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Advances in Processing and Packaging of Fish and Fishery Products

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Abstract

Health, nutrition and convenience are the major factors driving the global food industry in this era. Fish products have attracted considerable attention as a source of high amounts of important nutritional Components like high-quality protein, essential vitamins, minerals and healthful polyunsaturated fatty acids to the human diet. As a result of this the fresh fish and seafood's rank third among the food categories with the fastest overall growth worldwide, next to drinkable yogurt (18%) and fresh soup (18%). Consumption of both freshwater and seawater fish is expected to increase in the future. As fish is highly nutritious, it is also highly susceptible to spoilage, due to intrinsic and extrinsic factors. Proper processing and packaging helps in maintaining the eating quality of fish for extended period. Worldwide, an array of processing and packaging methods is followed. This ranges from a simple chilled or ice storage, salted and drying to most recent and advanced high pressure and electromagnetic field applications, which attracts opportunities from both small scale and industrial level entrepreneurs. Fish products in live, fresh chilled, whole cleaned, fillets steaks, battered and breaded products, variety of dried products, smoked fish, fish sausage and traditional products are the range of low cost processing methods which can be readily adopted by small-scale fishers. The processing methods like canning or heat processing, freezing, vacuum and modified atmosphere packaging, analogue products, high pressure processing, pulsed light processing, irradiation, electromagnetic field etc are the processing methods which requires higher investments can be adopted by large scale entrepreneurs, apart from the above mentioned processing methods. Apart from proper processing, attractive, suitable packaging and advertising are also important which determine the success of any product. Present article gives an insight into the recent advancements in the processing and packaging of fishery products.

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Introduction

Consumers demand high quality processed foods with minimal changes in nutritional and sensory properties. Alternative or novel processing technologies are being explored and implemented to provide safe, fresher-tasting, nutritive foods without the use of heat or chemical preservatives. Recent developments have improved techniques in handling, product development, packaging, preservation and storage. Entrepreneurs shall be benefited with a method capable of increasing the safety and shelf life of their foods.

Taking advantage of specific potentials and opportunities of these new processes, including the understanding and control of the complex process-structure-function relationships, offers the possibility for a science-based development of tailor-made foods. To consumers, the most important attributes of a food product are its sensory characteristics (e.g. texture, flavour, aroma, shape and colour). A goal of food manufacturers is to develop and employ processing technologies that retain or create desirable sensory qualities or reduce undesirable changes in food due to processing.

Sea foods are highly perishable and usually spoil faster than other muscle foods. They are more vulnerable to post-mortem texture deterioration than other meats. Freshly caught fish undergoes quality changes as a result of autolysis and bacterial activity. Extent of these changes with time determines shelf life of the product. Proper storage conditions are essential to prevent the spoilage of fish and fishery products. Many emerging technologies have the potential to extend the shelf life and are also welcomed by seafood industries globally but some are still in the research arena waiting to be worked on.

Few of the emerging technologies that have application in fish processing are High Pressure Processing, Irradiation, Pulsed light technology, Pulsed Electric Field, Microwave Processing, Radio frequency, Ultrasound, etc. Packaging technologies like Modified Atmosphere, Active and Intelligent packaging also plays an important role in fish preservation.

High Pressure Processing

High pressure (HP) processing is an emerging and innovative technology that has a great potential for extending the shelf-life with minimal or no heat treatment. It is also effective in preserving the organoleptic attributes of many foods.

High pressure Processing (HPP) is a non-thermal technology in which the food product to be treated is placed in a pressure vessel capable of sustaining the required pressure and the product is submerged in a liquid, which acts as the pressure transmitting medium. Water, castor oil, silicone oil, sodium benzoate, ethanol or glycol may be used as the pressure transmitting medium. The ability of the pressure transmitting fluid to protect the inner vessel surface from corrosion, the specific HP system being used, the process temperature range and the viscosity of the fluid under pressure are some of the factors involved in selecting the medium.

The early efforts for HP technology have been initiated in Japan, but now have been commercialized in North America, Europe and in China. The first high pressure processing line was introduced in Japan for jam manufacture in 1990 and has since been upgraded to several food products. High pressure processed foods were first commercialized in Japan in 1992. Machines are now available with operating pressures in the range 400-700 MPa. HP processing affects mainly the non-covalent bonds of the food and quality characteristics of foods such as color, flavor and nutrients generally remain unaffected.

There are two general scientific principles of direct relevance to the use of high pressure in food processing. The first is Le Chatelier's Principle, which applies to all physical processes and states that, when a system at equilibrium is disturbed the system responds in a way that tends to minimize the disturbance. This means that HP stimulates reactions that result in a decrease in volume but opposes reactions that involve an increase in volume. Any phenomenon (e.g. phase transition, change in molecular configuration, chemical reaction) that is accompanied by a decrease in volume will be enhanced by pressure. Secondly, the Isostatic Rule states that pressure is instantaneously and uniformly transmitted throughout a sample under pressure, whether the sample is in direct contact with the pressure medium or hermetically sealed in a flexible package that transmits pressure. Pressure is transmitted in a uniform (isostatic) manner throughout the sample; the time necessary for pressure processing is therefore independent of sample size, in contrast to thermal processing.

High-pressure processing (HPP) holds the potential for preserving foods by combining elevated pressures (up to 900 MPa or approximately 9000 atmospheres) and moderate temperatures (up to 120°C) over a short period. Other advantages of the technology include uniform pressure application, minimal heat damage to food and potential for altering functional properties of foods. The possibility of extending shelf-life without heating the food for prolonged periods greatly helps to satisfy consumer demand for fresher and higher quality heat-sensitive foods that are otherwise difficult to process using conventional food preservation methods.

Effects of HPP on microorganisms in *surimi* paste showed that all of the microbes were destroyed at 300–400 MPa; fungi showed highest sensitivity to HPP, followed by Gram negative and Gram positive bacteria. Pressure resistant bacteria, *Moraxella* spp. was viable at 200 MPa and *Acinetobacter calcoaceticus* was viable at 300 MPa. In Japan, hydrostatic pressure has been used to induce the gelation of different kinds of surimi from pollack, sardine, skipjack tuna and squid. High pressure at levels of 300-3740 atm for 30 min to formulate gels from bluefish meat paste, and the properties of the resulting gels were compared with those of heat-induced gels formulated at 90ºC for 20 min or 60ºC for 60 min. When shrimp was pressure treated at levels of 100, 270, and 435 MPa for 5 min at room temperature (25±2ºC), a shelf life was extension of 15 days was possible in high pressure treated shrimp at 435 MPa compared with 5 days in untreated sample. Pressure level of 220 MPa and a 30 min holding time were optimal and most effective in prolonging the storage period of tuna muscle (up to 9 days), as well as in reducing the proteolysis activity, texture degradation, TVBN and histamine formation. High pressure processing increased pH, protected from lipid oxidation, maintained low microorganisms levels, changed the color of the muscle, and induced the formation of high molecular weight polypeptides most likely through disulfide bonding promoting texture improvement and thereby improve the shelf life of minced albacore muscle for more than 22 days at 4ºC and more than 93 days at −20ºC when high pressure of 275 and 310 MPa applied for 2, 4 and 6 sec to minced albacore muscle.

Studies carried out at CIFT indicated high pressure treatment increased shelf life of fish and shellfishes and improved gel strength in mince and surimi. Indian white prawns (*Fenneropeneaus indicus*) were subjected to pressure of 150, 200, 250 and 300MPa with holding time of 5 min at 25ºC and subsequently stored in iced condition for shelf life evaluation. High pressure of 250 MPa found better in retaining sensory quality of shrimp and it increased shelf life up to 30 days. Yellowfin tuna chunks were subjected to 100, 200 and 300 MPa for 5 min at 25ºC and subsequent stored in iced condition for shelf life evaluation. High pressure treatment extended shelf life up to 30 days compared to 20 days for control samples in which 200MPa was found superior. High pressure treatment had positive effect on the gelling properties of unwashed fish mince and single washed surimi and sausage.

