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An Introduction to Seafood and Recent Advances in the Processing of Seafood Products

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ABSTRACT
Seafood is one of the highly traded food which provide essential local food and hold a major share in the economy of many countries. Finfish and shellfish are two major classes of the fish which includes white fish, oil-rich fish, molluscs and crustaceans. Seafood has been regarded as an excellent source of various nutritional compounds like proteins, healthy fats (polyunsaturated fatty acids especially omega-3 and omega-6), iodine, vitamin D, calcium etc and these compounds are having preventive effects over many heart diseases and autoimmune disorders. Sea foods are having high water content with neutral pH and these conditions make it a good harbour for the proliferation of microorganisms along with accelerated biochemical spoilage process. The freshly caught fish undergoes faster rigor mortis, oxidative spoilage, autolysis, microbial degradation and these processes are responsible for breakdown/formation of various compounds followed by changes in odour, flavor and texture of the fish meat. So there is a strict need of studying various innovative food processing techniques like high pressure processing, pulse electric field, ultrasound, irradiation, pulsed light technology, microwave processing, ohmic heating, high pressure freezing, high pressure thawing etc which can be employed for the processing and preservation of sea foods. As the consumers of present era is highly concerned about nutritional value of the food along with minimal processing and additive-free food products these emerging innovative processing technologies can help to provide safe, nutritive, additive free foods with minimum levels of processing.
Keywords: Fish, Fishery products, Innovative techniques, Preservation, Processing, Seafood

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INTRODUCTION

Seafood is one of the important sources for food, nutrition, income and livelihoods and has been recommended to be consumed more frequently by nutritionists and health experts[1]. The broad classification of fish includes finfish (white fish and oil-rich fish) and shellfish (molluscs and crustaceans).The average annual increase in global food fish consumption has been reported as 3.20 per cent (1961-2016) which exceeded that of meat from all terrestrial animals (2.80 percent). The per capita food fish consumption has grown from 9.00 kg in 1961 to 20.20 kg in 2015, at an average rate of about 1.50 percent per year [2].Fish and fishery products are one of the valuable sources of animal protein and 150 g of fish can provide up to 50 to 60% of the daily protein requirements for an adult [3].In some small island developing countries like Bangladesh, Cambodia, the Gambia, Ghana, Indonesia, Sierra Leone and Sri Lanka fish contributes, or exceeds, 50% of total animal protein intake[3,4].The fresh fish and seafood's has the fastest overall growth worldwide after drinkable yogurt and fresh soup and rank third among the various food categories [5].Enzymatic autolysis, oxidation and microbial growth are the three major causes for the fish spoilage and fresh fish spoilage is a very rapid process [6]. The extent of these changes with time determines the shelf life of the product and many emerging technologies have the potential to extend the shelf life of fish and fishery products. In modern era, the high quality processed foods with minimal changes in nutritional and sensory properties is the first choice of the consumers and various novel processing technologies are being explored and implemented to provide safe, fresh-tasting, and nutritive foods [7].The recent emerging technologies in processing of seafoods includes high pressure freezing and thawing, high pressure processing, pulsed electric field, ultrasound, irradiation, intense pulsed light technology, ohmic heating, microwave processing etc [7,8,9].The paper includes an overview on introduction to seafoods, spoilage and the recent innovative techniques of processing and preservation which are related with the extension of shelf life of fish and fishery products.

SEAFOOD CLASSIFICATION AND SPOILAGE

Seafood is any form of sea life regarded as food by humans and broadly classified as fish (white and oily varieties) and shellfish such as mussels, crustaceans such as prawns, crabs, lobsters and squid. The white fish is referred as “lean fish” because all the oils are contained in the liver, which is removed during gutting. In other type, the oils are distributed throughout the flesh of the fish and categorized as oil-rich fish. The other broad class shellfish has been further divided into molluscs and crustaceans which include mussels, oysters and scallops prawns, shrimp, crab and lobster. The detailed classification and world trade share of various seafood species has been given in Figure 1 and Table 1.
The main reasons behind the spoilage of food products are chemical, enzymatic or microbial activities. Out of these chemical deterioration and microbial spoilage are responsible for loss of 25 per cent of gross primary agricultural and fishery products every year [6,11]. The fresh fish spoilage is a very rapid process and the spoilage process (Rigor mortis) generally starts within 12 h of storage at high ambient temperatures[6,12].Enzymatic autolysis, oxidation and microbial growth are the three major causes for the fish spoilage [6].The oxidative spoilage of fish is mainly concerned with lipid oxidation and it is one of the major reason for the spoilage of pelagic fish species such as mackerel and herring with high oil/fat content in the flesh [13]. With the initiation of spoilage, a sickly sweet odor develops followed by stale-fish odor which is due to the formation of trimethylamine. At the end there is generation of ammonia odor followed by putrid odors due to H_2S and indole compounds [14].The other spoilage compounds formed by various bacteria are hydrogen sulphide, methylmercarptan, dimethylsulphide, hypoxanthine ammonia ketones, aldehydes, esters,acetic acid, butyric acid and propionic acid [15].The various enzymes and micro-organisms associated with spoilage have been mentioned in Table 2.

