Revolutionizing Seafood Safety and Sustainability: ensuring safe seas to plates

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Fisheries and aquaculture are some of the key industries in the Southeast Asian region, not only supplying fish and fishery products to the local demand but also exporting worldwide to meet the growing demand for seafood. However, the perishable nature of seafood poses challenges in maintaining its quality and safety. Hence, there is a need to develop good handling practices and reputable technologies that would mitigate the high microbiological risk while retaining the high nutritional content. Rapid deterioration of quality due to irreversible processes such as microbiological metabolism, oxidative reactions, and enzymatic activity take place soon after the capture and/or harvest of seafood. From catch to consumer, good handling practices and processing technologies are crucial to safeguard the freshness and safety of seafood products by extending shelf life as well as maintaining nutritional quality and economic value.

In this regard, Strategy 3 of the Resolution on the Future of SEAFDEC adopted in 2017 specified "*Ensuring the food safety and quality of fish and fishery products for the Southeast Asian region*" through the "*Development and promotion of technology to produce high quality, healthy and safe fish and fishery products to meet the international standards.*" Therefore, SEAFDEC Marine Fisheries Research Development (MFRD) implemented the project "Enhancing Food Safety and Competitiveness of Seafood Products" from 2020-2024 with support from the Japanese Trust Fund (JTF). The Project aims to develop the Regional Guidelines on Good Manufacturing (GMP) and Handling Practices (GHP) for Ready-to-Eat Raw Fish and Fishery Products as well as High-Pressure Processing (HPP) Protocols for Seafood.

What is High-Pressure Processing (HPP)?

From the moment a fish is caught to its journey to your plate, stringent measures and best practices that safeguard our seafood supply chain and protect consumers are set in place. The fundamental guidelines that ensure that the fish you savour is not only delicious but safe for consumption, shall be published in the upcoming Regional Guidelines which are aligned with international standards. Local seafood processers' capabilities can be strengthened in handling high-risk seafood products, such as ready-to-eat raw fish and fishery products, ensuring these products are consistently produced and controlled according to quality and safety standards. Best practices for quality assurance in handling, processing, storage, transportation, and retail of raw fish and fishery products (**Figure 1**) can then be adopted.

Prevailing traditional food preservation techniques, like thermal processing, render seafood extended shelf-life at the cost of loss of original flavour, taste, appearance, colour, and nutritional quality (Ohlsson *et al*., 2013). Safety is often prioritized over sensorial quality in thermal processing. Consumers today expect the foods purchased and consumed to be not only safe but of high quality, providing sensory characteristics such as taste, aroma, palatability, and appearance (**Figure 2**).

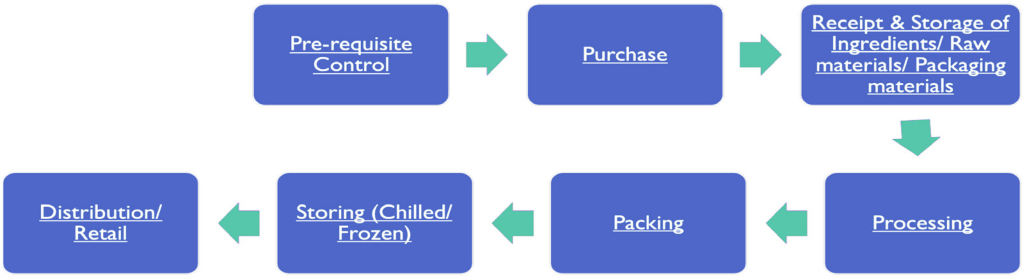

Figure 1. Process flow for handling of ready-to-eat raw fish and fishery products

Figure 2. Pan-fried salmon with asparagus and mash

High-pressure processing (HPP) is an emergent food processing and preservation technique that extends shelf life without altering the nutritional and health attributes of food products (**Figure 3**). It is also called high hydrostatic pressure (HHP) processing and has had various applications with fish and shellfish products over the years. The technology's high pressures destroy or inactivate microbial cells in seafood to improve shelf life, quality, and food safety. As a non-thermal preservation technique, HPP preserves the heat-sensitive sensorial properties (flavour and aftertaste) due to the absence of heat treatment. In HPP, a high hydrostatic pressure (between 100 and 1000 MPa) is applied to food material consistently and simultaneously from all directions which will eventually destroy the detrimental microbes and indigenous enzymes by providing the pasteurization effect without thermal treatment. This technique can be effectively applied to both liquids and solid foods with comparatively higher moisture content (**Box**). Essentially, the objective of introducing HPP is to make high-quality fish accessible to all.