Pressure Shift Freezing

Pressure shift freezing (PSF) has the potential benefits for producing fine and uniform ice crystals within the food systems, particularly meat. PSF helps to reduce tissue deformation and shrinkage since these two novel processes create smaller and uniformly distributed ice crystals and well isotropic spread of ice crystals in meat tissues. Therefore, this method can be used to freeze foods with uniform ice crystal distribution and small size of ice crystal, resulting in a significant improvement of product quality.

Studies conducted on Atlantic salmon indicated that pressure shift freezing is advantageous over glycol/ water bath freezing and conventional air freezing. In the study, Atlantic salmon samples were frozen by pressure shift freezing (PSF) at 100 MPa (-8.4 ºC), 150 MPa (-14 ºC) and 200 MPa (-20ºC), by conventional air freezing (CAF) at -30ºC and glycol/water bath freezing (GBF) at -20ºC. CAF created larger and irregular ice crystals, and resulted in irreversible damage to muscle tissues. Due to its higher freezing rate, GBF produced smaller ice crystals than CAF, but the cross-section area and roundness values had larger deviations. The PSF process produced large amounts of fine and regular intracellular ice crystals that were homogeneously distributed throughout the sample. Microscopic images clearly showed that the muscle fibers were well maintained in the PSF treated samples as compared with unfrozen muscle structures.

Pressure Assisted Thawing

It is well recognized that the success of freezing preservation depends on careful pre-freezing preparation, control of the freezing rate, storage conditions and thawing conditions. Only limited investigations have aimed at improving the thawing rate. Due to microbial growth during thawing, minimal ambient temperature must be ensured. The use of high pressure (HP) for thawing offers a new alternative to this process. The use of HP for thawing biological substances offers a unique alternative to conventional processes in that it decreases the phase change temperature of pure water (down to -22°C at 220 MPa). The lowering of the melting point of ice under HP allows the temperature gap between the heat source and the phase change front to increase, and thus enhances the heat flux rate in the case of pressure assisted thawing. The phase change temperature increases with pressure above 220 MPa, and thus 220 MPa appears as the maximum pressure of interest in thawing with respect to the heat transfer criterion.

Pulse Light Technology

Pulsed light (PL) is an emerging non-thermal technology for decontamination of food surfaces and food packages, consisting of short time high-peak pulses of broad-spectrum white light. The term light is generally used to mean radiations having wavelength ranging from 180 to 1100 nm, which includes ultraviolet rays (UV 180–400 nm, roughly subdivided into UV-A, 315–400 nm, UV-B, 280–315 nm, UV-C, 180–280 nm), visible light (400–700 nm) and infrared rays (IR 700–1100 nm).

Pulsed light is produced using technologies that multiply power manifold. It is used for the rapid inactivation of microorganisms on food surfaces, equipment, and food packaging materials. The effect on microorganisms is mostly due to the photochemical action of the Ultra Violet part of the light spectrum that causes thymine dimerization in the DNA chain preventing replication and ultimately leading to cell death. PL treatment of foods has been approved by the FDA in 1996 under the code 21CFR179.41.

Many research findings have shown that this can be used for the reduction of microbial load of *Listeria monocytogens*, *Salmonella enteritidis*, *Pseudomonas aeruginosa*, *Bacillus ce*reus and *Staphylococcus aureus*, *Escherichia coli* etc. Many works have shown extended shelf life in shrimp treated with pulsed light. Shrimp treated with pulsed light and stored at refrigerated condition for seven days remained edible whereas untreated shrimp showed extensive microbial degradation and were discoloured, foul smelling and not edible. Pulsed light was able to reduce the psychotroph and coliform population on the surface of summer flounder fillets. The sensory attributes indicates the fillets remained acceptable after 15 days of refrigerated storage.

There have been findings that indicate 1 log reduction of *Escherichia co*li O157:H7 or Listeria monocytogenes on salmon fillets, when pulsed light treatment (5.6 J cm^{-1}) per 60 second treatment was done at 8 cm distance without affecting the quality. Studies conducted at

McGill University, Canada show promise for pulsed light treatment for cold smoked vacuum packed salmon to control *Listeria monocytogens* and *Clostridium botulinum* A and E.

Although many studies are related to microbial reduction in dairy products, vegetables and fruits, there are limited studies about effectiveness of pulsed light on fish micro flora and shelf life. Studies need to be conducted to assess the effects of PL treatments on food properties beyond safety and spoilage.

Packaging plays in important role in the preservation, transporting and marketing of the products. Suitable packaging materials are to be selected for packaging of animal products for PL treatment. Pulsed light can be used to inactivate microorganisms on the surface of food packaging materials, and potentially on the surface of products packaged in UV transparent materials. The use of pulsed light could lead to a reduction in the need for preservatives or chemical sterilizing agents. Chemical surface sterilizers such as hydrogen peroxide, propylene oxide or per acetic acid may leave a residue or require time to reduce to an acceptable level but pulsed light has the advantage of not leaving undesirable residue after treatment The inactivation of microbial load by pulsed light is a fast process and takes place in a very short period. It is a green technology because the energy consumption is very less during its application. Due to the absence of any harmful residues, chemical and toxic by-products in pulsed treated foods, this technology is proven to be safe. It does not affect the nutritional and sensory quality of the products. The concerns of ionized radicals and radioactive by-products in foods by consumers are removed in PL due to its non-ionizing spectrum. Low penetration power and lipid oxidation are a major constraints in meat industry. Packing material having high penetration of pulsed light should be used while treatment of packed food. The limited control over food heating still remains the main concern in pulsed light technology. Sample heating is perhaps the most important limiting factor of PL for practical applications.

Pulsed light treatment done on pearlspot (*Etroplus suratensis*) fillets for 12 sec with a total energy of 25 J cm^{-2} indicated a shelf life extension of 6 days when compared to control. Yellowfin tuna (*Thunnus albacares*) steaks packed in cast polypropylene was found to give maximum bacterial reduction. Pulse treatment for 6 sec. with an energy output of 11.5 J cm^{-2} was found to be acceptable microbiologically and with regard to sensory attributes. Dip treatment in 2% sodium acetate, 2% potassium sorbate and a combination of 2% sodium acetate-potassium sorbate solution with pulsed light treatment resulted better sensory and L*a*b* colour values of pulse treated tuna steaks than dip and pulsed treated combinations. Shelf life extension of 13 days for pulsed treated and pulsed-dip combinations was obtained, however organoleptically; the pulse treated samples were rated superior.

Pulsed light treatment is effective in reducing the microorganisms load considerably. Masmin treated with pulse light resulted in a reduction of 0.7 log fungal counts. Challenge studies were conducted to assess the efficiency of the pulse light treatment on the pathogenic bacteria. A reduction of 2.66 log was observed for *Escherichia coli* O157 in tuna homogenate for 30 sec pulse light treatment. The D value was found to be 12.38 sec. A 0.90 log reduction on 30 sec of treatment was found when *Staphylococcus aureus* ATCC 6538 was inoculated in Tuna Homogenate. The D value was found to be 35.90 sec.

