, develop

ing ozonated-ice systems and validating the technology at commercial scale (de Arruda *et al.*, 2025; Antos *et al.*, 2025) [15, 16].

Comparative analysis of the five technologies

HPP, PEF, cold plasma, ultrasound and ozone operate through different preservation mechanisms and vary in treatment intensity and suitability for specific seafood products. Their effectiveness is therefore

Parameter	HPP	PEF	Cold Plasma	Ultrasound	Ozone
Microbial reduction	High (Roobab <i>et al.</i> , 2022)	High (Alkanan <i>et al.</i> , 2024)	High (Rathod <i>et al.</i> , 2021)	Moderate–High (Sireesha <i>et al.</i> , 2022)	High (Russo <i>et al.</i> , 2024)
Processing time	Minutes (Roobab <i>et al.</i> , 2022)	Very short (Alkanan <i>et al.</i> , 2024)	Short (Rathod <i>et al.</i> , 2021)	Short (Sireesha <i>et al.</i> , 2022)	Short (Russo <i>et al.</i> , 2024)
Penetration	Excellent (Roobab <i>et al.</i> , 2022)	Limited (Alkanan <i>et al.</i> , 2024)	Mainly surface (Rathod <i>et al.</i> , 2021)	Limited (Sireesha <i>et al.</i> , 2022)	Mainly surface (Russo <i>et al.</i> , 2024)
Oxidation risk	Moderate (Roobab <i>et al.</i> , 2022)	Low–Moderate (Alkanan <i>et al.</i> , 2024)	Possible (Rathod <i>et al.</i> , 2021)	Dose-dependent (Sireesha <i>et al.</i> , 2022)	Dose-dependent (Russo <i>et al.</i> , 2024)
Nutrient retention	High (Roobab <i>et al.</i> , 2022)	High (Alkanan <i>et al.</i> , 2024)	Generally high (Rathod <i>et al.</i> , 2021)	High (Sireesha <i>et al.</i> , 2022)	Generally high (Russo <i>et al.</i> , 2024)
Industrial scalability	High (Roobab <i>et al.</i> , 2022)	Moderate (Alkanan <i>et al.</i> , 2024)	Emerging (Rathod <i>et al.</i> , 2021)	Moderate (Sireesha <i>et al.</i> , 2022)	Moderate (Russo <i>et al.</i> , 2024)

Combination / hurdle technologies

Hurdle technology means using two or more preservation methods together to control microbial growth and slow down quality deterioration. Instead of depending on one intense treatment, several mild treatments can work together to improve the shelf life and quality of fish and seafood products (Abel *et al.*, 2022; Rathod *et al.*, 2021) [19, 18].

Combination	Application/benefit
HPP + Refrigeration	HPP reduces microorganisms, while refrigeration helps control their growth during storage (Roobab <i>et al.</i> , 2022).
HPP + Natural Preservatives	Pressure treatment together with natural antimicrobial compounds can provide better microbial protection.
PEF + Mild Heat	PEF affects microbial cell membranes, while mild heat further improves microbial inactivation (Abel <i>et al.</i> , 2022).
Cold Plasma + Packaging	Plasma helps reduce microorganisms on the product surface, while packaging protects the product from further contamination.
Ultrasound + Ozone	The two treatments can work through different antimicrobial mechanisms and improve microbial reduction.
Ultrasound + HPP	Combining ultrasound and pressure treatment may improve microbial control without requiring severe processing conditions.
Cold Plasma + MAP	Cold plasma reduces surface contamination, while modified-atmosphere packaging helps slow microbial growth during storage.

Effects on fish quality

The quality of fish treated with non-thermal technologies is influenced by microbial, chemical, nutritional and sensory changes. These treatments can help reduce spoilage and pathogenic microorganisms, but their effectiveness varies with processing conditions, fish species and storage. Freshness is commonly assessed using TVB-N, TMA-N, pH and *K*-value, while peroxide value and TBARS are useful indicators of lipid oxidation. Protein quality may also change during pro-

cessing. This is especially important in fatty fish, as EPA and DHA are prone to oxidation, which can affect both flavour and nutritional value (Ekonomou & Boziaris, 2021; Rathod *et al.*, 2022; Kaur *et al.*, 2018) [20, 18].

Food Safety: Preservation and food safety should be assessed separately. Non-thermal technologies can reduce important seafood hazards such as *Listeria monocytogenes*, *Salmonella*, *Vibrio* spp., *Staphylococcus aureus* and *Clostridium* spp., as well as some parasites where relevant. However, microbial reduction does not necessarily mean complete food safety. Their effectiveness depends on organism resistance, food composition and treatment conditions. Therefore, validated processing, good hygiene, HACCP and appropriate cold-chain management remain essential (Ekonomou *et al.*, 2021; EFSA, 2022) [20, 21].

Sustainability and Environmental Perspective

The sustainability of these technologies should be evaluated through energy and water consumption, chemical use, waste generation, carbon footprint, equipment lifetime and resource efficiency. Ozone and plasma may reduce the need for certain chemical treatments, while HPP and other non-thermal methods may reduce dependence on intensive thermal processing. Life Cycle Assessment (LCA) can therefore provide a more complete comparison from processing to storage and distribution (Hospido *et al.*, 2021) [22].

