Novel Emerging Processing Technologies: A New Wave in Seafood Quality and Safety

Rishi Pal Yadav[1*], Sanjeev Sharma[1], Khushbu Gurawa[1], Pallavi Bhalavey[1], Virbhan[2]

[1]College of Fisheries, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana (125 004), India

[2]College of Fisheries, Central Agricultural University (Imphal), Lembucherra, Agartala, Tripura-799210, India

*Corresponding author

Email address: yadavsonurao888@gmail.com

How to cite this article:

Yadav, R. P., Sharma, S., Gurawa, K., Bhalavey, P., & Virbhan. (2026). Novel emerging processing technologies: A new wave in seafood quality and safety. Agrolife Frontiers, 1(2), 28-35.

Abstract

The global seafood industry plays a vital role in food security and economic development but faces challenges such as stagnant marine capture production, high post-harvest losses, food safety risks, and growing demand for minimally processed products. Marine landings have plateaued at 78–80 million tonnes since 1990, while post-harvest losses reach nearly 35%, necessitating advanced preservation approaches. Emerging technologies including high-pressure processing (HPP), pulsed light, ultrasound, cold plasma, ozone treatment, irradiation, radiofrequency thawing, microwave and ohmic heating, vacuum cooling, and sous-vide cooking provide effective alternatives to conventional thermal methods. These non-thermal or minimally thermal techniques ensure microbial inactivation while preserving omega-3 fatty acids, texture, colour, and sensory quality. By improving efficiency, reducing energy consumption and chemical preservatives, and extending shelf life, these innovations support sustainable and high-quality seafood processing systems.

Keywords: Seafood preservation, Emerging technologies, Non-thermal Processing, Electro-Thermal technologies, Microbial inactivation

Introduction

The seafood industry is a cornerstone of the global food economy, generating over $200 billion annually and supporting more than 56 million livelihoods worldwide (FAO, 2020). As a nutrient-dense and widely traded commodity, seafood contributes significantly to food security and economic growth. However, marine capture fisheries have plateaued at 78–80 million tonnes since 1990, limiting expansion through wild harvest. Consequently, reducing pre- and post-harvest losses is essential to meet rising demand. Current post-harvest losses average about 35%, ranging from 20% to 75% depending on infrastructure and handling practices (Keerthana et al., 2022). Seafood's high moisture content and delicate muscle structure accelerate spoilage, while food safety remains a concern. Between 2011 and 2017, fish products accounted for 6–8% of foodborne outbreaks in the USA, compared with 3.6% for chicken and 1.9% for beef. Environmental pressures and consumer demand for minimally processed, safe products further intensify challenges.

To address these issues, advanced non-thermal technologies such as high-pressure processing (HPP), pulsed electric field (PEF), and cold plasma, alongside edible coatings and intelligent packaging, are improving shelf life, safety, and quality while preserving sensory and nutritional attributes (Bhalavey et al., 2025; Hasan et al., 2023; Yadav et al., 2025). These innovations offer a sustainable pathway for a safer, value-driven seafood industry.

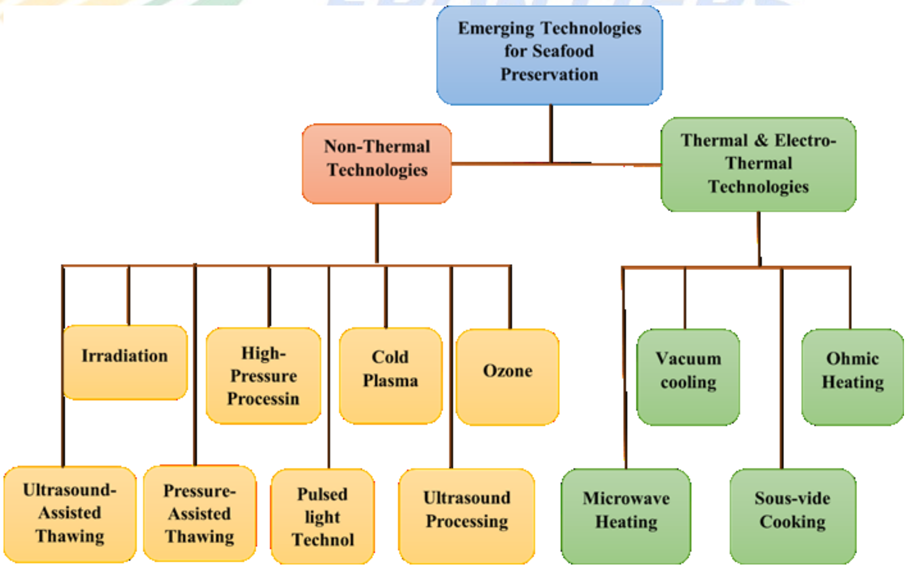

Fig. 1 Emerging technologies and its types

Non-Thermal Technologies

High-Pressure Processing (HPP)

High-pressure processing (HPP) is a minimal-processing technology that extends shelf life while preserving sensory and nutritional quality. Unlike thermal methods, it applies very high pressures (up to 900 MPa), sometimes with moderate temperatures for short durations, to inactivate microorganisms with minimal heat damage. Packaged food is placed in a pressure vessel and immersed in a pressure-transmitting medium selected based on product and equipment compatibility. In addition to ensuring microbial safety, HPP can modify functional properties while maintaining organoleptic attributes—allowing seafood preservation without conventional cooking.