Pulsed Electric Field Processing

PEF processing consists of the application of very short electric pulses (1–100 μs) at electric field intensities in the range of 0.1–1 kV cm^{-1} (reversible permeabilization for stress induction in plant cells), 0.5–3 kV cm^{-1} (irreversible permeabilization of plant and animal tissue), and 15–40 kV cm^{-1} for the irreversible permeabilization of microbial cells. The PEF technology is considered a non-thermal cell disintegration or preservation process. It is possible that a rapid rupture occurs in limited areas without affecting the entire cell membrane but that depends on the external electric field applied. It provides an alternative to mechanical, thermal, or enzymatic cell disintegration of plant and animal raw materials, providing a short-time (milli seconds), low energy treatment, as well as to the traditional thermal pasteurization of liquid food products Electrical stimulation of meat, an electric field of 5–10 V cm^{-1} is applied as alternating current (ac) pulses to the sample through electrodes fixed at opposite ends of the long axis of the muscle

It is generally accepted that the primary effect of PEF on biological cells is related to local structural changes and the breakdown of the cell membrane, which is a highly important component of the biological cell as it acts as a semipermeable barrier responsible for mass transfer and plays an important role in the synthesis of RNA and DNA, protein and cell wall components as well as many other complex metabolic activities. Disruption of intracellular organelles and other structural changes have also been described. The electrical breakdown of cellular membranes has been explored based on model systems such as phospholipid esicles and planar bilayers as well as microorganisms. Microbial inactivation by PEF has been extensively investigated within the last few decades initially in batch treatment systems and model foods which are free of fat or proteins.

The low energy consumption (1–2 kJ kg^{-1} for stress induction and 5–10 kJ kg^{-1} for plant cell permeabilization) and the continuous operability of this short-time, waste free membrane permeabilization technique are key advantages and allow the development of innovative, cost effective and sustainable processing concepts in the food and drink industry as well as in the biotechnology and pharmaceutical industry. PEF processing offers high quality fresh-like liquid foods with excellent flavor, nutritional value, and shelf-life. Since it preserves foods without using heat, foods treated this way retain their fresh aroma, taste, and appearance. Application of PEF technology has been successfully demonstrated for the pasteurization of foods fish soups, tomato juice and liquid eggs. Application of PEF processing is restricted to food products with no air bubbles and with low electrical conductivity. PEF is a continuous processing method, which is not suitable for solid food products that cannot be pumped.

Modified Atmospheric Packaging

Fresh fish is highly susceptible to spoilage from post mortem autolysis and microbial growth. The high ambient temperature of our country favours rapid growth of microorganisms. Presently ice and mechanical refrigeration are the most common means of retarding microbial and biochemical spoilage in freshly caught seafood during distribution and marketing. However, as ice melts it tends to contaminate fish accelerating spoilage and reduces shelf life. Modified atmosphere packaging, a technologically viable method has been developed as a supplement to ice or mechanical refrigeration to reduce the losses and extend the storage life of fresh seafood products. In modified atmosphere packaging air is replaced with different gas mixtures to regulate microbial activity and /or retard discolouration of the products. The proportion of each component gas is fixed when the mixture is introduced into the package; however, no control is exercised during storage. The composition of the gas mixture changes from its initial composition as a result of chemical, enzymatic and microbial activity of the product during storage. It is primarily the enrichment of Carbon dioxide in the storage atmosphere as a means of controlling microbial growth, which results in the extension of shelf life of products.

Carbon dioxide lowers the intra and extracellular pH of tissues and possibly that of microorganisms. Further it may affect the membrane potential of microorganisms and influence on the equilibrium of decarboxylating enzymes of microorganisms. The gases normally employed are carbon dioxide, mixtures of carbon dioxide and nitrogen, carbon dioxide and oxygen and carbon dioxide, oxygen and nitrogen with the sole objective to extend the shelf life of the product beyond that obtained in conventional refrigerated storages. Inhibition by Carbon dioxide manifests in an increased lag phase and a slower rate of growth of microorganisms during logorathmic phase. Inhibition by Carbon dioxide was found to be more effective when the product was stored at the lowest range of refrigerated temperatures. Packaging materials generally employed for this purpose are flexible films of nylon/surylyn laminates, PVC moulded trays laminated with polythene, polyester/ low density polythene film etc. The use of high barrier film along with MAP that contains CO_2 effectively inhibits bacterial growth during refrigerated storage of packaged fresh fishery products. The composition of the gas mixtures used for MAP of fresh fish varies, depending upon whether the fish in the package is lean or oily fish. For lean fish, a ratio of 30% Oxygen, 40% Carbon dioxide, 30% Nitrogen is recommended. Higher values of Carbon dioxide are used for fatty and oily fish with a comparable reduction in level of Oxygen in the mixture leading to 40-60% Nitrogen. By excluding oxygen, the development of oxidative rancidity in fatty fish is slowed. On the other hand, oxygen can inhibit the growth of strictly anaerobic bacteria like *Clostridium botulinum* although there is a very wide variation in the sensitivity of anaerobes to Oxygen. It is also seen that inclusion of only some Oxygen with Nitrogen or Carbon dioxide will not prevent botulism with absolute certainty.

Vaccum Packaging

Vacuum packaging involves the removal of air from the package and the application of a hermetic seal. The air removal creates a vacuum inside the packs and lack of O_2 in packages may minimise the oxidative deteriorative reactions and aerobic bacterial growth. It also helps the pigments to be in the deoxymyoglobin state. Vacuum packaging can considerably extend the viable shelf life of many cooked foods. It should be stressed that vacuum packaging must be used under strict conditions of hygiene and control, and not as means to forgo proper sanitation. This could be applied to cook-chill food systems to increase food quality & microbiological assurance. The use of vacuum packaging, in gas impermeable and heat stable materials, has many advantages, which include; no or low risks of post pasteurisation contamination, ease of handling, Inhibition of growth of aerobic spoilage organisms and inhibition or slowing of deleterious oxidative reactions in the food during storage due to oxygen barrier properties of the packaging material.

There are number of criteria required for the films used for vacuum packaging in large scale production methods, especially those which require in-pack pasteurisation (i.e. the pasteurisation of the food after it has been packaged). These requirements include: high durability, ie. ability to withstand considerable mechanical stresses during packaging, handling and transport, retention of flexibility even at low temperatures (-2 to 4°C) to enable satisfactory handling in the packaging and refrigeration rooms, ability to withstand heating to at least 150°C without structural damage, leaching of potentially toxic plastics or plasticisers, impermeability to liquids, including oils and fats and macromolecules, impermeability to gases, in particular oxygen, so that oxidative deterioration of the packaged food stuffs is limited or inhibited, manufactured from non-toxic, food acceptable, odourless materials and must be able to create air tight durable heat seals to close packs. Many of these criteria have been met by a range of materials mostly multi-laminated plastics. A wide range of materials are now manufactured throughout the world which are suitable or even specifically designed for use in large scale vacuum packaging/cook-chill operations.

Vacuum packed foods maintain their freshness and flavor 3-5 times longer than with conventional storage methods, because they don't come in contact with oxygen. Foods maintain their texture and appearance, because microorganisms such as bacteria mold and yeast cannot grow in a vacuum. Freezer burn is eliminated, because foods no longer become dehydrated from contact with cold, dry air. Moist foods won't dry out, because there's no air to absorb the moisture from the food. Dry, solid foods, won't become hard, because they don't come in contact with air and, therefore, can't absorb moisture from the air. Foods that are high in fats and oils won't become rancid, because there's no oxygen coming in contact with the fats, which causes the rancid taste and smell. Insect infestation is eliminated, because insects require oxygen to survive and hatch. Meat and fish will marinade in minutes when vacuum packaged in canisters, because as air is being removed from the canister, the pores of the mat or fish open up and allow the marinade to penetrate.