Figure 3. High-pressure processing equipment in a tolling facility in Singapore

Box. Some of the advantages of high-pressure processing (Campus, 2010)

- Increased yield from seafood especially crustaceans and molluscs (Murchie *et al.*, 2005), where shucking and extraction of crustacean meat could be done effortlessly after HPP
- Foods are rendered free of pathogenic and spoilage organisms, whereby *Vibrio* species detected in control, unprocessed crabs were no longer detected in HPP-processed one
- Improvement of shelf life, while microbial load of HPP-processed seafood was still within Singapore Food Regulations Eleventh Schedule microbial limits after chiller storage of these seafood up to 19 days, demonstrating an extension to existing seafood products which are often tagged with not more than seven days shelf-life
- Retention of nutrition, color, and flavor since HPP imparts less effect on low molecular-weight compounds such as vitamins, color pigments, and high volatile flavoring compounds as compared to ultraheat treatment
- Value addition like convenience with the development of new product ranges such as natural/ fresh-like ready-to-eat fishery products
- Reduction of processing time

In collaboration between MFRD and Nanyang Polytechnic, the preliminary trials were carried out on local seafood products (red grouper fillet, squid rings, green mussels, *Vannamei* prawns, and mangrove crab) (**Figure 4**). The trial demonstrated the inactivation of microbial spoilage, verified the improvement of the shelf life of these seafood products (**Table 1**), and value-added these with the conception of a new ready-to-eat (marinated) fish fillet.

Figure 4. Seafood products before being processed in HPP for the preliminary trial

Table 1. Comparison of microbial results of HPP-processed at 5,000 bar, 180 sec of seafood and non-HPP processed control seafood products at Day 0 and Day 19 (EB: Enterobacteriaceae, EC: *Escherichia coli*, Sal: *Salmonella*, VP: *Vibrio parahaemolyticus*, LM: *Listeria monocytogenes*, ND: Not Detected; D: Detected)

Pressure (bar) at 180s	Seafood product	EB (CFU/g)	EC (CFU/g)	Sal (per 25g)	VP (per 25g)	LM (per 25g)
5,000 (Day 0)	Fish	<10	<10	ND	ND	ND
	Squid	<10	<10	ND	ND	ND
	Mussel	<10	<10	ND	ND	ND
	Prawn	<10	<10	ND	ND	ND
	Crab	<10	<10	ND	ND	ND
5,000 (Day 19, stored in chiller)	Fish	<10	<10	ND	ND	ND
	Squid	<10	<10	ND	ND	ND
	Mussel	360	<10	ND	ND	ND
	Prawn	<10	<10	ND	ND	ND
Control (Day 0, non-HPP)	Fish	420	<10	ND	ND	ND
	Squid	80	<10	ND	ND	ND
	Mussel	640	60	ND	ND	ND
	Prawn	320	<10	ND	ND	ND
	Crab	200	<10	ND	D	ND

Effect of HPP on Protein

In general, covalent bonding is not affected by pressure processing, with the exception of sulfhydryl groups and thiol-disulphide interchange reaction. Primary structure of large molecule is minimally affected by pressure (**Figure 5**). HPP modifies secondary, tertiary and quaternary structure of proteins (Kato *et al*., 2002). Small molecules like vitamins, flavour compounds allow preservation of nutritional value and sensory appeal (Linton *et al*., 2002).

