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Application of Emerging Non-Thermal Technologies in Fish and Shellfish Processing

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SUMMARY

Fish and shellfish are highly perishable and sensitive to quality deterioration during processing and storage. Conventional thermal methods ensure safety but often reduce sensory and nutritional quality. Emerging non thermal technologies such as high pressure processing, cold plasma, pulsed electric field, ultrasound and ozone treatment offer effective microbial control with minimal heat damage. These technologies help preserve fresh texture, flavour and nutritional components while extending shelf life. Their application supports the development of safe, minimally processed and value added seafood products making them promising tools for modern fish and shellfish processing.

INTRODUCTION

The importance of fish and shellfish in the global food security is attributed to good protein source, essential fatty acids and micronutrients. These commodities however are also one of the most delicate foods and that they deteriorate quickly after harvesting because of enzymatic degradation, lipid peroxidation among microbial proliferation. Quality deterioration in seafood is rapid even in the chilled state resulting in the softening of the texture, off odours formation, color and decreased acceptability by the consumers (Ashie et al., 1996). Historically, cooking, pasteurization and canning have been used as thermal processing methods to enhance the quality and shelf life of fishery products in terms of safety. Although such techniques can be efficient in the inactivation of microorganisms, they tend to cause undesired modifications of sensorial characteristics and nutritional values especially with heat sensitive molecules like omega-3 fatty acids, vitamins and proteins with functional attributes. The constraints of heat based processing have become more apparent as consumer preference towards fresh, minimally processed and ready-to-eat seafood products continues to evolve (Nie et al., 2022). New non-thermal processing methods have become of interest in the seafood industry in reaction to these challenges. The purpose of the technologies is to manage the spoilage and microorganisms that cause diseases and do not expose the product to high temperatures to maintain the quality properties that befall fish and shellfish. Due to the interrelation of food safety and quality retention, non-thermal methods present some of the promising alternatives to the contemporary seafood processing systems and would meet the existing market and regulatory requirements (Nema et al., 2022).

Perishability and Processing Challenges in Fish and Shellfish

Fish and shellfish start to deteriorate practically as soon as they are harvested. This quick degradation is largely influenced by the endogenous enzymes, high level of water activity, pH of neutrality and the availability of unsaturated lipids which are very susceptible to oxidation. Autolytic enzymes result in softening of muscle tissue shortly after death whereas oxidative reactions produce rancidity, discolouration and loss of nutritional value especially of omega-3 fatty acids (Ashie et al., 1996). Microbial spoilage also serves to increase the loss of quality during storage and distribution. Psychrotrophic organisms like the Pseudomonas and Shewanella dominate chilled fish to produce volatile compounds that cause distasteful smell and flavour. Other safety issues in shellfish include naturally occurring pathogens including Vibrio spp. which could not be eliminated even during refrigeration. The complicated surface topography and elevated water content of seafood complicate accomplishing the entirety of microbial control through the application of conventional surface treatments (Nie et al., 2022). There are a number of technological challenges in fish and shellfish processing. Thermal treatments though efficient in providing safety usually result in protein denaturation, loss of moisture, loss of texture and loss of sensory values. Besides, greater consumption of seafood fresh and minimally processed and ready-to-eat foods also exerted pressure on the processors to implement more moderate preservation methods. These issues indicate the necessity of new processing methods that can be used to manage

the spoilage and safety risks effectively and preserve the natural quality characteristics of fish and shellfish (Nema et al., 2022).

Need For Non-Thermal Processing Technologies in Seafood

Increasing need of fresh minimally processed seafood has brought to light the drawbacks of traditional preservation practices founded on heat. Although the thermal processing method makes the food safe in terms of microbes, it tends to change the delicate texture, natural colour and characteristic flavour of fish and shellfish. Furthermore, heat sensitive nutritional components like polyunsaturated fatty acids, vitamins and some bioactive products can be partly lost in high temperature treatments. Such quality differences are becoming intolerable to consumers who attribute freshness with high nutritional and sensory value (Nie et al., 2022). Alternative techniques of non-thermal processing technologies have occurred as viable methods of meeting the safety and quality needs. These techniques can inactivate spoilage and pathogenic microorganisms by operating at ambient or moderately low temperatures and cause minimal damage to muscle proteins and lipids. They may be especially applicable to seafood items that are eaten raw or minimally processed such as shellfish, marinated fish and ready-to-eat chilled items, in which preservations of fresh attributes are critically required (Nema et al., 2022). Non-thermal technologies besides quality retention have convenient benefits in the processing of seafood today. They can be used either as independent treatments or as part of the conventional to achieve better results in processing efficiency, energy saving and shelf life. With the changes in regulatory frameworks and the availability of systems based on non-thermal processing, the latter will play a significant role in fulfilling the safety, quality and sustainability requirements of the seafood industry (Farooq et al., 2023).