Active and Intelligent Packaging

Active packaging

Active packaging is an innovative concept that can be defined as ‘a type of packaging that changes the condition of the packaging and maintains these conditions throughout the storage period to extend shelf-life or to improve safety or sensory properties while maintaining the quality of packaged food’ Active packaging (AP) performs some desired role other than providing an inert barrier between the product and external conditions and combines advances in food technology, bio-technology, packaging and material science, in an effort to comply with consumer demands for ‘fresh like’ products. This involves incorporation of certain additives into the packaging film or within packaging containers with the aim of maintaining and extending product shelf life. Active packaging technique is either scavenging or emitting systems added to emit (e.g. N_2, CO_2, ethanol, antimicrobials, antioxidants) and/or to remove (e.g. O_2, CO_2, odour, ethylene) gases during packaging, storage and distribution. Major active packaging techniques are concerned with substances that absorb oxygen, ethylene, moisture, carbon dioxide, flavours/odours and those which release carbon dioxide, antimicrobial agents, antioxidants and flavours. Some of the active packaging systems include

- Oxygen scavenger
- Carbondioxide emitter
- Moisture regulator
- Antimicrobial packaging
- Antioxidant release
- Release or absorption of flavours and odours
- Carbondioxide scavenger
- Active packaging systems with dual functionality (combination of oxygen scavengers with carbon dioxide and/or antimicrobial/antioxidant substances)

Other active packaging systems that are expected to find increased attention in the future include colour containing films, light absorbing or regulating system, susceptors for microwave heating, gas permeable/ breathable films, anti fogging films and insect repellant package.

Intelligent Packaging

Intelligent packaging, sometimes referred as smart packaging, senses some properties of the food it encloses or the environment in which it is kept and informs the manufacturer, retailer and consumer of the state of these properties. Although it is distinctly different from the active packaging concept, features of intelligent packaging can be used to check the effectiveness and integrity of active packaging systems. Intelligent packaging has been defined as ‘packaging systems which monitor the condition of packaged foods to provide information about the quality of the packaged food during transport and storage

- Time temperature indicators
- Leakage indicator
- Freshness indicator

Active and intelligent packaging systems contribute to the improvement of food safety and extend the shelf-life of the packaged foods. However these are evolving technologies in the seafood area and many of these systems are in the developmental stage. Continued innovations in active and intelligent packaging are expected to lead to further improvements in food quality, safety and stability.

Vacuum Cooling

Vacuum cooling is a rapid evaporative cooling method for porous and moisture foods to meet the special cooling requirements. During vacuum cooling, the products to be cooled are loaded into a closed chamber. Vacuum pumps are then used to evacuate air from the chamber. As the pressure inside the chamber is reduced to the saturation pressure corresponding to the initial temperature of the product, water starts to evaporate. The latent heat required for the evaporation is supplied by product itself. Recent research has highlighted the feasibility of vacuum cooling for cooked meats, fishery products and ready meals, for which rapid cooling is beneficial to controlling growth of microorganisms and preserving quality of the products. The difference between vacuum cooling and conventional refrigeration methods is that for the vacuum cooling, the cooling effect is achieved by evaporating some water from a product directly, rather than by blowing cold air or other cold medium over the product. Any product which has free water and whose structure will not be damaged by the removal of such water can be vacuum cooled. The speed and effectiveness of vacuum cooling are mainly related to the ratio between its evaporation surface area and the mass of foods.

Liquid evaporation is the most popular cooling sink in the refrigeration industry. Whenever any portion of a liquid evaporates to become its vapour state, an amount of heat equal to the latent heat of evaporation must be absorbed by the evaporated portion either from the liquid body or from the surroundings, resulting in reduction of the temperature of the liquid body or surroundings. Water boils at 100^{o}C if it is subjected to the atmospheric pressure (1 atm). However, reduction in the imposed pressure on water lowers the boiling temperature of water, that is, water can also boil at as a low temperature as 0^{o}C if the imposed pressure is reduced to 611 Pa (0.006 bar). The imposed pressure on water determines the minimum temperature, which can cause water to boil to produce a cooling effect.

Vacuum cooling may be introduced into the fishery industry. During processing tuna, the tuna are caught at sea and frozen in brine immediately. They are then transported to canning plants, where they are thawed and then steam cooked to 65^{o}C. After cooking, the tuna are cooled to between 35 and 40^{o}C by vacuum cooling, which typically results in a 3–4% weight loss. Vacuum cooling can also be used to cool small fish such as whiting or crustacean such as shrimp by using waste stack gases to power the equipment.

Irradiation

Irradiation is a physical treatment that consists of exposing foods to the direct action of electronic, electromagnetic rays to assure the innocuity of foods and to prolong the shelf life. Irradiation of food can control insect infestation, reduce the numbers of pathogenic or spoilage microorganisms, and delay or eliminate natural biological processes such as ripening, germination, or sprouting in fresh food. Like all preservation methods, irradiation should supplement rather than replace good food hygiene, handling, and preparation practices.

Three types of ionizing radiation are used in commercial radiation to process products such as foods and medical and pharmaceutical devices (International Atomic Energy Agency (IAEA), radiation from high-energy gamma rays, X-rays, and accelerated electrons.

- Gamma rays, which are produced by radioactive substances (called radioisotopes). The approved sources of gamma rays for food irradiation are the radionuclides cobalt-60 (^{60}Co; the most common) and cesium-137 (^{137}Cs). They contain energy levels of 1.17 and 1.33 MeV (^{60}Co) and 0.662 MeV (^{137}Cs).
- Electron beams, which are produced in accelerators, such as in a linear accelerator (linac) or a Van de Graaff generator at nearly the speed of light. Maximum quantum energy is not to exceed 10 MeV.
- X-rays or decelerating rays, which can be likewise produced in accelerators. Maximum quantum energy of the electrons is not to exceed 5 MeV

Different forms of irradiation treatment are raduarization (for shelf life extension), radicidation (for elimination of target pathogens) and radappertization (for sterilization). Irradiation of packaging materials - in most cases like plastics, generally leads to the formation of free radicals and ions, which eventually result either in cross-linking or in chain scission. The latter leads to the release of volatile radiolysis products that may induce off-odours in the polymers, thereby altering the migration characteristics of packaging materials. Irradiation also affects polymer additives, which change the specific migration behaviour of polymer additives and additiverelated decomposition products. Both migration and sensory changes of packaging materials strongly affect the quality of packaged goods and consumer safety. Radiation processing is widely used for medical product sterilization and food irradiation. Moreover, the use of irradiation has become a standard treatment to sterilize packages in aseptic processing of foods and pharmaceuticals. Nowadays, packaging consists of natural or synthetic plastics; therefore, the effect of irradiation on these materials is crucial for packaging engineering

Irradiation produces some chemical changes, which, although lethal to foodborne bacteria, do not affect the nutritional quality of the food but lead to the production of small amounts of radiolytic products. Gamma irradiation has been considered as an interesting method of preservation to extend the shelf life of fish and also to reduce qualitatively and quantitatively the microbial population in fish and fish products. Irradiation doses of 2–7 kGy can reduce important food pathogens such as Salmonella, Listeria, and Vibrio spp., as well as many fish-specific spoilers such as Pseudomonaceae and Enterobacteriaceae that can be significantly decreased in number. Studies on 4-day-old frozen tuna loins (*Thunnus obesus*) packed in polyethylene PE bags and irradiated by an X-ray machine at a dose of 2.2 kGy, the non-irradiated control samples to be acceptable 15 days in comparison to 25 days observed for the irradiated samples.