Effect of HPP on microorganisms

Microbe's cells are inactivated in HPP due to a combination of certain factors (Simpson & Gilmour, 1997) like changes in cell membranes and cell walls; and changes in proteins and enzyme-mediated cellular function (**Figure 6**). It has been said for microbial inactivation by HPP, *Staphylococcus aureus* (cocci) is more resistant to pressure but rod-shaped pathogenic bacteria like *Escherichia coli*, *Pseudomonas aeroginosa*, and

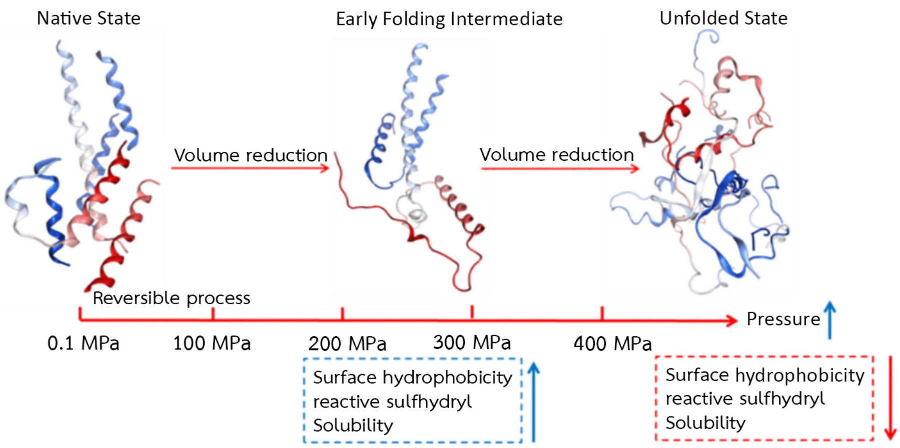

Figure 5. Schematic diagram of the mechanism of pressure-induced protein denaturation (MDPI Foods, 2021)

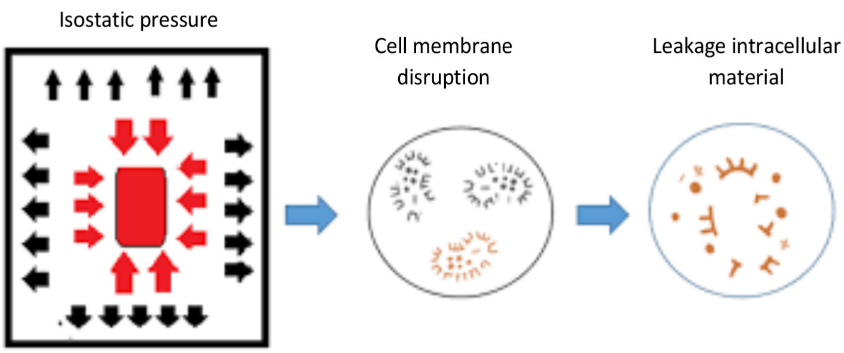

Figure 6. Bacterial inactivation by HPP (Food Research, 2021)

Listeria monocytogenes change their morphology under HPP (Ludwig & Schreck, 1997).

Effect of HPP on colour and texture of the seafood muscle

When fish with red and white muscles are pressurized, the muscle tissue becomes opaque. The effect is similar to that of boiling or grilling with increasing pressures and holding times. Therefore, the fish obtains the characteristics of a cooked, rather than fresh, product. This color change may not be perceived by consumers as desirable; thus, there is a need to develop a new ready-to-eat alternative for such fish products. Furthermore, high pressure can affect molecular interactions (hydrogen bonds, hydrophobic interactions, and electrostatic bonds) and protein conformation leading to protein denaturation, aggregation, or gelation (Messens *et al*., 1997) (**Figure 7**).

Figure 7. Fish fillet before *(left)* and after *(right)* HPP

Building the capacity of the AMSs on HPP

The Project commenced in October 2020 with the inception meeting conducted virtually due to travel restrictions brought about by the COVID-19 pandemic. The scope for both tracks of the Project was discussed and agreed upon by the ASEAN Member States (AMSs).

The virtual training "Good Manufacturing and Handling Practices (GMP & GHP) for Ready-to-Eat Raw Fish and Fishery Products" was conducted in April 2022 with representatives from the AMSs. Subsequently, the AMSs were required to carry out pilot trials on GMP and GHP for ready-to-eat fish and fishery products in their respective countries.

