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Modern Fish Preservation Methods Enhancing the Quality and Safety of Fish and Fishery Products

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Fish and Fisheries products are highly perishable that requires appropriate preservation techniques to maintain their quality and safety throughout the storage period. Recently, different preservation methods were adopted to extend shelf-life and retain the organoleptic properties. The present review intends to explain the principal mechanisms of some of these modern methods employed to preserve quality and safety of fish and fishery products; specifically, High Hydrostatic Pressure Processing (HPP), Pulse Electric Field (PEF), Plasma technology and Microbial preservation. The advantages and disadvantages of each method are discussed in this review so as to provide a global outline about these techniques. In general, all the preservation methods shown a good efficiency to control microbial growth in fish and fisheries products and maintain their sensory, organoleptic and nutritional properties. Conversely, future studies are required to develop a single or combined hurdle-like method to meet both the production requirements and consumers' need.

Keywords

High Hydrostatic Pressure Processing, Pulse electric field, plasma technology, microbial preservation

Introduction

The dependence on seafood as a healthy diet option is on an increasing trend worldwide, owing to its exceptional nutritional properties. According to Food and Agriculture Organisation, the consumption of seafood has increased noticeably from 9.9 kg per capita in the 1960s to 20.2 kg in 2020. Furthermore, the International export value of seafood is 151 billion US dollars on world scale in 2020 (FAO, 2022). Seafood products are regarded as highly perishable foodstuff, being prone to different kinds of contaminants during its course from catch to composition. These contaminants are the chief reason for the onset and consequent detrimental quality changes of these products. Therefore, the seafood processing technology is a state of continuous development over the years to carry away these challenges.

Fish and shellfishes pass through different post process treatments subsequent to their catch, before it gets reaches the processors or the consumers. These processes are categorized into primary and secondary. The primary processing includes the steps such as washing, beheading, gilling, descaling, gutting, grading, filleting, deboning, skinning, chilling and freezing. The secondary processing includes the production of "Value added products" such as salting, drying, smoking, canning, marinating, and packaging of ready to eat products. The proximate composition of seafood has a direct influence on the various mechanisms of spoilage that are associated with microbial, enzymatic and chemical deteriorations, all of which contribute in reducing the shelf life of seafood. Thus, an array of fish preservation techniques have been developed in the field of seafood processing, such as high hydrostatic pressure (HHP), irradiation, microwave heating, ultrasound, pulsed electric field (PEF) and cold plasma technology. These technologies bring about a considerable reduction in the time taken for processing by improvement in the operating conditions. This chapter represents an overview of the different modern fish preservation technologies by classifying them in to three broad categories; physical, chemical and microbiological methods (Mahmud *et al*., 2018).

Priniple of fish preservation techniques

Based on the mode of action, the major fish preservation techniques can be categorized as

i. Slowing down or inhibiting chemical deterioration and microbial growth

ii. Directly inactivitng bacteria, yeasts, molds or enzymes and

iii. Controlling recontamination before and after processing

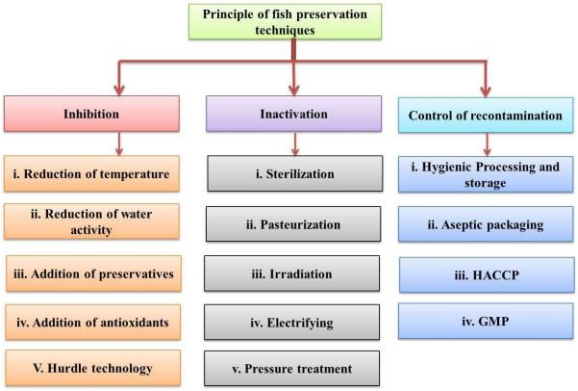

Fig.1. Principle of fish preservation techniques

Different fish preservation methods applied to fish and fishery products

The fish preservation techniques are categorized into three distinctive groups; physical, chemical and microbiological methods. The physical methods of fish preservation can be illustrated as three distinct spoilage control measures, such as moisture control, thermal control and non-thermal control technologies. The chemical methods includes application of antimicrobial preservatives, natural or synthetic antioxidants. The microbiological methods work

by inhibiting the growth of unfavorable microorganisms by favoring the growth of competitive microorganisms in the food product by the application of hurdle technology (Borda *et al*., 2017).