Ultrasound Processing

Ultrasound refers to sound that is just above the range of human hearing, i.e. above frequency of 20 MHz. Ultrasound when propagated through a biological structure induces compressions and depressions of the medium particles imparting a high amount of energy to the material. The sound ranges for food applications employed can be divided into two, namely, low energy, high frequency diagnostic ultrasound and high energy low frequency power ultrasound. Low energy applications involve the use of ultrasound in the frequency range of 5-10 MHz at intensities below 1 W cm^{-2}. Ultrasonic waves at this range are capable of causing physical, mechanical, or chemical changes in the material leading to disrupting the physical integrity, acceleration of certain chemical reactions through generation of immense pressure, shear, and temperature gradient in the medium. Ultrasonics has been successfully used to inactivate *Salmonella* spp., *Escherichia coli*, *Listeria monocytogenes*, *Staphylcoccus aureus* and other pathogens.

Ultrasound is probably the most simple and most versatile method for the disruption of cells and for the production of extracts. It is efficient safe and reliable. Ultrasound cavitation creates shear forces that break cell walls mechanically and improves material transfer. This effect is being used in the extraction of liquid compounds from solid cells. The compound to be dissolved into a solvent is enclosed in an insoluble structure. In order to extract it, the cell membrane must be destructed. For the purpose, ultrasound is faster and more completed than maceration or stirring. The particle size reduction by the ultrasonic cavitation increases the surface area in contact between the solid and liquid phase, significantly. The mechanical activity of this technique enhances the diffusion of the solvent into the tissue; Ultrasound breaks the cell wall mechanically by the cavitation shear forces at it facilitate the transfer from the cell into the solvent. This technique has potential advantages over other techniques including freedom from radiation hazards, which may appear in some of the existing non-destructive methods. The presence of the small gas bubbles in a sample can greatly attenuate ultrasound making signal detection impossible. This can be solved by using reflection measurements rather than transmission measurement. The advantages of ultrasonics in food processing are lower energy consumption, reduced processing time, higher throughput, reduced flavour loss, greater homogeneity and significant energy saving.

Ultrasound Thawing of Frozen Foods

Effective acoustic or ultrasound thawing relies on the selection of an appropriate frequency and intensity to defrost the food efficiently without excessive heating near the surface. When ultrasound was applied directly to meat (beef, pork, or fish), excessive heating near the surface was particularly a problem at high intensities (1–3 W cm^{-2}) and over a range of frequencies (220 kHz to 3.3 MHz), with cavitation causing problems at lower frequencies, while high attenuation caused excessive heating at higher frequencies. A combination of 500 kHz and 0.5 W cm^{-2} was found to offer effective thawing while minimizing surface heating. Acoustic defrosting (1500 Hz) of fish blocks in an agitated water bath (18 °C, 3.8 m s^{-1} water velocity at block surface) reduced the time to go from -29°C to -1°C by approximately 25%–70% (depending on ultrasound power input level), while larger reductions were seen going from -5°C to -1°C (approximately 32%–82%). Some rapid thawing techniques can cause excessive heating at the product surface leading to loss of product quality. However, combined acoustic and water bath thawing gave the same surface temperature as water bath thawing alone. US patent No: US 4464401 A on acoustic thawing of frozen food in 1982 explains the use of ultrasound waves in thawing frozen foods.

Microwave Processing

The applications of microwave heating on fish processing include drying, pasteurization, sterilization, thawing, tempering, baking etc. Microwaves are electromagnetic wave whose frequency varies within 300 MHz to 300 GHz. Microwave heating is caused by the ability of the materials to absorb microwave energy and convert it into heat. Microwave heating of food materials mainly occurs due to dipolar and ionic mechanisms. Water content in the food material causes dielectric heating due to the dipolar nature of water. When an oscillating electric field is incident on the water molecules, the permanently polarized dipolar molecules try to realign in the direction of the electric field. At high frequency electric field, this realignment occurs at a million times per second and causes internal friction of molecules resulting in the volumetric heating of the material. Microwave heating also occur due to the oscillatory migration of ions in the food which generates heat in the presence of a high frequency oscillating electric field. Studies showed that chemical changes involved during different microwave cooking practices of skipjack tuna and will retain omega-3 fatty acids compared to frying/canning. Microwave blanching can be carried out for color retention and enzyme inactivation which is carried out by immersing food materials in hot water, steam or boiling solutions containing acids or salts. Microwave drying is used to remove moisture from fish and fishery products. Microwave drying has advantage of fast drying rates and improving the quality of product. In microwave drying, due to volumetric heating, the vapors are generated inside and an internal pressure gradient is developed which forces the water outside. Thus shrinkage of food materials is prevented in microwave drying. One of the disadvantages of microwave drying is that excessive temperature along the corner or edges of food products results in scorching and production of off-flavors especially during final stages of drying. Microwave combined with other drying methods such as air drying or infrared or vacuum drying or freeze drying gave better drying characteristics compared to their respective drying methods or microwave drying alone.

Ohmic Heating

Ohmic heating is an emerging technology with large number of actual and future applications. Ohmic heating technology is considered a major advance in the continuous processing of particulate food products. Ohmic heating is direct resistance heating by the flow of an electrical current through foods, so that heating is by internal heat generation. Ohmic heating is defined as a process wherein electric current is passed through materials with the primary purpose of heating the object. During ohmic heating, heating occurs in the form of internal energy transformation (from electric to thermal) within the material. Therefore it can be explained as an internal thermal energy generation technology and it enables the material to heat at extremely rapid rates from a few seconds to a few minutes. Ohmic heating have a large number of actual and potential future applications, including its use in blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization and heating of foods. The microbial inactivation due to ohmic heating can be explained by the presence of electric field. The additional effect of ohmic treatment may be its low frequency (usually 50e60 Hz), which allows cell walls to build up charges and form pores. As a main consequence of this effect, the D value observed for the microbial inactivation under ohmic heating is reduced when compared to traditional heating methods. More research is needed to completely understand all effects produced by ohmic heating to food products, effects of applied electric field, the applied electric frequency during ohmic heating over different microorganisms and foods, cold spot determination etc.

Infrared and Radiofrequency processing technologies

Electromagnetic radiation is a form of energy that is transmitted through the space at an enormous velocity (speed of light). The heat generation in material exposed to EMR could be due to vibrational movement (as in case IR) or rotational movement (as in case of RF and MW) of molecules. Application of EMR heating is gaining popularity in food processing because of its definite advantages over the conventional processes. Faster and efficient heat transfer, low processing cost, uniform product heating and better organoleptic and nutritional value in the processed material are some of the important feature of EMR processing. In conventional heating system like hot air heating, the heat is applied at the surface which is carried inwards through conduction mode of heating. In case of EMR/dielectric heating, the waves can penetrate the material to be absorbed by inner layers. The quick energy absorption causes rapid heat and mass transfer leading to reduced processing time and better product quality.

The main advantage of electromagnetic heating over conventional electric and gas oven based heating is its high thermal efficiency in converting the electrical energy to heat in the food. In ordinary ovens, a major portion of the energy is lost in heating the air that surrounds the food, fairly a good amount escapes through the vent, besides being lost through the conduction to the outside air. In contrast, almost all the heat generated by electromagnetic radiations, which reaches the interior of the oven, is produced inside the food material itself. According to the reports the energy efficiency of EMR based systems is 40-70%, as compared to approximately

7-14% in case of conventional electric and gas ovens.