High Pressure Processing (HPP) in Fish and Shellfish Processing

One of the most successfully commercialized non-thermal technologies in the seafood industry is High Pressure Processing (HPP). It is the exposure of packaged fish or shellfish to extremely high hydrostatic pressures ranging between 300- 600 Mpa in the short run. The pressure used interferes with cellular membranes and metabolism of microorganisms without the use of high temperatures hence providing microbial safety whereby preserves the fresh properties of the product to a large extent (Ma et al., 2011). HPP has been demonstrated to greatly prolong the chilled shelf life in fish processing by decreasing the count of spoilage microorganisms and slowing down the rate of enzymatic degradation. The alterations that occur on non covalent bonds of proteins due to the pressure applied rather than thermal treatment make the muscle structure to remain substantially intact as opposed to thermal treatments. Consequently, fish products treated do not lose valuable texture, colour and flavour and do not form any harmful substances including omega-3 fatty acids in the process (Nie et al., 2022). The use of HPP has been of especial importance in the processing of shellfish. A major application of it is the pressure assisted shucking of oysters, clams and mussels. The adductor muscle is removed when subjected to high pressure that allows the muscle to easily shuck and preserve the original look and the quality of the raw meat. Also, HPP has been found to be effective in eliminating pathogenic bacteria like Vibrio spp. in shellfish to improve food safety without affecting consumer palatability (Ma et al., 2011). Although HPP has many benefits, the general use of the product is constrained by high capital cost and operation cost. Moreover, the pressure resistance of bacterial spores and some enzymes requires the precise optimization of the process or its combination with other preservative techniques. However, HPP has still been propelling technology to create high quality, safe and value added fish and shellfish products especially to high end and export markets (Nema et al., 2022).

Cold Plasma Technology for Seafood Preservation

Cold plasma technology has emerged as a promising non-thermal approach for improving the microbial safety of seafood products without the use of heat or chemical preservatives. Plasma is an ionized gas composed of charged particles, free radicals and reactive species that can effectively inactivate microorganisms at or near room temperature. When applied to fish and shellfish, cold plasma primarily acts on the product surface where microbial contamination is most prevalent (Farooq et al., 2023). In seafood processing, cold plasma has been investigated for surface decontamination of fish fillets, shrimp and ready-to-eat products. The reactive oxygen and nitrogen species generated during plasma treatment damage microbial cell walls, membranes and genetic material leading to rapid inactivation of spoilage and pathogenic microorganisms. Because the treatment temperature remains low, undesirable changes in texture, colour and flavour are minimal when process parameters are properly controlled (Nie et al., 2022). Cold plasma also offers advantages in terms of

environmental and consumer safety. It does not leave chemical residues and requires little water or energy compared to conventional sanitizing methods. Additionally, plasma treatment can be applied to packaging materials thus helping reduce post processing contamination. However, its effectiveness is largely limited to surface treatment and excessive exposure may promote oxidative changes in lipid rich seafood products. Therefore, careful optimization is required to balance microbial reduction and product quality (Farooq et al., 2023).

Pulsed Electric Field (PEF) Applications in Fish and Shellfish

Pulsed Electric Field (PEF) technology is a non-thermal preservation method that involves the application of short bursts of high voltage electric pulses to food placed between electrodes. These pulses cause temporary or permanent disruption of microbial cell membranes, a phenomenon known as electroporation, which leads to microbial inactivation with minimal heat generation. Because the treatment duration is extremely short, PEF preserves the structural and nutritional integrity of fish and shellfish products (Gómez-Estaca et al., 2019). In fish processing, PEF is mainly used as a pre treatment rather than a standalone preservation method. It enhances mass transfer during salting, brining and marination allowing for more uniform and rapid uptake of curing agents. PEF has also been reported to improve tenderness of fish muscle by altering cell permeability which can be beneficial for value added products. Additionally, PEF pre treatment can reduce drying and freezing time thereby improving processing efficiency and energy utilization (Abad et al., 2023). PEF has further gained attention for its role in improving the extraction of bioactive compounds from fish and shellfish byproducts, including proteins, lipids and antioxidants. However, its application in solid seafood matrices is limited by non uniform electric field distribution and the need for precise control of treatment parameters. Industrial adoption requires species specific optimization and integration with other preservation techniques to achieve consistent microbial safety. Despite these challenges, PEF shows strong potential as a supportive technology in modern seafood processing systems (Gómez-Estaca et al., 2019; Abad et al., 2023).

Ultrasound Assisted Processing of Seafood

Ultrasound technology has gained increasing attention in seafood processing due to its ability to enhance physical and mass transfer processes without the application of high temperatures. High power, low frequency ultrasound generates cavitation bubbles in liquid media which collapse violently and produce localized mechanical effects. These effects can disrupt microbial cells, loosen surface contaminants and modify muscle structure, making ultrasound a versatile tool for fish and shellfish processing (Bhargava et al., 2020). In practical applications, ultrasound has been used to improve cleaning and washing efficiency of fish and shellfish assisting in the removal of slime, scales and surface microorganisms. It also accelerates marination, brining and curing processes by increasing permeability of muscle tissue resulting in more uniform salt or marinade uptake in a shorter time. When applied as a pre treatment before drying or freezing, ultrasound has been shown to reduce processing time and improve product quality by enhancing moisture removal and minimizing structural damage (Sireesha et al., 2022). Despite its advantages, excessive ultrasound intensity or prolonged exposure may lead to undesirable effects such as lipid oxidation and textural softening particularly in fatty fish species. Therefore, ultrasound is most effective when used in combination with other mild preservation techniques such as refrigeration or natural antimicrobials. With proper optimization, ultrasound assisted processing offers an efficient and environmentally friendly approach to improving quality and processing efficiency in seafood products (Bhargava et al., 2020; Taha et al., 2024).