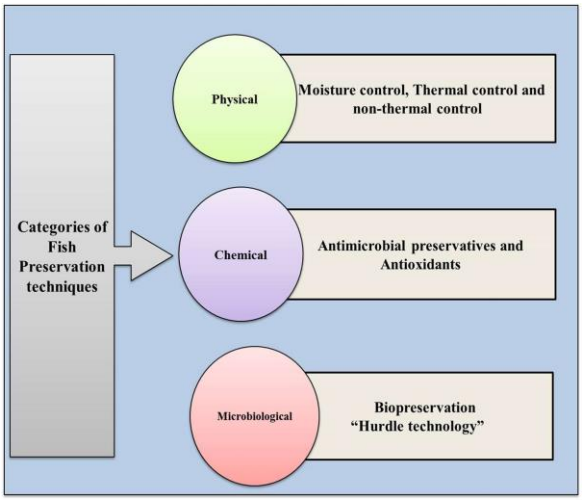

Fig.2. Categories of fish Preservation techniques

Non-Thermal fish preservation techniques

The novel non-thermal food preservation technologies include High hydrostatic pressure processing, Ultrasonic, Ozone application, Pulsed light technology and Pulsed electric field. They find application in seafood preservation and are in the line of commercialization. These technologies present more opportunities in non-thermal or mild heat preservations rather than the common conventional heat processing techniques (Boziaris, 2014).

High Hydrostatic Pressure Processing (HPP)

HPP is otherwise known as ultrahigh pressure processing or pascalization which works on the principle of applying high pressure to the products in an enclosed container for a particular period of time adequate enough to kill all the harmful pathogenic and vegetative spoilage microorganisms and selective enzymes. The pressure applied to the product range from 100 – 1000 MPa and temperature vary from below 0 °C to above 100 °C.

Principle of HPP

The basic principles of the application of high pressure on seafood are Pascal's isotactic and Le chatlier's principles. According to the isotatctics principle of Pascal, high pressure acts consistently and promptly throughout the sample, irrespective of the size and shape of the product. The physico-chemical changes transpired during high pressure follow the principle of Le chatlier's statement that, "when a system at equilibrium is disturbed, then the system counters in a way that tends to reduce the disturbance".

Mechanism of pressure treatment in preservation

The processing cycle of pressure treatment comprises of an initial pressurization period, during which there is build-up of pressure and the food is processed with or without the application of heat to the product. The product subjected to the high-pressure treatment will be packed in a flexible or semi flexible container or pouch and placed in a pressure vessel capable of withstanding the required pressure. The product is immersed in to a pressure transmitting liquid such as water, ethanol, castor oil, silicone oil, etc., that prevents the inner vessel from corrosion. During pressure processing, the temperature of the product increases by adiabatic heating which is influenced by the type of fluid, pressurization rate, temperature and pressure (Board, 2012).

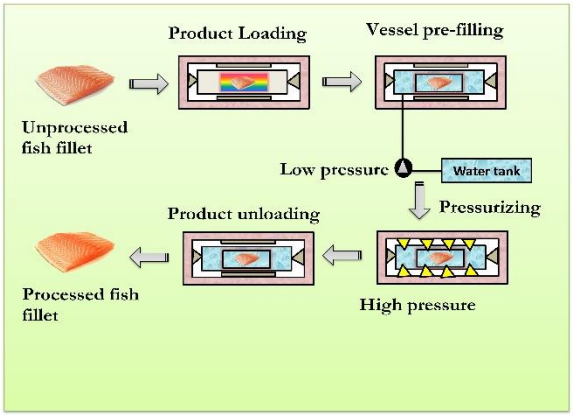

Fig.3. High Pressure Processing

When the process commences, the hydraulic fluid is pressurized with a pump and the pressure generated spreads uniformly in all the directions of the packaged fish product. Because of this uniform application of pressure, the food retains its structure, at higher pressures. The products are maintained in the desired level of pressure for few minutes followed by the decompression or the release of pressure. Followed by the decrease in pressure, the temperature also declines below that of initial product temperature.

Advantages of the HPP technology

1. HPP maintains the natural freshness and quality of the product
2. It does not alter the palatability and functional properties of the product
3. The high-pressure treatment is independent of the size and geometry of the product
4. HPP is an eco-friendly process that do not generate wastes
5. The processing time required for HPP is comparatively low
6. HPP employs uniform application of pressure to all food particles

Disadvantages of the HPP technology

1. The requirement of high infrastructure
2. The technology is less cost effective
3. The higher resistance of spores to pressure
4. Certain enzymes are very resistant to pressure such as polyphenol oxidase
5. The residual oxygen and the enzyme activity in the food could lead to degradation.

