



Cold Plasma: An Electric Wind That Can Transform the Way We Preserve Fish

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ABSTRACT

Fishes and other aquatic foods are highly susceptible to spoilage because of their high levels of water content, proteins, and unsaturated fats, and thus efficient preservation is very essential to the seafood industry. Traditional techniques such as cooling, freezing, canning, and smoking have proven to be quite effective in preserving seafood but they often affect the taste or the nutritive quality of the food. Cold plasma (CP), a non-thermal technique that involves the ionisation of gases at ambient temperature, is being considered as a viable means of preserving fish without damaging it or leaving any chemical traces. The following discussion will examine some of the latest studies carried out in relation to CP and plasma-activated water and ice in fish preservation and their applications.

KEYWORDS

Cold plasma; Fish preservation; Non-thermal processing; Plasma-activated water; shelf life

Introduction

As you stroll past the aisles of a fish market, the worst enemy in the room isn't another consumer trying to haggle for a better deal – it is time. The moment the fish is taken out of the water, enzymes, bacteria, and oxygen work together in their efforts to destroy what the nature has spent years producing. For many decades, the food industry has tried to win against these forces using such methods as ice, salt, smoke, and heat. Now, a new invention, used in physics laboratories, has provided a completely new option.

Cold Plasma

Plasma has been referred to as an electrically excited glowing gas – the very same principle which illuminates neon lights and gives the northern lights their brilliance. Cold or "non-thermal" plasma is produced by subjecting a gas such as air, nitrogen, or oxygen to an electric field at around or just below room temperature. It produces a combination of reactive molecules and particles such as electrons, ions, and reactive oxygen and nitrogen species without the high temperatures associated with flames and sparks. Since it maintains a low temperature, it can be used directly on food and will not cook it.

Cold plasma has been referred to as an entirely new, non-thermal process for agriculture and food industries since the specific mechanism of action of plasma is yet to be fully understood while already demonstrating its benefits in the laboratory setting (Cherif et al., 2023). In contrast to freezing or pasteurization, it utilizes no high temperatures, and unlike chemical dips, there is no residue since the reactive species formed disappear very quickly (Jiang et al., 2022).

Why Fish Requires a New Preservation Method

The nature of fish and shellfish makes it particularly prone to decay. The presence of water and unstable fats, as well as delicate protein, makes it highly attractive to spoilage bacteria and oxidation, which lead not only to

decreased shelf life but also to food safety issues that arise before the food even becomes visually and odorous unacceptable (Rathod et al., 2021). There are already proven techniques of fish preservation such as chilling, freezing, canning and smoking but each has its drawbacks as freezing degrades the texture, smoking changes the taste while heat treatment damages vital nutrients contained in fish.

Application of cold plasma technique may allow overcoming this problem by attacking the spoilage microorganisms directly at the site of the potential contamination without causing any harm to underlying tissues due to temperature.

What the research tells us

Early trials have been promising. Untreated fish showed a significant shelf-life extension when packaged with herring which had undergone in-package atmospheric plasma treatment because of decreased microbial growth inside the sealed package itself (Albertos et al., 2019). Antimicrobial effects have also been reported against foodborne pathogens such as *Listeria* and *Staphylococcus aureus* in ready-to-eat fish products, indicating that the technology could improve food safety as well as freshness (Hajhoseini et al., 2020).

But the technology isn't just about treating the fish. Researchers have also experimented with "plasma-activated water" — normal water bristling with the same reactive species created by a plasma discharge — as a rinse or ice-making medium. Research has shown that the composition of the fish itself, such as the levels of fat and protein, can influence the effectiveness of this activated water in killing microbes, indicating that treatment procedures may need to be adapted on a species-by-species basis (Zhao et al., 2020).

More recently, plasma-activated ice has moved out of the lab. An industrial-scale trial on sea bream filets found that fish packed in plasma-activated ice saw its shelf-life extended by approximately 74%, compared to around 42% for filets simply rinsed in plasma-activated water, alongside a favorable cost analysis for

processors considering the switch (Giannoglou et al., 2026).

In fact, cold plasma has shown potential against viruses: one study showed that an atmospheric pressure plasma jet could inactivate norovirus, a frequent cause of foodborne illness, on salmon sashimi—a product that, because it is eaten raw, cannot be protected at all by standard heat treatment (Huang et al., 2021).