Pulsed Light Technology

Pulsed light technology is a non-thermal preservation method that uses intense, broad-spectrum white light (180–1100 nm) delivered in short, high-energy pulses to sanitize food surfaces and packaging. It effectively inactivates microorganisms without leaving harmful residues, making it safe for food applications. Pulsed light significantly reduces pathogens such as *Listeria monocytogenes*, *Salmonella enteritidis*, and *Staphylococcus aureus*, thereby improving food safety and extending shelf life.

Ultrasound Processing

Ultrasound involves sound waves beyond human hearing and, in food processing, mainly uses high-energy, low-frequency power ultrasound. In seafood applications, it inactivates pathogens such as *E. coli*, *Staphylococcus aureus*, *Salmonella* spp., and *Listeria monocytogenes* through acoustic cavitation, where shear forces disrupt microbial cells. It provides advantages including low energy consumption, absence of radiation, minimal sensory impact, uniform treatment, and shorter processing times.

Radiofrequency (RF) Thawing

Radiofrequency (RF) thawing uses electromagnetic energy to rapidly and uniformly thaw frozen foods. The product is placed between parallel electrodes, and RF energy generates heat through ionic conductivity. In seafood processing, RF enables deep energy penetration, allowing rapid thawing of fish blocks (e.g., 5 cm thick) from –20 °C to near 0 °C. Compared to conventional methods, it provides faster and more uniform thawing.

Pressure-Assisted Thawing (PAT)

Pressure-assisted thawing (PAT) uses high pressure as an alternative to conventional thawing. By lowering the melting point of ice (to about –22 °C at 220 MPa), it accelerates phase transition and enhances heat transfer. Around 220 MPa is considered optimal for improving thawing efficiency through increased temperature gradients at the ice–water interface. PAT enables faster, controlled thawing while potentially limiting microbial growth.

Ultrasound Thawing of Frozen Foods

Ultrasound-assisted thawing enables rapid and uniform defrosting without excessive surface heating. At controlled conditions (e.g., 500 kHz, 0.5 W/cm²), it can reduce fish block thawing time by 25–70%, depending on operating parameters. By enhancing heat transfer, this method shortens processing time and better preserves product quality compared to conventional thawing techniques.

Irradiation

Food irradiation involves exposing products to controlled doses of electromagnetic or electron-beam radiation to reduce pathogenic microorganisms and extend shelf life. As a physical, non-thermal treatment, it effectively controls bacteria, insects, and certain biological processes such as sprouting and ripening. Irradiation is also widely used for sterilizing packaging materials in aseptic food and pharmaceutical processing.

Ozone Treatment

Ozone is a highly reactive and unstable gas used as a strong antimicrobial agent in food processing. It can be applied in gaseous form or dissolved in water as ozonated water. Ozone inactivates microorganisms by damaging cellular proteins and enzymes, disrupting metabolic functions, and leading to cell death. Although widely used for equipment disinfection, careful control is required due to its reactive nature.

Cold Plasma

Cold plasma is a non-thermal process operating at 25–65 °C, generated by ionizing gases such as helium, air, or nitrogen. It produces reactive species (e.g., ozone and singlet oxygen) with strong antimicrobial effects. In seafood processing, it reduces microbial load and sterilizes equipment and packaging without harming heat-sensitive products, inactivating microbes through oxidative damage to cellular components.

Thermal & Electro-Thermal Technologies

Ohmic Heating

Ohmic heating is an advanced thermal processing method in which electric current passes directly through food, generating uniform internal heat due to electrical resistance. Typically operating at 50–60 Hz, it enables rapid heating of liquid and particulate foods in continuous systems. Electric field effects may enhance microbial inactivation by inducing pore formation in cell membranes, while better preserving sensory and nutritional quality compared to conventional heating.

Microwave Heating

Microwave processing employs electromagnetic waves (300 MHz–300 GHz) for rapid and efficient seafood processing. It is widely used in tempering, thawing, pasteurization, drying, baking, and sterilization. Microwave blanching helps inactivate enzymes and preserve colour, often combined with steam or acidified solutions. Due to volumetric heating, internal pressure gradients drive moisture outward, enabling faster drying rates and efficient water removal while maintaining improved product quality compared to conventional methods.

Vacuum Cooling

Vacuum cooling is a rapid preservation method suitable for moisture-rich seafood prone to microbial growth. Food is placed in an airtight chamber where pressure is reduced, causing rapid evaporation of water at saturation temperature and resulting in uniform cooling. In tuna processing, brine-frozen fish are thawed, cooked at ~65 °C, and vacuum cooled to 35–40 °C, reducing bacterial load by approximately 3–4%. The technique is also effective for small fish and crustaceans such as whiting and shrimp, enhancing safety and extending shelf life.

