**Review Article**

**Quality and Shelf life of Irradiated Seafood Products – An overview**

**ABSTRACT**

Non-thermal processing techniques for fish and fish products preservation are gaining importance at present due to no loss of properties during heating. Irradiation forms better option for fish and fishery products preservation due to its lethal effect on microbes. Seafood irradiation has been proved as effective and safe method without adverse effects increasing integrity and safety of fish and fishery products as food is not becoming radioactive at low and medium doses up to 10 kGy proved by scientific research. Irradiation of fish and fishery products reduces microbial load and total volatile base nitrogen value however it may increase thio barbituric acid reducing substances (TBARS) due to formation of radiolytic products. Irradiation is now being commonly used in many countries, as people are becoming more aware of the role of food irradiation in regard to seafood safety and product shelf-life extension. Reliable methods for the detection of irradiation are now available and are effective in confirming compliance with regulations regarding food irradiation. An extensive education is needed for broad public acceptance. In this book chapter, irradiation for preservation of fish and fishery products has been explained.

**N.B**

**INTRODUCTION**

**Global population will reach about 9 billion by 2024. Supply of adequate basic needs is necessary for growing population. Most important is the supply of nutritious and safe food** free from additives, microbial pathogens, pesticides, and other chemicals. **Minimally processed foods are preferred based on this need. Food industry is utilizing and adopting advanced techniques for preservation of food including seafood. Seafood ranges from low value to highly valued food products of economic importance wherein freshness plays fundamental role in judgement of quality of fish. Being perishable in nature, effective methods of preservation are necessary to maintain quality and safety of fish and fishery products (Sampels, 2015).** Fish and fish products comprises fairly large portion of total protein consumption and a major part of animal protein consumption in many of the parts of the World. Fish is rich in unsaturated fatty acids (Sioen et al., 2007). Seafood undergoes various physical, biochemical and microbiological reactions. It may be due to the growth of microbes, enzymatic actions, insect manifestation, inadequate temperature control, moisture level, and oxidation (Rahman and Perera, 2007) resulting into loss in organoleptic and sensory quality attributes (Miller, 2005). **In order to meet the rising needs, there is need of operative preservation methods (Rahman and Perera, 1999).** Along with quality, seafood safety is also an important parameter (Ashley et al, 2004). Contamination of seafood by pathogens is an enormous problem of public health related significance throughout the world. Thus, there is need of preservation of these fish and fishery products in order to supply quality fish and fishery products for reducing or elimination of spoilage causing agents for prevention of growth of pathogens and other microbes causing food oxidation (Sadecka, 2007). All the preventive processes are collectively called as seafood preservation. Seafood preservation methods prevent or delay spoilage and shelf life of seafood. Many preservation techniques are available ranging from simple drying to high pressure processing of seafood commodities, Ionizing radiation or radiation preservation of food which is versatile among the various treatments (Rahman and Perera, 2007).

**Radiation Processing**

Radiation processing is one such technology applicable to a wide variety of seafood. **Non-thermal processing technologies may be used to eliminate pathogens in raw foods, pasteurize delicate food products such as fresh produce, and perform phytosanitary treatment ( ).** Ionizing radiation is one of the best options for processing of food without heat still exhibiting lethal effect on microbes. Food irradiation is the process of exposing food commodities to controlled amounts of low-energy ionizing radiation. It is one of the successful techniques guarantying food safety along with added benefits such as shelf life extension (Arvanitoyannis et al., 2009). The process of irradiation destroys insects, molds, fungi, bacteria, and pathogens that can cause foodborne disease and food spoilage (Genc and Diler, 2013). The process is gentle enough to maintain the quality of the treated food. Food irradiation is used for pest control, pathogen control, and extension of shelf-life. Irradiation won endorsements by the United Nations’ Food and Agricultural Organization (FAO), World Health Organization (WHO), the U.S. Food and Drug Administration (USFDA), the U.S. Dept. of Agriculture (USDA), and the international food standards setting organization Codex Alimentarius (Arvanitoyannis, 2010) for variety of foods including seafood, meat products, spices, poultry, vegetables, fruits, nuts, grain and wide range of food products. Quality is not compromised during safety concern in radiation preservation of fish (Josephson and Peterson, 2000; Mahapatra et al., 2005).

Radiation techniques exploit part of electromagnetic spectra encompassing shorter wavelengths than 10-10 m. Ionizing radiations are nothing but the radiations from electromagnetic spectrum. Gamma radiation, X-ray, and electron Beam radiation are examples of ionizing radiation (Barbosa-Canovas et al., 1998). Radio waves, microwaves, and ultraviolet (UV) radiation are examples of non-ionizing radiation. Food irradiation has traditionally employed gamma radiation. Gamma irradiation is the older among these techniques of irradiation wherein radioactive isotopes such as cobalt 60 and cesium 137 are utilized for generation of gamma rays as a result of photons emitted from radioactive isotopes. Due to their radioactive nature there are limitations in their use (Bhat and Karim, 2009).