Not a Silver Bullet — For Now

The promise is there, but researchers are honest about what the technology can and can't do. Some reviewers say cold plasma can enhance lipid oxidation in fatty fish, which can affect flavor and nutritional quality if treatment parameters are not controlled properly (Rathod et al., 2021). The results are also very diverse depending on the plasma generator, the gas mixture, the duration of the treatment and even the fish species treated, so it is still difficult to establish a single industry standard (Kulawik and Tiwari, 2019).

The other major issue is the expense and size. Most studies conducted so far have been performed using small, laboratory sizes of plasma units, and applying them to full commercial fish-processing lines — where enormous amounts of fish are handled every day in the process — is yet to be accomplished, although the latest industrial tests are showing that things are changing.

Importance Beyond Fillet

Cold plasma is important not just on fish counters. Since the technology is based on electricity and air or gas, without requiring any chemicals or huge amounts of hot water, it complies with the requirements of the food industry for green and sustainable processing. Furthermore, it can be used in other aspects, such as the sanitisation of packaging, equipment, or even wastewater from seafood facilities (Jiang et al., 2022).

Applications in Fish Processing

The function of cold plasma in the sector of fish industry has now spread widely through different aspects of the value chain such as:

- Surface decontamination of whole fish, fillets, and shellfish (e.g., sea bass, sea bream, tilapia, shrimp) preventing spoilage bacteria and extending the life of chilled fish (Rathod et al., 2021).
- Plasma activated water and plasma activated ice used as antimicrobial rinse or chilling medium during transport and storage resulting in considerable shelf-life extension over 70% in the experiment (Giannoglou et al., 2026).
- Treatment inside the package of ready-to-eat vacuum fish products producing plasma inside the sealed package to keep the food uncontaminated after the process (Albertos et al., 2019).
- Pathogen and virus removal from raw and minimally processed products, for instance, sashimi, where there is no possibility to apply heat treatment (Huang et al., 2021).
- Sanitization of processing equipment, packaging materials, and plant wastewater thereby meeting the requirements of wider hygiene and sustainability goals pursued by the facility (Jiang et al., 2022).

Benefits of Cold Plasma Technology

- Maintains nutrient and sensory quality: since the treatment is applied near room temperature, sensitive nutrients like Omega 3 fatty acids, protein, and the original texture are retained compared to thermal treatment (Cherif et al., 2023).
- Environmentally safe: generated reactive species are decomposed after treatment and there is no artificial additive or chemical residue on fish (Jiang et al., 2022).
- Wide-spectrum efficiency: cold plasma has been found to destroy food spoilage organisms, pathogens like *Listeria* and *Staphylococcus aureus*, and viruses like norovirus (Hajhoseini et al., 2021).
- Eco-friendly production method: the procedure is based on electricity only, which does not involve a huge amount of heated water

or chemical disinfectants used in traditional preservation processes (Jiang et al., 2022).

- **Application versatility:** Apart from just seafood, the same system cleans packaging, processing machines, and wastewater from the facility, and it can be supplied in the form of plasma-activated water or ice giving the technology more adaptability for different parts of the food supply chain (Giannoglou et al., 2026).
- **Applicable to packaged and raw products:** Since the process does not require heat, cold plasma can be generated within sealed packages, or used on raw ready-to-eat products like sashimi, which can't be otherwise treated with heat (Albertos et al., 2019; Huang et al., 2021).

Drawbacks and Challenges

- **The risk of lipid oxidation:** in oily fish species, the reactive oxygen species released during treatment may increase lipid oxidation which can adversely change the taste, color and nutritional value of fish (Rathod et al. 2021).
- **Variability and lack of standardization of results:** the outcome of treatments is affected by the type of plasma-generating equipment, gas composition, level of voltage, duration of exposure, and the type of fish, and that complicates the establishment of standard protocols in the industry (Kulawik and Tiwari, 2019).
- **Limited large-scale validation:** majority of studies conducted so far have been performed with the help of small laboratory-scale plasma setups, while the results of commercial application of continuous methods are still insufficient (Giannoglou et al., 2026).
- **Cost of equipment and operation:** High voltage plasma generation equipment and specialized gas are considerable investments in starting up operations, acting as a deterrent to small operatives.
- **Unclear regulations:** Transparent and coordinated food safety regulations and approval mechanisms of cold plasma technique involving seafood are still being formulated.

- **Need for species-specific optimization:** Fish composition (fat, protein, moisture) affects treatment efficiency, and hence methods can't be used directly across the fish types (Zhao et al., 2020).