Pulse Electric Field processing

PEF is a non-thermal processing technology that applies high intensity electric pulses to food products to achieve microbial inactivation and the product is subsequently stored under refrigeration with proper packaging mechanism resulting in the increased shelf life of the product. This technology was intended to maintain the quality attributes of the food products such as colour, flavour, texture and nutritional value.

Principle of Pulse Electric Field

PEF includes application of external electrical field to liquid or semi-solid food placed between two electrodes for a few microseconds to milliseconds which bring about the inactivation of microorganisms, alteration of enzymes and intensification of some processes like dehydration and drying. The PEF induces the structural changes and rapid breakdown of the cell membrane and the occurrence of this phenomenon is called electroporation (Angersbach *et al*., 2000).

Mechanism of Pulse Electric Field

The pulse electric field can be emitted from various sources by different mechanisms, making use of the impulsive transition of some atoms from an excited state to a state of lower energy. The pulse electric field system consists of various components such as power unit, adjustable xenon lamp units and a voltage connection which allows the transfer of high-current electric pulse. When the current pass through the gas chamber of the lamp unit, the electrons surrounding the atoms are excited, leading them to excite to higher energy levels. These electrons release the energy and fall back to a lower energy level by emitting an intense burst of light. The distribution of wavelength for the optical spectrum ranges from 100 to 1,100 nm (UV to Near infrared).

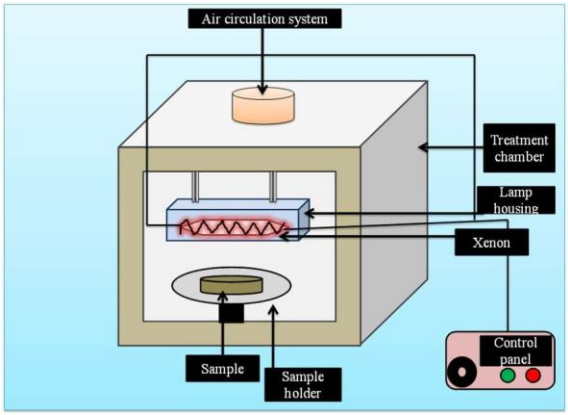

Fig.4. Pulse Electric Field Processing

Advantages of Pulse Electric Field technology

1. The inactivation of microorganisms by pulse light is a rapid process and achieves the disinfection with a short span of time
2. It is categorized as a green technology because the energy consumption is very less during its application
3. The pulse light treated foods is safe for human consumption as it does not produce harmful residues, chemicals and toxic by-products
4. The quality and nutrient properties of the food are retained properly as there is no thermal effect because of the intensity of pulse light applied to food lasts only for few seconds
5. The Xenon-flash lamps used in pulse light technology is eco-friendly compared with other techniques
6. The pulse light technology has low operating costs and less environmental effects as they do not produce volatile organic compounds or suspended airborne particulates and also generates less wastes (Mandal *et al*., 2020)

Disadvantages of Pulse Electric Field technology

1. Low penetration power and possibilities of lipid oxidation
2. Certain microorganisms are resistant to the PL treatment
3. Sample heating is one of the limitations in the practical applications

Plasma technology

The term “Plasma” was coined by an American physicist, Irving Langmuir, which can be defined as “the fourth matter next to liquid, gas and solid”. The plasma technology is an eco-friendly technology as it does not produce organic compounds and have less environmental impacts. It is a partly or wholly ionized gas or a combination of ionized gases which is generated by the exposure of gas under high or low pressure using various electrical discharge sources. This highly reactive gas species generated by the electrical discharge is called plasma which comprises of photon, electron, ions, free radicals and atoms. The plasma can be classified into two different types based on their generation as high – temperature or fusion plasma and low – temperature. In high – temperature plasma, all the reactive species exist in a state of thermal equilibrium. Whereas, low – temperature plasma is further classified into thermal plasma or non – thermal (cold) plasma (Olatunde *et al*.,2020).

Principle of Plasma in fish preservation

The highly reactive species produced by the electrical discharge is called plasma that acquires electron, photon, ions, free radicals, atoms and meta-stables but have net neutral charges in its fundamental or excited state. The factors that affect plasma processing are ionization, reaction rate, rate constants, the mean free path and the electron energy distribution. The increase in energy input of matter, when past a certain level of a gaseous state produces an excited stage of molecules, called plasma. They possess net neutral charge which is associated with positive and negative charge carriers present in uniform ratio. The chemical process of plasma can be differentiated into two

types. i.e. heterogeneous and homogenous gas phase reaction (Shaw *et al*., 2015).