Infrared (IR) Radiation

In the electromagnetic spectrum, IR occupies the region between visible and microwave radiation and has wavelength in the range of 0.78-1000 µm. Infrared radiation is broadly classified into near infrared (NIR), mid infrared (MIR) and far infrared (FIR) radiation. While NIR is suitable for HTST processes, FIR is employed for surface heating. Hybrid drying involving MIR and hot air are reported to be suitable for drying of high moisture materials. The major advantages of IR heating are i) versatility for any heating applications, ii) energy efficiency of properly designed IR heating system compared to conventional processing, iii) efficient heat transfer to the food material reducing the processing time and energy cost, iv) air inside the chamber is not heated, consequently ambient temperature may be kept at normal levels, v) heating is more uniform than in conventional methods because of simultaneous heating of surface and inner layers, vi) damages to the food product during heating is less due to uniform and controlled heating vii) retention of nutrients and organoleptic properties and viii) easy accommodation of IR heating with convective, conductive, and microwave heating making it ideal for hybrid processes. Some of the limitations of IR heating are; it is essentially a surface heating process, thus making it unsuitable for heating material requiring deep heat penetration and high heat insulating materials, since radiation is emitted in straight lines form the source or reflector, the shape of the object to be treated is also an important factor and clean metal surfaces are difficult to heat, especially if they are bright and polished.

Radiofrequency (RF) Radiation

Radiofrequency heating refers to the use of electromagnetic waves of certain frequencies to generate heat in the material. Radiofrequency heating can be performed in any of the 3 frequencies (13.56 MHz ± 6.68 kHz; 27.12 MHz ± 160 kHz and 40.68 MHz ± 20 kHz). The principle of RF heating relies on the fact that, the heat is generated in most dielectric materials when a high frequency electric field is applied across them. In many cases, this heat is simply due to the resistance to the flow of high frequency electric current through the material. In other cases the heat arises from a resonant absorption mechanism whereby the frequency of applied electric field is such that the dipoles, within the material reorient themselves to continually reversing electric field. The amount of heat generated in the product is determined by the frequency, the square of the applied voltage, dimensions of the product and the dielectric loss factor of the material, which is essentially a measure of the ease with which the material can be heated by radio frequency waves. It is reported that the RF applications have shown a number of benefits over conventional heating methods. The advantages of RF heating are increased heating and processing speed, improved product quality and yield because of uniform heating, usage of only 1/3 of the floor space of conventional heating units, instant on/off and temperature change and higher energy savings up to 60-70%. Another important advantage claimed for RF heating is its 'self-limiting' property, which controls the consumption of RF energy according to the workload.

Application of IR and RF for Food Processing

Although, IR and RF waves have found application in non-food industry, their usage in food industry was limited till recently. The reasons that could be attributed for the above are lack of information on heat and mass transfer aspects, theoretical models for process understanding and optimization and limited information on economic viability of the process. The need for developing custom made equipment and limited sources for the supply of such processing equipment are the other factors that had hindered their application in food industry. However, in the recent past, EMR based processes, especially hybrid processes, have gained popularity in various food processing operations such as drying, baking, roasting, blanching, pasteurization and sterilization.

The use of IR spectrum for selective heating, wherein a specific spectral range obtained by passing the radiation through suitable filters is used for heating was found to be more effective for microbial inactivation. The RF radiation can be used for precooking, blanching, sterilization, tempering, thawing and baking of food materials. Dielectric thawing of fish, meat and meat products, defrosting of meat and fish at 35 MHz frequency radio waves, pasteurization of small cured hams, have been reported.

Radio-frequency Thawing

Radiofrequency thawing is similar to microwave ovens where fish products passing through the oven (heater), are subjected to a direct or volumetric heating process in the form of a radio frequency (RF) energy source. The RF heating process depends upon the ionic conductivity of the material being heated. Radio-frequency thawing systems are also available, where the frozen product is placed between two parallel electrodes and alternating radiofrequency energy is applied to the electrodes. Temperature rise within the product is relatively uniform, the degree of uniformity being dependent on the size and composition of the product. It is suggested that 5 cm blocks of fish can be thawed rapidly. However, radio frequency treatments have more promising attributes for processing seafood. At the lower frequencies of RF, penetration of the RF energy into foods is much greater and enables the temperature of blocks to increase from –20 °C to –2 or 0 °C. Radio-frequency systems are available in both batch and continuous methods. Batch RF systems operate from 40 to 350 kg/hour while continuous RF systems can operate from 900 to 3000 kg/hour.

Retort Pouch Processing

As in canning, retort pouch food is sterilized after packing, but the sterilizing procedure differs. The pouches are processed in an over pressure retort. The time and temperature will be standardized depending on the product. With the availability of indigenous retort pouches it can function as an excellent import substitute for metallic cans**.** Besides, cost reduction retort pouch packages have unique advantages like boil in bag facility, ease of opening, reduced weight and do not require refrigeration for storage. Processed food products can be kept for long periods at room temperature. The energy saving is more in processing in flexible pouches compared to cans. On a comparison of total costs, including energy, warehousing and shipping, the pouch looks even more favourable. There is 30 to 40% reduction in processing time compared to cans, solids fill is greater per unit, empty warehousing is 85% smaller and weight of the empty package is substantially smaller.

Extrusion

In order to improve the utilization of underutilized fisheries resources, there is a need to minimize the post-harvest losses, develop innovative processing technologies and utilize processing waste for industrial and human use. One such technology, which will be suitable for utilization of low value fish or by catch, is extrusion technology. Use of fish mince with cereals for extrusion process will enable production of shelf-stable products at ambient temperature. Extrusion cooking is used in the manufacture of food products such as ready-to-eat breakfast cereals, expanded snacks, pasta, fat-bread, soup and drink bases. The raw material in the form of powder at ambient temperature is fed into extruder at a known feeding rate. The material first gets compacted and then softens and gelatinizes and/or melts to form a plasticized material, which flows downstream into extruder channel. Basically an extruder is a pump, heat exchanger and bio-reactor that simultaneously transfer, mixes, heats, shears, stretches, shapes and transforms chemically and physically at elevated pressure and temperature in a short time. At times, the extrusion cooking process is also referred as High Temperature Short Time process. In extrusion process gelatinization of starch and denaturation of protein ingredient is achieved by combined effect of temperature and mechanical shear. The conversion of raw starch to cook and digestible materials by the application of heat and moisture is called gelatinization. During extrusion the conditions that prevail are high temperature, high shear rate and low moisture available for starch may lead to breakdown of starch molecules to dextrins.

***Sous-Vide* Cooking**

Sous vide or vacuum cooked food is defined as raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat stable vacuum pouches. *Sous vide* cooking differs from traditional cooking methods in two fundamental ways: the raw food is vacuum sealed in heat stable, food grade plastic pouches and the food is cooked using precisely controlled heating. Vacuum sealing has several benefits. It allows heat to be efficiently transferred to the food. It increases the food's shelf life by eliminating the risk of recontamination during storage. It inhibits off flavors from oxidation and prevents evaporative losses of flavor volatiles and moisture during cooking and reduces aerobic bacterial growth. *Sous vide* products are cooked at 65-95 ^{o}C for a long period of time. After cooking the products are cooled and kept under chill storage. The main factors which determines the microbial safety of *sous vide* products are intensity of heat used for cooking, cooling time and temperature, control of chilled storage temperature. Fish cooked *sous vide* retains more healthful omega-3 fatty acids and nutrients than traditionally cooked fish.

Bio Preservation

Bacteriocins are a heterogeneous group of antibacterial proteins that vary in spectrum of activity, mode of action, molecular weight, genetic origin and biochemical properties. Various spices and essential oils have preservative properties and have been used to extend the storage life of fish and fishery products. Natural compounds such as essential oils, chitosan, nisin and lysozyme, bacteriocins have been investigated to replace chemical preservatives and to obtain green label products.