Future scope

In order for cold plasma to convert from an area of interest in research to a commonplace industrial technology, various changes need to take place. Standardization of treatment protocols that include the type of gas, voltage and exposure time might be the key to normalizing contradictory results that different fish species and treatment technologies demonstrate (Kulawik and Tiwari, 2019). Continuous decrease in costs and the emergence of bigger and endless plasma systems is of paramount importance for implementation of the technology on high-capacity production lines and is based on the achievements that were reached during pilot investigations (Giannoglou et al, 2026). Combining cold plasma with other hurdle technologies such modified atmosphere packaging, natural antimicrobials or edible films is likely to compensate for the drawback of this method that promotes oxidation of fats. Additionally, clear regulations and safety standards in countries that dominate in terms of fish production and import will be set before this technology becomes widely used. Finally, in the distant future, inclusion of real-time quality monitoring devices and life cycle assessments might assist producers in developing optimal treatment protocols for every species as well as in calculating the impact of chemical preservatives replacement by physical techniques.

Conclusion

All things considered, the available data indicates that cold plasma technology is among the most viable forms of non-thermal technology to arise recently within the seafood industry. It targets two major threats to fish quality, namely, microbial spoilage and enzymatic degradation, without the risk of heat-based damage, presence of chemical residues, or

loss of flavor experienced with traditional methods of preservation. The transition of cold plasma from laboratory tests to pilots being conducted at the industrial scale with products such as sea bream fillets proves that this technology is applied in practical conditions of production, distribution, and sale of the product (Giannoglou et al., 2022).

However, it is safe to say that cold plasma technology serves as a promising new technique rather than as an alternative to established methods such as cooling, freezing, or simply following hygiene rules. It remains true, however, that the performance of the technology is very much dependent on the design of the equipment, composition of the gas, treatment duration, and the kind of fish being processed (Rathod et al., 2021; Kulawik and Tiwari, 2019). The success of the venture relies on three particular factors: further standardisation of the treatment procedure across the board, a decrease in prices of the technology as more and more seafood processors implement cold plasma processing on a larger scale, and a comprehensive regulatory framework in the world's largest seafood exporting countries. If these factors are met, cold plasma should be able to transition from a scientific experiment to a commonplace step in the fish processing process.

References

- Albertos, I., Martin-Diana, A. B., Cullen, P. J., Tiwari, B. K., Ojha, K. S., Bourke, P., & Rico, D. (2019). Shelf-life extension of herring (*Clupea harengus*) using in-package atmospheric plasma technology. *Innovative Food Science & Emerging Technologies*, 53, 85-91.
- Cherif, M. M., Assadi, I., Khezami, L., Ben Hamadi, N., Assadi, A. A., & Elfalleh, W. (2023). Review on recent applications of cold plasma for safe and sustainable food production: principles, implementation, and application limits. *Applied Sciences*, 13(4), 2381.
- Giannoglou, M., Chanioti, S., Andreou, V., Stergiou, P., Passaras, D., Mouchtouris, S., ... & Katsaros, G. (2026). Industrial scale application of cold atmospheric plasma technology for fish fillets decontamination and shelf-life extension—quality assessment from production to consumption. *Food Research International*, 119206.
- Hajhoseini, A., Sharifan, A., & Yousefi, H. R. (2020). Effects of atmospheric cold plasma on microbial growth of *Listeria innocua* and *Staphylococcus aureus* in ready-to-eat fish products.
- Huang, Y. M., Chang, W. C., & Hsu, C. L. (2021). Inactivation of norovirus by atmospheric pressure plasma jet on salmon sashimi. *Food Research International*, 141, 110108.
- Jiang, H., Lin, Q., Shi, W., Yu, X., & Wang, S. (2022). Food preservation by cold plasma from dielectric barrier discharges in agri-food industries. *Frontiers in Nutrition*, 9, 1015980.
- Kulawik, P., & Kumar Tiwari, B. (2019). Recent advancements in the application of non-thermal plasma technology for the seafood industry. *Critical Reviews in Food Science and Nutrition*, 59(19), 3199-3210.
- Rathod, N. B., Ranveer, R. C., Bhagwat, P. K., Ozogul, F., Benjakul, S., Pillai, S., & Annapure, U. S. (2021). Cold plasma for the preservation of aquatic food products: An overview. *Comprehensive Reviews in Food Science and Food Safety*, 20(5), 4407-4425.
- Zhao, Y. M., Ojha, S., Burgess, C. M., Sun, D. W., & Tiwari, B. K. (2020). Influence of various fish constituents on inactivation efficacy of plasma-activated water. *International Journal of Food Science & Technology*, 55(6), 2630-2641.