In June 2023, the "Mid-Term Review Meeting for Track I: Regional Guidelines on Good Manufacturing and Handling Practices (GMP & GHP) for Ready-to-Eat Raw Fish and Fishery Products" was held in Singapore (**Figure 8**). During the Meeting, the respective AMSs reported the current food safety guidelines for the safe handling and processing of raw fish and fishery products. They shared their experiences and findings during the trial period (*e.g.* monitoring and enforcement of implementation, hesitancy of fishery establishments adapting food safety measures and difficulty implementing the guidelines in local small scale fishery companies). Being aware of the importance of GMP and GHP in guaranteeing the safety and quality of raw fish and seafood, the respective AMSs are currently adhering to country-specific hygiene requirements, food safety assurance programs, and food safety policies.

Figure 8. Participants in the "Mid-Term Review Meeting for Track I: Regional Guidelines on Good Manufacturing and Handling Practices (GMP & GHP) for Ready-to-Eat Raw Fish and Fishery Products" in Singapore in June 2023

Furthermore, the "High-Pressure Processing (HPP) Training Workshop" was held in June 2023 at Nanyang Polytechnic in Singapore (**Figure 9**). The Training covered the basics of HPP for seafood, HPP parameters for seafood products (*i.e.* crab, red grouper fish, *Vannamei* prawn, squid ring, and mussels), and raw seafood and marinated seafood. A trial run at an HPP facility in Singapore (**Figure 10**) was also included in the Training for the participants to observe the changes after the seafood was processed in HPP.

Figure 9. Participants in the "High-Pressure Processing (HPP) Training Workshop" at Nanyang Polytechnic in Singapore in June 2023

Figure 10. Visit to a HPP facility in Singapore for the participants in the "High-Pressure Processing (HPP) Training Workshop" in June 2023 to observe the changes after the seafood is processed in HPP in Singapore

MFRD would publish a handbook on HPP of fish and fishery products which will include procedures for HPP of fish and fishery products (such as fish meat, oyster, lobster, crabmeat, cooked shrimp, etc.) to add value and extend the shelf life of these products, benefiting both consumers and the industry. Consumers will have access to better quality and safe products that retain their natural flavour, colour, and texture, while the industry will benefit from the extended product shelf life, resulting in less loss due to expired products and the ability to sell or export products to markets further afield. Once completed, the handbook will be disseminated to the AMSs during the End-of-Project Meeting in 2024. Soft copies of the handbook will also be made available via the SEAFDEC website.

Way Forward

More research should be carried out on local seafood products to explore the opportunities that HPP can bring to a broader range of seafood varieties, including delicate fish species, to understand the impact on texture, taste, and shelf life. There is more room in investigating and optimizing pressure-time profiles to achieve the desired pathogen reduction while minimizing any adverse effects on the sensory attributes of fish products. Shelf-life enhancement can be further studied for synergies with other preservation methods, such as modified atmosphere packaging (MAP) or natural antimicrobials, to develop comprehensive preservation strategies that improve both safety and quality.

More deliberate research and development can create innovative HPP-treated fish products that cater to evolving consumer preferences, such as convenient and healthy seafood snacks. Understanding the science behind HPP and its transformative impact on fish preservation, safety, and sustainability will help expand the optimization of this technology for the sustainable management and development of fisheries in the region. Increased adoption and larger-scale production facilities could contribute to economies of scale, to reduce the overall cost of HPP equipment and processing. At the same time, it is critical to assess and minimize the environmental impact of HPP processes, including energy consumption and waste generation, to align with sustainability goals.

The future of HPP in the fish and fishery products industry lies in the continuous refinement of techniques, collaboration across the value chain, and a commitment to addressing consumer expectations, regulatory requirements, and sustainability considerations. Facilitating international collaboration and knowledge sharing to leverage global expertise and experiences in the application of HPP to different fish species and cultural preferences will increase market acceptance in key seafood-consuming regions globally.

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