INNOVATIONS IN SEAFOOD PROCESSING

The various conventional techniques employed in seafood processing are drying, curing, salting,smoking, pickling,canning and refrigeration. While the novel innovative techniques includes high pressure freezing and thawing, high pressure processing, pulsed electric field, ultrasound, irradiation, intense pulsed light technology, ohmic heating, microwave processing etc.

High pressure freezing and thawing

High pressure freezing and thawing processes plays an important role in improvement of the quality of frozen and thawed foods. These processes dates back from the beginning of the eighties and nowadays commercialization of high pressure processed products have been started in Japan, USA and Europe [19]. The melting temperature of water decreases as the pressure is lowered down to -21^{o}C at210 MPa and the opposite effect is observed above this pressure. This property helps in rapid freezing and thawing of foods which are having high water content as in case of seafoods [19]. During high pressure freezing there is very rapid and uniform icenucleation at high pressure which is followed by cooling to a temperature just above the freezing point at the applied pressure andfinally the pressure is suddenly released and this process is termed as pressureshift freezing (PSF). This process causes instantaneous and uniform nucleation throughout the food material and formation of small ice crystals takes place [20,21,22]. During thawing process the high pressure decreases the melting point and specific heat capacity of ice which increase the temperature gap between the heat medium and the phase change front. As the high pressure creates large temperature difference between the thawing medium and frozen samples the thawing rate is consequently increased [23]. The other recent thawing technologies other than ultra-high pressure assisted thawing includes ultrasound-assisted thawing, high-voltage electrostatic field thawing, ohmic thawing, and radio frequency thawing [23]. The various studies carried out under high pressure freezing and thawing have been mentioned in Table 3.

High pressure processing

High pressure processing (HPP) is a "non-thermal" technique for food preservation which is carried out by application of intense pressure of 100-1000 Mpa. The high pressure inactivates the microorganisms like yeasts, molds and bacteria (*E. coli*, *Salmonella* and *Vibrio*) and maintains the sensory and nutritional characteristics of treated food [31].There are two general scientific principles associated with HPP namely Le Chatelier's principle and Isostatic rule. The first principle states that with the application of pressure there is a decrease in volume whereas, the Isostatic rule states that the applied pressure is instantaneously and uniformly transmitted throughout the sample. The various studies carried out in high pressure processing of seafoods have been summarized in Table 4.

Pulsed electric field processing

Pulsed electric field (PEF) processing is the application of very short pulses of high electric fields with the duration of micro seconds (1–100 μs) with an intensity of 10-80 kV/cm. The electric pulses with electric field intensities in the range of 0.1 to 1 $kV\cdot cm^{-1}$, 0.5 to 3 $kV\cdot cm^{-1}$ and 15 to 40 $kV\cdot cm^{-1}$ causes reversible permeabilization for stress induction in plant cells, irreversible permeabilization of plant and animal tissue and the irreversible permeabilization of microbial cells, respectively [7].The working of pulsed electric field is based on two basic mechanisms namely electroporation (exposure to high voltage electric field pulses) and electric breakdown which causes perforation of cell wall by electroporation leading to leaking of cytoplasmic content and cell death [42,43].Pulsed electric field has lethal effects on vegetative bacteria (gram negative), moulds and yeasts while gram positive bacteria and bacterial spores are moderately and highly resistant towards PEF processing[44]. PEF is a continuous processing method and it is not suitable for solid food products that cannot be pumped, so it is restricted to food products (fish soups) with no air bubbles and low electrical conductivity [5].PEF treatment has potential applications in several processes such as preservation, tenderization, and aging and it can be successfully used for increasing water holding properties of fish products as well as for fish drying. In sea food industry it can also be also used for by-products valorization as it has huge potential to enhance the extraction of high added-value compounds [45].PEF plays an important role in utilization of fishbone and fishbone waste, serves as a new clue for processing and extraction of natural products. The fishbone hydrolysate prepared by addition of these extracted products can further processed into multi-active and high-added-value compound products [46].