Economic and Industrial Feasibility

Commercial implementation depends on capital and operating costs, energy consumption, throughput, maintenance, skilled manpower, processing capacity and scale-up requirements. High equipment costs and process uniformity remain important challenges for some technologies. Particular attention should be given to whether these systems can be adapted to small- and medium-scale fish-processing enterprises through modular equipment, shared facilities and integration with existing chilling and packaging systems (Arumugam *et al.*, 2026) [23].

Regulatory and Commercial Considerations

Commercial application requires food-safety validation, regulatory compliance, processing standards, appropriate labelling and consumer acceptance. Regulatory requirements differ among countries and therefore should be considered according to the intended market. Consumer familiarity, perceived safety, product quality and trust can

influence acceptance of non-thermal processing technologies (EFSA, 2022; Melios *et al.*, 2025) [21, 24].

Research gaps

Major research gaps include laboratory-scale dominance, limited long-term storage studies, inconsistent processing parameters, insufficient studies on combined technologies, limited economic and LCA assessments, inadequate information on tropical fish species, limited commercial cold-chain validation and insufficient consumer-acceptance studies. More studies are also required to evaluate microbial, chemical, nutritional and sensory quality together rather than separately (Rathod *et al.*, 2022; Arumugam *et al.*, 2026) [18, 23].

Future research direction

Future seafood preservation should move towards integrated and data-driven systems: Fish landing → Rapid quality assessment → Selection of HPP/PEF/Plasma/Ultrasonication/Ozone → Smart packaging → Cold-chain monitoring → Real-time quality prediction → Consumer. Combining non-thermal technologies with smart packaging, sensors, predictive modelling, artificial intelligence and cold-chain monitoring could improve quality control and process optimization. Hurdle combinations should also be investigated to achieve microbial safety with minimum quality loss, energy use and processing cost.

Conclusion

HPP, PEF, cold plasma, ultrasound and ozone offer promising approaches for extending fish shelf life while maintaining quality. However, their performance remains dependent on species, product characteristics, treatment parameters and storage conditions. Future research should therefore shift from laboratory demonstrations towards validated, economically feasible and environmentally sustainable processing systems that integrate preservation technology, packaging, cold-chain management and real-time quality monitoring.