Ozone Treatment in Fish and Shellfish Processing

Ozone has been widely studied as a non-thermal antimicrobial agent in seafood processing due to its strong oxidizing capacity and residue free nature. It can be applied either in gaseous form or dissolved in water and ice, making it suitable for washing, chilling and storage of fish and shellfish. Ozone acts by oxidizing microbial cell membranes and intracellular components leading to rapid inactivation of a broad range of bacteria, fungi and viruses at relatively low concentrations (Chawla, 2006). In fish processing, ozonated water is commonly used during washing and handling operations to reduce surface microbial load and delay spoilage. The use of ozonated ice during chilled storage has also been reported to suppress microbial growth and maintain sensory quality for longer periods compared to conventional ice. In shellfish processing, ozone helps control microbial contamination during depuration and post harvest handling thereby improving product safety without

introducing chemical residues (Epelle et al., 2023). Despite its effectiveness, the application of ozone requires careful control of concentration and exposure time. Excessive ozone levels may promote lipid oxidation, discoloration and off flavour development particularly in fatty fish species. Additionally, the presence of organic matter can reduce ozone efficacy, necessitating proper pre cleaning of raw materials. When applied judiciously, ozone treatment serves as an efficient and environmentally friendly tool for enhancing the safety and shelf life of fish and shellfish products (Epelle et al., 2023; Giménez et al., 2024).

REFERENCES

Abad, E., Raso, J., & Álvarez, I. (2023). Pulsed electric fields in fish processing: Mechanisms, applications, and future perspectives. Foods, 12(3), 614. https://doi.org/10.3390/foods12030614

Ashie, I. N. A., Smith, J. P., & Simpson, B. K. (1996). Spoilage and shelf-life extension of fresh fish and shellfish. Critical Reviews in Food Science and Nutrition, 36(1–2), 87–121. https://doi.org/10.1080/10408399609527720

Bhargava, N., Mor, R. S., Kumar, K., & Sharanagat, V. S. (2020). Advances in application of ultrasound in food processing: A review. Ultrasonics Sonochemistry, 64, 104998. https://doi.org/10.1016/j.ultsonch.2020.104998

Chawla, S. P. (2006). Ozone applications in food processing and preservation. Journal of Food Science and Technology, 43(1), 1–12.

Epelle, E. I., Mackenzie, A. R., & Smith, J. A. (2023). Ozone technology in food and fish processing: Principles, applications, and challenges. Trends in Food Science & Technology, 134, 35–47. https://doi.org/10.1016/j.tifs.2023.02.006

Farooq, U., Aadil, R. M., Roobab, U., & Manzoor, M. F. (2023). Cold plasma technology as an emerging non-thermal processing method for seafood: A review. Food Control, 144, 109334. https://doi.org/10.1016/j.foodcont.2022.109334

Giménez, B., Roncalés, P., & Beltrán, J. A. (2024). Ozone treatment in fish preservation: Effects on microbial safety and quality attributes. Food Control, 155, 110101. https://doi.org/10.1016/j.foodcont.2023.110101

Gómez-Estaca, J., Calvo, M. M., & Gómez-Guillén, M. C. (2019). Pulsed electric fields and ultrasound as processing tools for seafood: Effects on quality and functionality. Innovative Food Science & Emerging Technologies, 52, 102–114. https://doi.org/10.1016/j.ifset.2018.11.003

Ma, L., Su, Y. C., & Hussain, M. A. (2011). High pressure processing of oysters: Inactivation of Vibrio spp. and quality changes. Journal of Food Science, 76(2), M133–M138. https://doi.org/10.1111/j.1750-3841.2010.02041.x

Nema, P. K., Kaur, B. P., & Patel, R. K. (2022). Emerging non-thermal technologies for preservation of fish and fishery products. Journal of Food Science and Technology, 59(2), 493–507. https://doi.org/10.1007/s13197-021-05018-7

Nie, X., Lin, S., Zhang, Q., & Zhang, L. (2022). Application of non-thermal technologies in fish and seafood processing: A review. Trends in Food Science & Technology, 119, 135–148. https://doi.org/10.1016/j.tifs.2021.12.007

Sireesha, M., Dhanapal, K., & Reddy, G. V. S. (2022). Ultrasound-assisted processing of fish and fishery products: A review. Journal of Food Processing and Preservation, 46(6), e16544. https://doi.org/10.1111/jfpp.16544

Taha, A., Ahmed, E., & Ismail, M. (2024). Ultrasound processing of aquatic foods: Quality and safety implications. Food Reviews International, 40(2), 220–239. https://doi.org/10.1080/87559129.2023.2187465