Ultrasound processing

Ultrasound processing refers to the use of high frequency sound waves (> 20 MHz) which cause physical, mechanical or chemical changes in the food material [7]. The two types of sound waves which have huge potential in food processing applications are high frequency low energy power ultrasound and low frequency high energy power ultrasound. The low energy ultrasound has frequency in the range of 100 KHz with intensities less than $1W/cm^2$ and used for monitoring of food products during processing and storage. Its other potential applications are evaluation of the composition of meat products, poultry and fish of raw and fermented stages and checking quality of fruits, vegetables, cheese, oil, bread, cereals etc. On the other hand higher intensity ultrasound has frequency in the range of 20 to 100 KHz with intensities more than $1W/cm^2$ and used for controlling microstructures and modification, emulsification, de-foaming of food products [7,47,48]. Ultrasound is not very effective in killing bacteria so ultrasound is generally used with combination of other technologies like manosonication (MS: ultrasound and pressure amalgamation), thermosonication (TS: combination of ultrasound and heat), manothermosonication (MTS: combination of ultrasound, pressure and heat) and these combined technologies have wide applications in inactivation of micro-organisms, food freezing, thawing of frozen foods, drying, sterilization and extraction procedures [48]. The ultrasonic probe system (20-40 kHz) and ultrasonic bath system (20 kHz to >1 MHz) are most commonly used equipments used for the application of ultrasound in food industry. Ultrasound treatment of dried sea cucumber (*Stichopus japonicas*)increased the rehydration ratio and water holding capacity with increasing levels of ultrasound power from 100 W to 300 W and decreasing levels of ultrasound frequency from 45 KHz to 28 KHz. Further ultrasound assisted rehydration increased the rehydration efficiency of dried sea cucumber by 12 fold without any adverse effects on its textural properties [49].Naturally contaminated fish boxes with food residue and effluentsfrom a commercial crate cleaning system were subjected to ultrasonic water bath for 120 seconds at 60^{o}C and ultrasonic treatment reduced the *Enterobacteria* counts and aerobic plate count below the detection limit [50].

Irradiation

Food irradiation or cold pasteurization refers to the physical treatment or exposure of pre-packaged food or bulk foodstuffs to gamma rays, X-rays, or electrons with the dose in the range of 0.1-10 kGy which helps in controlling insect infestation, reducing the numbers of pathogenic or spoilage microorganisms, and delay or eliminate various natural biological processes such as ripening, germination, or sprouting in fresh food [7,51].Gamma radiations emitted from Cobalt-60 and Cesium-137(radioisotope source), X-rays and electrons generated from a machine source below 5 MeV and 10 MeV are generally used for irradiation of various food items [7]. The population of various pathogenic and fish spoilage micro-organisms like *Salmonella, Listeria,Vibrio* spp., *Pseudomonas* and *Enterobacteria* can be controlled with the irradiation doses in the range of 2 kGy and 7 kGy [52].International Consultative Group on Food Irradiation (ICGFI) has recommended the irradiation doses as2.0, 3.0and 5.0 kGy for the control of infection by parasites, shelf life extension and reduction of pathogenic micro-organisms in various seafoods and their products. The various studies carried out in high pressure processing of seafoods have been summarized in Table 5.

Intense pulsed light

Pulsed light technology also referred to as high-intensity pulsed UV light (HIPL),pulsed UV light (PUV), pulse light technology (PLT), high-intensity broad-spectrum UV light (BSPL),intense light pulsed (ILP) and pulsed white light (PWL)is a non thermal processing technique in which inert-gas flash lamps discharges short electric pulses of high voltage (70kV/cm) into the food product and consequently reduce the pathogenic as well as spoilage micro-organisms[61-64]. It is an improved form of ultraviolet-C treatment and its lethal effect on micro-organisms is dueto photo-chemical or photo-thermal mechanism [63]. Food and Drug Administration, 2015 [65] has approved the use of pulse light technology in 1996 for the production, processing and handling of foods with cumulative UV dose or fluence limits upto 12 J cm^{-2}, emission spectra 200 and 1100 nm and pulse duration at ≤2 m/s [66]. The potential applications of pulsed light technology in various seafoods and products have been mentioned in Table 6.