Mechanism of Plasma in preservation

The sources of Non-Thermal Plasma (NTP) are DC glow and RF discharge plasma, dielectric barrier discharge plasma, surface discharge plasma, atmospheric pressure discharge plasma, microwave discharge plasma and pulsed discharge plasma. Different microorganisms can be effectively inactivated by plasma treatment. The lethal effect of plasma on microbial cells is due to the interaction between the microbial cells and plasma ions. This phenomenon of destruction of microbial cells is called "etching". The mechanism behind inactivation of enzyme activity is the breakdown of peptide bonds and denaturation of protein. The plasma technology is a widely used technique for the preservation of various fish and fishery products (Shaw *et al*., 2015).

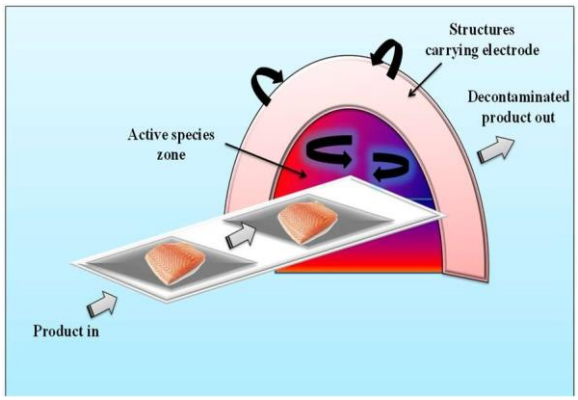

Fig.5. Plasma Technology

Advantages of plasma processing

1. Low operating temperature
2. Less heat loss
3. High surface modification
4. Microbial inactivation
5. Low cost

Disadvantages of plasma processing

1. It enhances lipid oxidation
2. It changes texture and colour
3. Increases the acidity of products
4. Since plasma treatment is a surface phenomenon, it is rather difficult to inactivate the endogenous enzymes.

Antimicrobial preservatives and antioxidants

Antimicrobial substances, both synthetic and natural are commonly used in fish preservation to extend the shelf life and maintain quality and safety. In recent times, researchers have laid abundant effort to search natural preservatives which could inhibit the growth of microorganisms in food. Also, the preference of consumers had changed due to the negative impact of synthetic chemical preservatives, which have now prompted use of natural preservatives in the food industry. Ideal natural preservatives should have broad attributes such as bactericidal and fungicidal activities, non-toxic, higher activity at lower concentrations, impart no flavour or colour to food, label friendly and cost-effective (Tsironi *et al*., 2020). Natural preservatives are primarily available from three main sources such as plants, microorganisms and animals. The plant-based preservatives are essential oils and polyphenols, microbial based preservative include bacteriocin and animal-based preservatives include chitosan obtained from crab or shrimp shells which are proved to have antimicrobial or antioxidant properties. Additionally, various bioactive compounds extracted from algae, mushroom etc. also provide a novel source of natural preservatives in the food industry (Speranza *et al*., 2021).

Microbial – Derived compounds

Certain strains of Lactic acid bacteria (LAB) produce some inhibitory substances such as bacteriocins, diacetyl, retrocyclin and antifungal compounds that can be employed against spoilage and disease-causing food-borne pathogens during fish storage. Bacteriocins are a group of potent antimicrobial peptides containing about 30 – 60 amino acids which are classified into four classes (Ghaly *et al*., 2010);

I. Lantibiotics – Low molecular weight (<5 KDa) thermostable peptides
II. Small thermostable peptides (<10 KDa)
III. High molecular weight (>30 KDa) thermolabile peptides
IV. Large peptides complexed with lipids or carbohydrates

Reuterin is considered as D-ribose analogue which is an intermediate compound generated by *Lactobacillus reuteri* during glycol metabolism (Speranza *et al*., 2021).

Conclusion

The quality deterioration of fish and fishery products is attributed to multiple reasons. There are a multitude of preservation methodologies recommended to overcome these deteriorative reactions. In the progress of technological developments, various innovative preservation techniques such as High-Pressure Processing (HPP), Pulse light technology and plasma technology are introduced in the field of fish processing technology although some constraints with respect to sensory characteristics have also been indicated. These limits could be overcome by using multi-dimensional approach in adopting these techniques in a synergistic and combined manner, thus increasing microbiological safety and sensory quality. Further investigations are needed to develop single or combined hurdle-like method to help the seafood industries to choose the paramount technology that meets their seafood production requirements and the consumers' need.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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