Application of Enzymes

Enzymes have been used for the production of various cured and fermented fish products from centuries. Because of their appreciable activity at moderate temperature, products and process have emerged that utilizes enzymes in a deliberate and controlled fashion in the field of food processing. Cold active enzymes including elastase, collagenase, chymotrypsin extracted from Atlantic cod are used in various food processing applications. It is used for some proteolysis that must be carried out in low temperatures. The other applications of cold active enzymes include caviar production, extraction of carotenoprotein etc. These proteolytic enzymes makes the riddling process easier during cavier preparation. Pepsin split the linkages between the egg cells and the roe sack without damaging the eggs. Treatment with protease under mild treatment conditions extending for a few hours can result in the recovery of the proteins from fish frame or shrimp shell waste. The role of transglutaminase in surimi production was reviewed by. The gel strength of surimi can be improved by the application of extracellular microbial transglutaminase. Lipase extracted from Pseudomonas spp can be used to produce PUFA enriched cod liver oil. Enzymatic de-skinning of fish *R. radiate* fillets was done by partial denaturation of skin collagen using a gentle heat treatment followed by immersion in enzyme solution for several hours at low temperature (0-10^{0}C). De-skinning of tuna, Herrin, Squid were also carried out by using different enzyme technology.

Suggested Readings

Ahvenainen R. 2003. Novel food packaging techniques. Elsevier.

Anderson J. G., Rowan N. J., MacGregor S. J., Fouracre R. A. and Farish O. 2000. Inactivation of food-borne enteropathogenic bacteria and spoilage fungi using pulsed-light. IEEE Trans Plasma Sci. 28: 83-88.

An H., Peters M. Y. and Seymour T. A. 1996. Roles of endogenous enzymes in surimi gelation. Trends Food Sci. Tech. 7: 321-327.

Appendini P. and Hotchkiss J. H. 2001. Surface modification of poly (styrene) by the attachment of an antimicrobial peptide. J. Appl. polymer sci. 81: 609-616.

Appendini P. and Hotchkiss J. H. 2002. Review of antimicrobial food packaging. Innovative Food Sci. Emerg. Tech. 3: 113-126.

Arvanitoyannis I. S. 2010. Irradiation of food commodities: techniques, applications, detection, legislation, safety and consumer opinion. Academic Press.

Awad T. S., Moharram H. A., Shaltout O. E., Asker D. and Youssef M. M. 2012. Applications of ultrasound in analysis, processing and quality control of food: A review. Food Res. Int. 48: 410-427.

Balasubramanian S., Balasubramaniam V. M. 2003.Compression heating influence of pressure transmitting fluids on bacteria inactivation during high pressure processing. Food Res. Int. 36: 661–668.

Barbosa-Canovas G. V., Pothakamury U. R., Palou E., and Swanson B. G. 1998. Nonthermal preservation of foods New York: Marcel Dekker. pp. 139–161.

Belcher J. N. 2006. Industrial packaging developments for the global meat market. Meat Sci. 74: 143−148

Belitz H. D., Grosch W. and Schieberle P. 2009. Cereals and cereal products. Food chem. 670-745.

Boskou G. and Debevere J. 1998. In vitro study of TMAO reduction by Shewanella putrefaciens isolated from cod fillets packed in modified atmosphere. Food Additives and Contaminants. 15: 229-236.

Carver C. H. 1975. Vacuum cooling and thawing fishery products. Mar. Fish. Rev. 37: 15-21.

Chandrasekaran S., Ramanathan S. and Basak T. 2013. Microwave food processing—A review. Food Res. Int. 52: 243-261.

Cheftel J. C. and Culioli J. 1997. Effects of high pressure on meat: a review. Meat sci. 46: 211-236.

Church I. 1998. The sensory quality, microbiological safety and shelf life of packaged foods. Sous Vide and Cook–Chill Processing for the Food Industry. 190-205.

Church I. J. and Parsons A. L. 2000. The sensory quality of chicken and potato products prepared using cook–chill and sous vide methods. Int. J.Food Sci. Tech. 35: 155-162.

Creed P. G. 1998. Sensory and nutritional aspects of sous vide processed foods. Sous vide and cook-chill processing for the food industry. 57-88.

Crosby L. 1982. Juices pasteurized ultrasonically. Food Production/ Management. 16.

Da-Wen S. 2005. Emerging Technologies for food processing, Elsevier Academic Press UK.

Daniels J. A., Krishnamurthi R. and Rizvi S. S. 1985. A review of effects of carbon dioxide on microbial growth and food quality. J. Food Protection, 48: 532-537.

Datta A. K. and Anantheswaran R. C. 2001. Handbook of Microwave Technology, for Food Applications.., Eds. Marcel Dekker, New York.

Datta A. K. and Davidson P. M. 2000. Microwave and radio frequency processing. J. Food Sci. 65: 32-41.

Day B. P. 2008. Active packaging of food. Smart packaging technologies for fast moving consumer goods. 1-18.

De la Fuente-Blanco S., De Sarabia E. R. F., Acosta-Aparicio V. M., Blanco-Blanco A. and Gallego-Juárez J. A. 2006. Food drying process by power ultrasound. Ultrasonics, 44, pp. 523-527.

Dossat R. J. 1991. Principles of refrigeration (3rd ed). Englewood Cliffs, NJ, USA: Prentice Hall.

Doyle M. E. 1999. Food irradiation. Madison: University of Wisconsin, Food Research Institute.

Dunn J., Ott T. and Clark W. 1995. Pulsed light treatment of food and packaging. Food Tech. 49: 95–98

Elmnasser N., Guillou S., Leroi F., Orange N., Bakhrouf A. and Federighi, M. 2007. Pulsed-light system as a novel food decontamination technology: a review. Can. J. Microbiol. 53: 813-821.

Everington D. W. 1993. Vacuum technology for food processing. Food Tech. Int. Europe. 993: 71-74.

Farber J. M. 1991. Microbiological aspects of modified-atmosphere packaging technology-a review. J. Food Protection. 54: 58-70.

Faustman C. and Cassens R. G. 1990. The biochemical basis for discoloration in fresh meat: a review. J. Muscle Foods. 1: 217-243.

Fehmerling G., Ocean Res Corp, 1973. Separation of edible tissue from edible flesh of marine creatures. U.S. Patent 3,729,324.

Fellows P. 2000. Food processing technology: Principles and Practice, II ed, CRC, New York.

Gallego-Juárez J. A., Rodriguez G., Acosta V. and Riera E. 2010. Power ultrasonic transducers with extensive radiators for industrial processing. Ultrasonics Sonochemistry, 17: 953-964.

Ghazala S., Aucoin J. and Alkanani T. 1996. Pasteurization effect on fatty acid stability in a sous vide product containing seal meat (Phoca groenlandica). J. food science, 61: 520-523.

Green, D. and Maloney, J. O. 1984. Perry's Chemical Engineers' Handbook.

Guern J., Mathieu Y., Pean M., Pasquier C., Beloeil J. C. and Lallemand J. Y., 1986. Cytoplasmic pH regulation in Acer pseudoplatanus cells I. A 31P NMR description of acid-load effects. Plant Physio. 82: 840-845.

Haard N. F. and Simpson B. K. 1994. Proteases from aquatic organisms and their uses in the seafood industry. In Fisheries Processing (pp. 132-154). Springer US.

Hebbar U. H. 2013. Emerging application of Infrared and Radio Frequency Processing Technologies for Foods. In Protech 2013. Proceedings of the National Seminar on "Application of Emerging Technologies in Fish Processing. CIFT, Cochin: 7-10.

Hogan E., Kelly A. L., and Sun D. W. 2005. High pressure processing of foods: an overview. In Emerging technologies for food processing. Sun D W Eds. Elsevier Academic Press. 525 B Street, California, USA.

Hugas M., Garriga M. and Monfort J. M. 2002. New mild technologies in meat processing: high pressure as a model technology. Meat science, 62: 359-371.

Jiménez-Colmenero F., Reig M. and Toldrá F., 2006. 11 New Approaches. Advanced technologies for meat processing 275.