Ohmic heating

Ohmic heating (joule heating, electrical resistance heating, direct electrical resistance heating, electro heating or electro conductive heating) is a process in which heat is generated in the food and food components and becomes the elements of an electric circuit through which an alternating current (AC) flows [73,74].Ohmic heating treatment prevents overheating of the food, helps in maintaining natural properties along with the inactivation of microorganisms and enzymes and these characteristic features can be utilized in wide range of potential applications like pasteurization, sterilization, aseptic processing, cooking, thawing, blanching, evaporation, extraction, fermentation of food materials [75,76,77]. The various applications of ohmic heating for the various seafood species has been given in Table 7.

Microwave processing

Microwaves are the electromagnetic waves having frequency and wavelength in the range of 300 MHz to 300 GHz and 1m to 1mm, respectively [7]. Most of the industrial microwave systems operate at 915 and 2450 MHz (2.45 GHz), whereas home appliances are based on the frequency levels of 2450 MHz [81]. The various applications of microwave drying in food processing including seafood sector include microwave assisted hot air drying, pasteurization, sterilization, thawing, microwave vacuum drying, microwave freeze drying, tempering and baking [7,82]. Recently, the microwaves have been extensively used in heating of foods so as to enhance microbial destruction and promote better product quality. This technology has been accepted by some of the European and Japanese food processing for commercial pasteurization and sterilization of foods, while in North America it is still under partial acceptance [81]. Microwave heating is generally based on the dipolar and ionic mechanism and the realignment of polarized dipolar molecules occurs at a speed of million times per second which causes internal friction of molecules followed by heating of the material [5,7,82]. Hot air micro-wave drying method (200-600 W at 40-50^oC) has been successfully employed for drying of tilapia fish with reduced drying time and improved quality in terms of rehydration ratio [83]. Wu and Mao (2008) have carried out hot air and microwave drying of grass carp fillets and reported microwave drying method as more efficient method [84]. A significant reduction in drying time of sardine fish (9.5 to 4.25 minutes) has been reported with the increasing microwave power from at 200 to 500 W [85]. Microwave power at 60% for 20 s of time has been reported as optimum cooking conditions of trout (*Onchorhyncus mykiss*) in microwave [86].

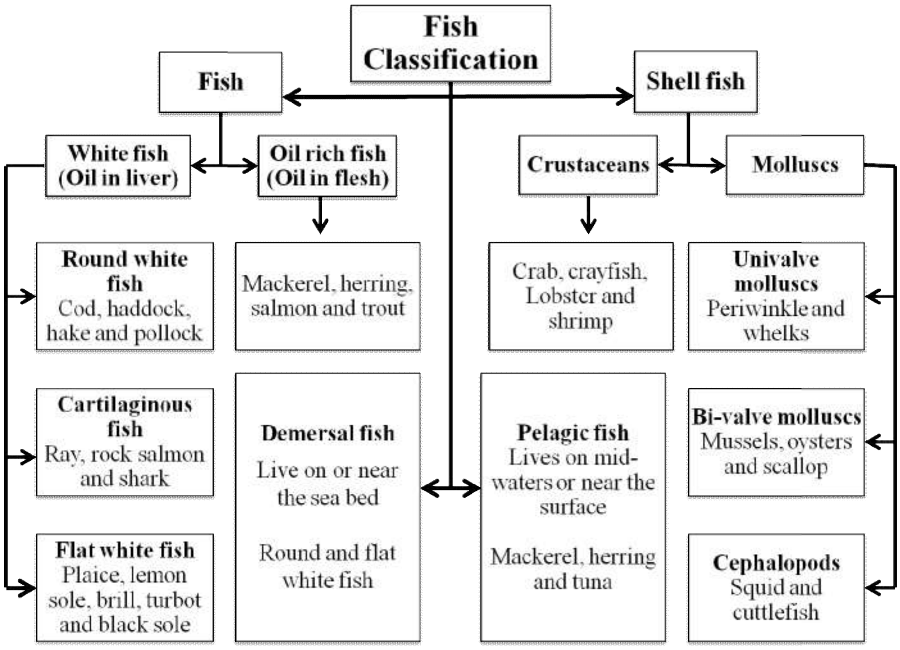

Figure 1: Classification of fish [10]

Table 1: World trade share of various seafood species, 2016 (FAO, 2018) [2]