Sous-vide Cooking

Sous-vide is a modern technique in which food is vacuum-sealed in heat-stable, food-grade pouches and cooked at precisely controlled temperatures (65–95 °C) for extended durations, followed by rapid cooling and refrigerated storage to ensure safety. Microbial stability and shelf life depend on appropriate time–temperature combinations and strict cold chain management. Compared to conventional cooking, sous-vide improves tenderness, juiciness, nutrient retention, microbial safety, and shelf life while reducing cooking loss and lipid oxidation (Mehta et al., 2025; Yadav et al., 2025a; 2025b). It also better preserves heat-sensitive nutrients and omega-3 fatty acids in fish.

Advantages Over Conventional Seafood Preservation Technologies

Emerging seafood processing technologies provide significant advantages over conventional methods by enhancing nutritional retention, sensory quality, microbial safety, energy efficiency, and shelf life. Unlike traditional high-temperature treatments that degrade heat-sensitive nutrients such as omega-3 fatty acids and vitamins, non-thermal and minimally thermal techniques preserve biochemical integrity and functional properties. They maintain fresh-like texture, colour, flavour, and overall organoleptic characteristics.

Fig. 2 Role and applications of emerging technologies in seafood preservation

Simultaneously, advanced mechanisms including high pressure, pulsed electric fields, cavitation, and reactive species effectively inactivate pathogenic and spoilage microorganisms, ensuring improved food safety. These technologies often require shorter processing times and enable uniform energy distribution, reducing energy consumption and minimizing chemical preservative use. By slowing enzymatic activity, lipid oxidation, and microbial proliferation, they significantly extend product shelf life. Additionally, precise control of processing parameters enhances consistency, reduces variability, and ensures superior quality compared to conventional seafood preservation methods.

Conclusion

The seafood industry is undergoing a significant technological evolution driven by the need to balance food safety, nutritional integrity, sensory quality, and environmental sustainability. Emerging processing technologies such as HPP, pulsed light, ultrasound, radiofrequency thawing, cold plasma, and ozone treatment provide scientifically validated alternatives to conventional preservation methods. By reducing thermal damage while ensuring effective microbial control, these innovations enable extended shelf life and improved product quality. Furthermore, their compatibility with advanced packaging systems and value-added processing enhances industrial applicability. Although challenges remain in terms of cost, regulatory harmonization, and large-scale adoption, the growing body of evidence supports their transformative potential in modern seafood preservation.

Reference

Bhalavey, P., Yadav, K. K., Murabiya, U., Patel, N., Hooda, D., Gurawa K., & Yadav, R.P. (2025). Traditional and Modern Fish Processing Techniques. In: Fisheries Science in the 21st Century Progress and Perspective. Elite Publishing House, New Delhi, 144-156

FAO. (2020). The state of world fisheries and aquaculture 2020. FAO. https://doi.org/10.4060/ca9229enFAO. (2022).

Hassan, S., Wahab, A., Ahmad, N., Ali, A., & Mazhar, S. S. (2023). Importance of emerging technologies in processing and preservation of seafood. *IPS Journal of Nutrition and Food Science*, *2*(1), 13-17. https://doi.org/10.54117/ijnfs.v2i1.16.

Keerthana, P. S., Gopan, S., Rajabudeen, R., Fathima, R., Shibu, K., Nisha, R., ... & Sreekanth, G. B. (2022). Post-harvest losses in the fisheries sector-facts, figures, challenges and strategies. *International Journal of Fisheries and Aquatic Studies*, *10*(4), 101-108. https://doi.org/10.22271/fish.2022.v10.i4b.2691.

Mehta, N. K., Vaishnav, A., Debbarma, P., Chandravanshi, S., Mohanty, S., Yadav, K. K., & Priyadarshini, M. B. (2025). Packaging technologies for low-temperature preserved fish products. In Quality Analysis and Packaging of Seafood Products (pp. 75-153). Academic Press.

Russo, G. L., Langellotti, A. L., Torrieri, E., & Masi, P. (2024). Emerging technologies in seafood processing: An overview of innovations reshaping the aquatic food industry. *Comprehensive Reviews in Food Science and Food Safety*, *23*(1), e13281. https://doi.org/10.1111/1541-4337.13281.

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*(1), 738-786. https://doi.org/10.1111/1541-4337.12671.

Yadav, K. K., Bhalavey, P., Patel, N. D., Chaudhury, S., & Yadav, R. P. (2025b). Seaweed composition and its diverse applications. Vigyan Varta: An International E-Magazine for Science Enthusiasts, 6(4), 42–47

Yadav, K. K., Mehta, N. K., Sharma, S., Bhajan, S., Kulshrestha, T., Gaurav, K., ... & pal Yadav, R. (2025a). Advances in sous-vide technology for meat processing: a comprehensive overview. *Journal of Agriculture and Food Research*, 102257. https://doi.org/10.1016/j.jafr.2025.102257.

Yadav, R. P., Yadav, K. K., Sharma, S., Chaudhury, S., & Bhalavey, P. (2025). Sustainable food systems with intelligent packaging: Monitoring quality and minimizing waste. The Fish World, 2(6), 653–662.