Joyce E., Phull S. S., Lorimer J. P. and Mason T. J. 2003. The development and evaluation of ultrasound for the treatment of bacterial suspensions. A study of frequency, power and sonication time on cultured Bacillus species. Ultrasonics sonochemistry, 10: 315-318.

Kerry J. P., O'grady M. N. and Hogan S. A. 2006. Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: A Rev. Meat Sci. 74: 113-130.

Kim S. K., Jeon Y. J., Byeun H. G., Kim Y. T. and Lee C. K. 1997. Enzymatic recovery of cod frame proteins with crude proteinase from tuna pyloric caeca. Fisheries Sci. 63: 421-427.

King J. W. and List G. R. 1996. Supercritical fluid technology in oil and lipid chemistry. The American Oil Chemists Society.

Kissam A., Nelson R., Ngao J. and Hunter P. 1982. Water thawing offish using low frequency acoustics. J. Food Science. 47: 71–75

Knirsch M. C., Dos Santos C. A., de Oliveira Soares A. A. M. and Penna T. C. V. 2010. Ohmic heating–a review. Trends in Food Sci. Tech. 21: 436-441.

Koutchma T., Forney L. J. and Moraru C. I. 2009. Ultraviolet light in food technology: principles and applications. CRC press.

Labuza T. P. and Breene W. M. 1989. Applications of "active packaging" for improvement of shelf-life and nutritional quality of fresh and extended shelf-life foods. J. Food Processing and Preservation, 13: 1-69.

Lacroix M. Irradiation of food. 2005. In Emerging technologies for food processing. Sun, D.W. Eds. 353-386. Elsevier Academic press, San Diego, California, USA.

Li B. and Sun D. W. 2002a. Effect of power ultrasound on freezing rate during immersion freezing of potatoes. J. Food Engineering. 55: 277–282.

Li B. and Sun D. W. 2002b. Novel methods for rapid freezing and thawing of foods—A review. J. Food Engineering. 54: 175–182

Mellor J. D. 1980. Vacuum techniques in the food industry [review]. Food Technology in Australia.

Myrnes B. Barstad H., Olsen R. L. and Elvevoll E. O. 1996. Solvent free enzymatic glycerolysis of marine oils. J. Amer. Oil Chemical Society. 72: 1339-1344

Noble R. 1985. A review of vacuum cooling of mushrooms. Mushroom J. 149: 168-170.

Ohshima T., Ushio H. and Koizumi C. 1993. High-pressure processing of fish and fish products. Trends Food Sci. Tech. 4: 370-375.

Oms-Oliu G., Martín-Belloso O. and Soliva-Fortuny R. 2010. Pulsed light treatments for food preservation. A review. Food Bioprocess Tech. 3: 13.

Otles S. and Yalcin B., 2008. Intelligent food packaging. LogForum 4, 4, 3.

Otwell W. S., Kristinsson H. G. and Balaban M. O. (eds.) 2008. Modified atmospheric processing and packaging of fish: filtered smokes, carbon monoxide, and reduced oxygen packaging. John Wiley and Sons.

Ozdemir M. and Floros J. D. 2004. Active food packaging technologies.

Critical Rev. Food Sci. Nutri. 44: 185-193.

Ozuna C., Cárcel J. A., Walde P. M. and Garcia-Perez J. V. 2014. Low-temperature drying of salted cod (Gadus morhua) assisted by high power ultrasound: Kinetics and physical properties. Innovative Food Sci. Emerging Tech. 23: 146-155.

Raa J. 1990. Biotechnology in aquaculture and the fish processing industry: A success story in Norway. Advances in fisheries technology and biotechnology for increased profitability, 509-524.

Rahman M. S. (ed.) 2009. Food properties handbook. CRC press.

Rasco B. A. and Bledsoe G. E. 2004. Seafood: frozen aquatic food products. Food Process. Princi. Appli. 447-458.

Raso J., Palop A., Pagan R. and Condon S. 1998. Inactivation of Bacillus subtilis spores by combining ultrasonic waves under pressure and mild heat treatment. J. Appli. Micro. 85: 849-854.

Reverchon E. 1997. Supercritical fluid extraction and fractionation of essential oils and related products. J. Supercritical Fluids, 10: 1-37.

Roller S., Sagoo S., Board R., O'mahony T., Caplice E., Fitzgerald G., Fogden M., Owen M. and Fletcher H. 2002. Novel combinations of chitosan, carnocin and sulphite for the preservation of chilled pork sausages. Meat Sci. 62: 165-177.

Rooney M. L. 1995. Active packaging in polymer films. In Active food packaging Springer US. 74-110.

Rowan N. J., MacGregor S. J., Anderson J. G., Fouracre R. A., McIlvaney L. and Farish O. 1999. Pulsed-light inactivation of food-related microorganisms. App. Environ. Microbio. 65: 1312-1315.

Sabhapathi S. N. 2013. Application of Pulse Electric Fields Technology for Food. In: Protech 2013. Proceedings of the National Seminar on "Application of Emerging Technologies in Fish Processing. CIFT, Cochin: 11-14.

Sastry S. K. 2005. Advances in ohmic heating and moderate electric field (MEF) processing. In Novel food processing technologies (pp. 491-500). CRC Press, Boca Raton, FL, USA.

Sastry S. K., Jun S., Somavat R., Samaranayake C., Yousef A. and Pandit R. B. 2009. Heating and Sterilization Technology for Long-duration Space Missions. Ann. New York Acad. Sci. 1161: 562-569.

Sastry S. K. and Barach, J. T. 2000. Ohmic and inductive heating. J. Food Sci. 65: 42-46.

Schellekens M. and Martens T. 1992. Sous vide state of the art. Commission of the European Communities Directorate General XII. Research and Development. Publication N, 1.

Stefansson G. and Steingrimsdottir U. 1990. Application of enzymes for fish processing in Iceland present and future aspects. Advances in Fisheries Technology and Biotechnology for Increased Profitability. 237-250.

Stiles M. E. and Hastings J. W. 1991. Bacteriocin production by lactic acid bacteria: potential for use in meat preservation. Trends Food Sci. Tech. 2: 247-251.

Tarleton E. S. and Wakeman R. J. 1998. Ultrasonically assisted separation process. Ultrasounds in food processing. London: Blackie Academic and Professional.

Tewari G. and Juneja V. (eds.) 2008. Advances in thermal and non-thermal food preservation. John Wiley and Sons.

USA-FDA. United States of America, Food and Drug Administration, Center for Food Safety and Applied Nutrition 2000. Kinetics of microbial inactivation for alternative food processing technologies: ohmic and inductive heating: http://www.cfsan.fda.gov/wcomm/ift-ohm.html.at: February 17th, 2009.

Venugopal V. 2006. Seafood processing. Taylor e Francis,.46.

Vilhelmsson O. 1997. The state of enzyme biotechnology in the fish processing industry. Trends Food Sci. Tech. 8: 266-270.

Wang L. and Sun D. W. 2001. Rapid cooling of porous and moisture foods by using vacuum cooling technology. Trends Food Sci. Tech. 12: 174-184.

Wrigley D. M. and Llorca N. G. 1992. Decrease of Salmonella typhimurium in skim milk and egg by heat and ultrasonic wave treatment. J. Food Protection. 55: 678-680.

Zhang M., Tang J., Mujumdar A. S. and Wang S. 2006. Trends in microwave-related drying of fruits and vegetables. Trends Food Sci. Tech. 17: 524-534.

Zheng L. and Sun D. W. 2004. Vacuum cooling for the food industry—a review of recent research advances. Trends Food Sci. Tech. 15: 555-568.

Zhou G. H., Xu X. L. and Liu Y. 2010. Preservation technologies for fresh meat–A review. Meat Sci. 86: 119-128.