Category	Share by value(%)	Share by quantity(%)
Fish	**65.40**	**79.8**
Salmons, trouts and smelts	18.10	7.4
Tunas, bonitos and billfishes	8.6	8.6
Cods, hakes and haddocks	9.6	14.0
Other pelagic fish	6.1	11.7
Freshwater fish	3.2	4.5
Flounders, halibuts and soles	2.1	1.6
Other fish	17.80	32.0
Crustaceans	**23.0**	**8.3**
Shrimps and prawns	16.1	6.2
Other crustaceans	6.9	2.1
Molluscs	**11.0**	**11.1**
Squids, cuttlefishes and octopuses	6.4	3.8
Bivalves	3.2	6.0
Other molluscs	1.4	1.3
Other aquatic invertebrates/animals	**0.6**	**0.8**
Total	**100.0**	**100.0**

Table 2: Enzymes and micro-organisms responsible for the spoilage of fish [6,16-18]		
Spoilage	**Class**	**Effects and examples**
Enzymatic spoilage	• Glycolytic enzymes	• Lactic acid production resulting in pH drop.
	• Autolytic enzymes	• Gradual production of hypoxanthine
	• Cathepsins	• Softening of tissue
	• Chymotrypsin, trypsin, carboxy-peptidases	• Belly-bursting
	• Calpain	• Softening
	• Collagenases	• Softening and gaping of tissue
	• Trimethylamine Oxide (TMAO) demethylase	• Formaldehyde production
Microbial spoilage	• Bacterial species	• *Pseudomonas*,*Alcaligenes*, *Vibrio*, *Serratia* and *Micrococcus*
	• Gram-negative fermentative bacteria	• *Vibrionaceae*
	• Psychrotolerant gram-negative bacteria	• *Pseudomonas* spp. and *Shewanella* spp.
	• Pathogenic bacteria	• *Streptococcus iniae*, *Vibrio vulnificus*, *Salmonella spp*, *Clostridium botulinum* type E, *Erysipelothrix rhusiopathiae*

Table 3: Effects of pressure shift freezing and thawing technique on seafood species [5,7,22,24-30]			
Technique	**Food Material**	**Treatment**	**Results**
Pressure shift freezing	• Atlantic salmon • Smoked salmon • Sea bass muscle • Lobsters	• 100-200 Mpa (-8.4 to -20 ^{o}C) • 207 Mpa (-21 ^{o}C) • 200 Mpa (-18 ^{o}C) • 200 Mpa (-18 ^{o}C)	• Smaller ice crystals and less damage to the muscle tissue. • Inactivation of various micro-organisms. • Improved and stable microstructure during frozen storage. • Increased toughness and reduced ice crystals.
Pressure shift thawing	• Whiting filets • Aiguillat & Scallops • Frozen salmon • Fish fillets	• 150 Mpa • 150 Mpa • 100,150 & 200 Mpa • 200 Mpa	• Minimization of drip losses during thawing process. • Reduced thawing drip losses (70 and 31 % in aiguillat & scallops). • Reduced thawing time by 23, 18 and 17 minutes • Reduced drip loss, low microbial count and better organoleptic characteristics (color & texture)

Table 4: Effects of high pressure processing on various seafood species [5,7,32-41]

Food Material	Treatment	Results
• Surimi paste	• 300-400 Mpa	• Destruction of all microbes
• Shrimp	• 435 Mpa	• 10 days increase in self life
• Tuna muscle	• 220 Mpa (30 min)	• Prolonged shelf life with reduced proteolysis activity and texture degradation
• Indian white prawns	• 250 Mpa	• Enhanced shelf life
• Minced albacore muscle	• 275 and 310 Mpa (2,4 and 6 min)	• Enhanced shelf life, color & texture improvement and lipid stabilization
• Mackerel (Filleted)	• 250 and 400 Mpa for 0-60 min(20-25 ^{o}C)	• Reduced activity of *Escherichia coli* (O157:H7) and *Listeria monocytogenes*
• Yellow tuna chunks	• 200 Mpa	• Enhanced shelf life
• Salmon	• 200 and 500 Mpa (120 s)	• Enhanced shelf life and acceptable up to18 days (Shelf life by producer: 10 days)
• Cod	• 200 and 500 Mpa (120 s)	• Spoilage after 21 (200 Mpa) and 26 (500 Mpa) days ; Control sample spoilage: 11-15 days
• Mackerel	• 200 and 500 Mpa (120 s)	• Bacterial levels below spoilage levels up to12 (200 Mpa) and 19 days (500 Mpa); Control sample spoilage: 9 days
• Mackerel	• 200 and 400 Mpa	• Shelf life of 17 and 19 days
• Raw ostrich sausages	• 300- 400 Mpa (40-60 ^{o}C)	• Increased gel strength
• Cold-smoked dolphin fish and salmon	• 300 Mpa for 15 min (20 ^{o}C)	• Increased hardness
• Sea bass	• 300 Mpa	• Decreased calpain activity
• Cold-smoked salmon	• 100 Mpa	• Decreased cathepsins activity
• Yellow fin tuna chunks	• 250 Mpa (5 min)	• Whitening effect due to myoglobin denaturation