References

1. Farmery AK, White A, Allison EH. Identifying policy best-practices to support the contribution of aquatic foods to food and nutrition security. *Foods*. 2021;10(7):1589.
2. Mohanty BP, Mahanty A, Ganguly S, Mitra T, Karunakaran D, Anandan R. Nutritional composition of food fishes and their importance in providing food and nutritional security. *Food Chemistry*. 2019;293:561-570.
3. Nie X, Zhang R, Cheng L, Zhu W, Li S, Chen X. Mechanisms underlying the deterioration of fish quality after harvest and methods of preservation. *Food Control*. 2022;135:108805.
4. Speranza B, Racioppo A, Bevilacqua A, Buzzo V, Marigliano P, Mocerino E, *et al.* Innovative preservation methods improving the quality and safety of fish products: beneficial effects and limits. *Foods*. 2021;10(11):2854.
5. Roobab U, Fidalgo LG, Arshad RN, Khan AW, Zeng XA, Bhat ZF, *et al.* High-pressure processing of fish and shellfish products: safety, quality, and research prospects. *Comprehensive Reviews in Food Science and Food Safety*. 2022;21(4):3297-3325.
6. Oliveira FA, Neto OC, Santos LMR, Ferreira EHR. Effect of high pressure on fish meat quality—a review. *Trends in Food Science & Technology*. 2017;66:1-19.
7. Aubourg SP. Impact of high-pressure processing on chemical constituents and nutritional properties in aquatic foods: a review. *International Journal of Food Science & Technology*. 2018;53(4):873-891.
8. Kumar V, Rao PS, Purohit SR, Kumar Y. Effects of high pressure processing (HPP) and acid pre-treatment on quality attributes of hilsa (*Tenualosa ilisha*) fillets. *LWT*. 2019;111:647-652.
9. Gómez B, Munekata PES, Gavahian M, Barba FJ, Martí-Quijal FJ, Bolumar T, *et al.* Application of pulsed electric fields in meat and fish processing industries: an overview. *Food Research International*. 2019;123:95-105.
10. Peng B, Ma H, Xu L, Zhou H, Yu C, Hu M, *et al.* Application, mechanism and future prospect of electric field in fish processing and preservation: a review. *Trends in Food Science & Technology*. 2025;163:105212.
11. Tomasevic I, *et al.* Pulsed electric fields for sustainable meat, poultry, and fish processing: recent advances, prospects, and industry challenges. *Innovative Food Science & Emerging Technologies*. 2025;102:104008.
12. Misra NN, Schlüter O, Cullen PJ. Cold plasma in food and agriculture: fundamentals and applications. Academic Press; 2019.
13. Thirumdas R, Kothakota A, Annapure U, Siliveru K, Blundell R, Gatt R, *et al.* Plasma activated water (PAW): chemistry, physico-chemical properties, applications in food and agriculture. *Trends in Food Science & Technology*. 2018;77:21-31.
14. Gavahian M, Khaneghah AM, Cullen PJ. Plasma-based technologies for food safety and quality. *Trends in Food Science & Technology*. 2021;112:1-14.
15. de Arruda LC, Porto YD, Vieira BS, dos Santos Fogaça FH, Castro VS, de Souza Figueiredo EE, *et al.* Use of ozone to reduce the proportion of mesophilic and psychrotrophic bacteria among aquatic organisms: a systematic review and meta-analysis. *Journal of Food Safety*. 2025;45:e70011.
16. Antos P, Piechowiak T, Balawejder M, Kowalczyk K, Tereszkievicz K. Impact of gaseous ozone treatment of fish carcasses (*Gadus morhua*) on the microbiological load and their quality. *PLOS ONE*. 2025;20(8):e0327866.
17. Kulawik P, Rathod NB, Ozogul Y, Ozogul F, Zhang W. Recent developments in the use of cold plasma, high hydrostatic pressure, and pulsed electric fields on microorganisms and viruses in seafood. *Critical Reviews in Food Science and Nutrition*. 2023;63(29):9716-9730.
18. Rathod NB, Kulawik P, Ozogul Y, Ozogul F, Bekhit AEDA. Recent developments in non-thermal processing for seafood and seafood products: cold plasma, pulsed electric field and high hydrostatic pressure. *International Journal of Food Science & Technology*. 2022;57(2):774-790.
19. Abel N, Rotabakk BT, Lerfall J. Mild processing of seafood—a review. *Comprehensive Reviews in Food Science and Food Safety*. 2022;21(1):340-370.
20. Ekonomou SI, Bozariis IS. Non-thermal methods for ensuring the microbiological quality and safety of seafood. *Applied Sciences*. 2021;11(2):833.
21. European Food Safety Authority (EFSA). The efficacy and safety of high-pressure processing of food. *EFSA Journal*. 2022;20(3):7128.
22. Hospido A, *et al.* Life cycle assessment of fish and seafood processed products—a review of methodologies and new challenges. *Science of the Total Environment*. 2021;761:144094.
23. Arumugam D, Li S, Rao M, Peng R, Liu H, Huo B, *et al.* Nonthermal technologies for seafood preservation and shelf-life extension: a detailed review. *Food Quality and Safety*. 2026;10:fyaf046.
24. Melios S, Stramarkou M, Grasso S. Innovations in food: a review on the consumer perception of non-thermal processing technologies. *LWT*. 2025;223:117688.
25. Alkanan ZT, Altemimi AB, Younis MI, Ali MR, Cacciola F, Abedelmaksoud TG. Trends, recent advances, and application of pulsed electric field in food processing: a review. *ChemBioEng Reviews*. 2024;11(4):e202300078.
26. Li Y, Liu Z, Li W, *et al.* A review of novel preservation techniques for aquatic products and their effects on flavor. *Food Science*. 2025;46(19):414-423.

27. Perez-Andres JM, Charoux CMG, Cullen PJ, Tiwari BK. Chemical modifications of lipids and proteins by nonthermal food processing technologies. *Journal of Agricultural and Food Chemistry*. 2018;66(20):5041-5054.
28. Russo GL, Langelotti AL, Torrieri E, Masi P. Emerging technologies in seafood processing: an overview of innovations reshaping the aquatic food industry. *Comprehensive Reviews in Food Science and Food Safety*. 2024;23(1):e13281.
29. Siddiqui SA, Singh S, Bahmid NA, Sasidharan A. Applying innovative technological interventions in the preservation and packaging of fresh seafood products to minimize spoilage: a systematic review and *meta*-analysis. *Heliyon*. 2024;10(8):e29066.
30. Sireesha T, Nanje Gowda NA, Kambhampati V. Ultrasonication in seafood processing and preservation: a comprehensive review. *Applied Food Research*. 2022;2(2):100208.
31. Tavares J, Martins A, Fidalgo LG, Lima V, Amaral RA, Pinto CA, *et al*. Fresh fish degradation and advances in preservation using physical emerging technologies. *Foods*. 2021;10(4):780.
32. Yi S, Hu J, Fan K. Ultrasound application in the quality preservation of aquatic products: a review. *Food and Bioprocess Technology*. 2026;19:74.
33. Zhao YM, de Alba M, Sun DW, Tiwari BK. Principles and recent applications of novel non-thermal processing technologies for the fish industry—a review. *Critical Reviews in Food Science and Nutrition*. 2019;59(5):728-742.

How to cite this article: Charandas TM, Tandel V, Soren K, Tandel M. Emerging non-thermal preservation technologies for fish and seafood: Mechanisms, quality effects, safety, sustainability and industrial prospects. *International Journal of Veterinary Sciences and Animal Husbandry*. 2026;11(10):97-102. doi: <https://www.doi.org/10.22271/veterinary.2026.v11.i10b.384>

2