Seafood irradiation is a process for the treatment of seafood to enhance their shelf life and to improve microbial safety (Venugopal et al., 1999). Irradiation is the only alternative to heat processing for food preservation that has a lethal effect on micro-organisms. Irradiation is the exposure of a substance to beams of electromagnetic radiation. For example, microwaving food involves exposing it to beams that have just enough energy to cause water molecules in the food to rub against each other and generate heat by friction. But food irradiation involves higher frequency beams that have enough energy to give atoms positive and negative electrical charges (ionization) for an instant. It is used to improve food safety and to maintain its quality. During irradiation, energy is transferred into the treated product just like when food is heated, but it doesn’t involve a significant increase in temperature (Lima et al., 2018).

Irradiation has a history of over 10 decades ( ). Irradiation has been used from long period of time since 1920s in preservation of food which was discovered at the beginning by scientists from France. Since that period, it is been used for various applications. Nearly 40 countries have approved irradiation use for food. Global turnover of irradiated foods exceeded $2.3 billion and is projected to grow to $22.5 billion by 2030 (Mollins, 2001; McHugh, 2017). Food irradiation doesn’t induce radioactivity due to the use of too low level of doses food irradiation. Food irradiation need to mark with radura international symbol as per the requirements by FDA however, foods which are not fully irradiated doesn’t require this symbol.

**How Irradiation Technique Works?**

Higher sensitivity of DNA to irradiation is due to their larger size compared to other molecules. Damage to DNA may be either direct by reactive oxygen species/ radicals from water radiolysis or indirect wherein nucleic acids are damaged by ionization of adjacent molecules which then react with genetic material (Sadecka, 2007). Enzymatic DNA repair system of microbe decides its survival during radiation (Mollins, 2001; Akram and Kwon, 2010). Chemical and physical structure as well as ability of recovering from radiation injuries of microbe decides amount of radiation or radiation dose (Sadecka, 2007). Various other parameters such as environmental parameters such as moisture, temperature, presence or absence of oxygen significantly influence their radiation resistance (Ashley et al, 2004). Electron beam irradiation works with accelerator which generates electrons in order to accelerate them to the speed of light. Generated electrons penetrate into the desired product which destroys the DNA molecules of pathogens (Mundt et al., 2014).

**Doses of irradiation**

Radiation includes chemical action induced by electron cloud surrounding the nucleus. Absorbed dose is the energy absorbed by foodstuff during irradiation treatment. Unit for irradiation is gray (Gy) which is equal to the energy absorption equivalent to 1 J/ kg of absorbing material (1 Gy = 1 joule. kG-1 = 100 rad) (McLaughlin et al., 1989). Irradiation dose is dependent on the purpose of application or intended use of irradiation. There is categorization of dose levels of irradiation as low dose, medium dose and high dose (Morehouse and Komolprasert, 2004). Low doses (≤1kGy) are applicable for reducing the rhythm in physiological processes like pest control in seafood. Medium doses (1-10 kGy) are to reduce spoilage rate, eliminate pathogens and for shelf life extension. High doses (>10 kGy) are basically for sterilization of seafood and other RTE foods and disinfection of spices. When an electron beams penetrates an aqueous medium, the dose somewhat below the surface is higher than at the surface. Energy in electron beam irradiation is measured in terms of electron volts (eV) which is the electron penetration power and depends on the accelerator. Whether particle or wave type radiation is used, its energy is measured in electron volts, eV, or more normally as MeV (106eV)

1 eV ~ 1.6x 10-12 ergs (1 Joule = 1 x 106 ergs)

A source of 5 MeV will induce radioactivity in food at a level of about 0.3 per cent above the natural level; this is considered not to represent a health hazard (Chapiro, 2004).

|  |
| --- |
| images |
| Figure 1. Electromagnetic spectrum indicating wavelength corresponding to radiation regions |

**Advantages**

Ionizing irradiation or electron beam irradiation from machine sources for fish preservation has a great potential role to play. Microbes and or insects can be effectively eliminated with the use of radiation technique of seafood preservation. It avoids denaturation of the fish and fishery products which is common in other methods of processing of fish such as heating of seafood, freezing, drying, curing and smoking along with exhibition of prolonged shelf life for fish and fishery products with very low doses of radiation. It does not compromise with colour, texture, odour, appearance, etc. Radiation technique can be used in combination with other preservation and processing methods as well making it useful to use as hurdle technology concept. Irradiation is advantageous due to processing under final packaging making the fish and fishery products hygienic (Arvanitoyannis and Tserkezou, 2014).

**Advantages of electron beam irradiation over other radiation processing techniques**

Irradiation techniques including electron beam irradiation is advantageous as it is possible to irradiate product in packaging itself which avoids recontamination. It is helpful for shelf life extension of food products (Morehouse and Komolprasert, 2004). Irradiation technology can destroy most of the types of microbes. It is possible to process product with irradiation even in chilled or frozen or dried state as well (Arvanitoyannis et al., 2009).