Table 5: Effects of irradiation on various seafood species [53-60]

Food Material	Treatment	Results
• Tuna fillets	• 0.6 kGy	• Reduction in microbial growth (>7 log CFU/g)
• Trout fillets	• 0-2 kGy	• Reduced accumulation of putrescine,cadaverine and tyramine, and retention of organolepticproperties.
• Crap fillets and seer fish steaks	• Irradiation + edible coating	• Inhibited lipid oxidation, reduced bacterial growth and maintained sensory acceptability.
• *Gwamegi* (Pacific saury)	• 3,5,7 and 10 kGy	• Reduction in murine norovirus 1 by 0.66, 0.88, 1.31 and1.66 log_{10}PFU/ml.
• Semi dried squid	• 3,5,7 and 10 kGy	• Reduction in murine norovirus 1 by 0.59, 0.88, 1.36 and 1.81 log_{10}PFU/ml.
• Chili shrimp paste	• 10 kGy	• Decontamination of samples without any significant effects on phenolic, capsaicinoids, volatile compounds and texture
• Shrimps	• 0,4,8 and 10 kGy @ 1.7 kGy/h	• 10 kGy was found adequate for preservation and enhanced shelf life without significant alteration in nutrients

Table 6: Effects of pulsed light treatments on various seafood species [67-72]		
Food Material	**Treatment**	**Results**
• Salmon fillets	• 5.6 J/cm^2	• Reduction in population of *Listeriamonocytogenes*and*E. coli*from 8.7 to 0.72–0.8 and 0.24-0.91 log, respectively.
• Flat fish	• 6.3 and 12.1 J/cm^2	• 2.2 and 2.4 log reduction in *L. monocytogenes* cells
• Salmon	• 6.3 and 12.1 J/cm^2	• 1.9 and 2.1 log reduction in *L. monocytogenes* cells
• Shrimp fillets	• 6.3 and 12.1 J/cm^2	• 1.7 and 1.9 log reduction in *L. monocytogenes* cells
• Raw salmon	• 3, 10 and 30 J/cm^2	• Reduction in aerobic plate count
• Tuna carpaccio	• ≤ 11.9 J/cm^2(4 ^{o}C)	• Reduction in population of *L. monocytogenes, E. coli, Vibrio parahaemolyticus* and *S. enterica*
• Fish products	• 0.053 J/cm^2	• Inactivation of various micro-organisms like *Photobacterium phosphoreum, Serratia liquefaciens, Shewanella putrefaciens, Brochothrix thermosphacta, Pseudomonas* and *Listeria innocua*
• Shrimps	-	• Extended shelf life and no discolouration and foul smelling with respect to control

Table 7: Applications of ohmic heating on processing of various seafood species [78-80]		
Food Material	**Treatment**	**Results**
• Chilean blue mussel (*Mytiluschilensis*)	• 50, 70 and 90 ^{o}C	• Reduction in mesophilic aerobic micro-organisms by 1.7 logarithmical units and *Enterobacteria*counts reduced to undetectable levels (90 ^{o}C). • Significant reduction in cadmium and lead contents in samples processed by ohmic heating at 70 and 90 ^{o}C. • Decreased cutting strength.
• Shrimp (Raw frozen at -18 ^{o}C)	• 72 ^{o}C	• No significant differences in texture and ohmic heating maintained comparable quality with conventionally heated samples
• Shrimp (Fresh frozen at -20 ^{o}C)	• 72^{o}C	• Uniform heating and reduced cooking time by 50 % • Similar texture, colour and yield when compared with steam cooking

CONCLUSION

The various health benefits of various seafood species over red meat is one of the main reason behind the increasing consumption of seafoods and it has become one of the major source of animal protein in the human diet. During past decades the aquaculture has grown at a very high rate and the fish or seafood is becoming more accessible to the consumers. So by keeping this factor in mind and the perishable nature of seafoods there is a greater need for various innovative and safer technologies for the processing of seafoods. The various innovative techniques employed for seafood processing have a tremendous potential for extending the shelf life, reducing the wastage and delivering high quality food in terms of nutritive and organoleptic properties.

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