E-beam processing has many benefits when compared with other forms of food irradiation. It uses electron beams that have been accelerated to near the speed of light. Commercial electricity is the source of energy. For this reason, e-beam processing does not require the shipment, handling, storage, or removal of any radioactive materials. Furthermore, electron beam equipment can readily be turned on and off, resulting in the presence of radiation only when the system is turned on. Any variation in dosage levels occurring during a processing run immediately shuts down the electron beam system, a capability not available with radioactive sources of irradiation. Another advantage of e-beam processing is that it employs a highly focused and precise beam of electrons that can be adjusted based on the size, density, or packaging material, enabling application of precise dosages. One of the disadvantages of e-beams in comparison to other forms of irradiation is their limited penetration depth. The penetration depth is dependent on a number of properties of the food and must be tested when applying this process. If needed, two opposing beams can be used to treat food products that are twice as thick (Barbosa-Canovas et al., 1998).

Another advantage of e-beam processing is that food products normally only need to be exposed to the e-beam for mere seconds, while gamma and x-ray processes require hours of exposure. The shorter exposure time results in less material degradation compared with gamma and x-ray irradiation. In addition, e-beam processing can be performed in final retail packaging, thus improving supply chain efficiency. E-beam processing also enables the cold chain to be maintained as it generates no heat and does not require the product to be out of temperature specifications (Pillai and Shayanfar, 2015). Thus, the process is frequently called cold pasteurization. Finally, cold pasteurization results in less damage to fresh foods because ripening processes are not accelerated by temperature changes. Process of irradiation causes minimal temperature raise and can be applied as terminal treatment as well through packaging (Sadecka, 2007).

**Gamma Irradiation and Electron Beam Processing Equipment**

There are 3 functional fundamental components of an electron-beam machine. First is an electron gun (comprising of a cathode, grid, and anode) for generation and acceleration of electron beams. Secondly, a magnetic optical system which is used to control the way of electron beam which typically consists of lens and deflection coils for positioning of beam in an oscillating manner. A high-speed conveyor carries cartons of product to be sterilized. The e-beam machine operates as a multi-stage electron accelerator generating a dense beam of high-energy electrons that are showered across the target food, providing saturation of the target with electrons. As the food products pass through this beam, they absorb energy. Commercial e-beam accelerators emit energy ranging from 3 meV to 12 meV. Bottom of Form

Sterilization complex of ebeam irradiation includes; accelerator for electron beam. Energy source between 1 to 10 MeV, power source between 10 to 100 kW, E-beam to x-ray mode switch, protection against radiation, ozone exhaust system, cooling system, emergency accelerator shut down system, conveyor belt, fire extinguishers, etc. \*\*In electron beam irradiators the beams are produced by electricity in a machine. Electrons have a negative charge and a small but appreciable mass and so readily interact with atoms in food. Electron beams can only be used to irradiate smaller food packets that they can easily penetrate. However, the energy can be delivered quickly, and the process takes a comparatively lesser time.

In gamma irradiators the source of radiation is a radionuclide, usually cobalt-60 (60Co) or cesium 137. Cobalt-60 isotopes (half-life, 5.3 years) emit 2 gamma rays of 1.17 and 1.33 million electron volts (MeV), whereas Cesium-137 (half-life, 30.2 years) emits a gamma ray of 0.66 MeV. Cobalt-60 is made by neutron bombardment of Co-59, which stabilizes by emitting radiations and forming non-radioactive nickel.From the practical point of view, Co-60 is preferable to Cesium-137 because the later apart from having weaker gamma rays are also water soluble, thus posing environment hazard. Gamma rays are electromagnetic waves and hence they can pass through dense materials. Products can be irradiated in large sacks or shipping cartons, carried through the irradiator in boxes or stacked on a pallet that will be transported to and from the irradiator in hanging carriers or on roller bed conveyors requiring longer period of time say about an hour. The U.S. Nuclear Regulatory Commission (NRC) has set an upper limit of 10 MeV for ebeam processing and 7.5 MeV for X-ray processing used on foods. Outside the U.S., the limit for ebeam processing is also 10 MeV, but for X-ray processing, the maximum allowable energy is 5 MeV (Pillai and Shayanfar, 2015). The photons in X-rays are similar to gamma irradiation in that they have very high penetration capabilities. However, X-ray processing is significantly faster than cobalt-60-based gamma processing and ebeam processing is faster than X-ray processing. E beam irradiation is classified as low energy (<1 meV) for sterilization of packaging materials, medium (1-8 meV) for phytosanitary purposes and high energy (8-10 meV) for seafood applications (Kashiwagi and Hoshi, 2012).

Seafood irradiation is tunable technique wherein doses of irradiation can be increased or decreased by means of changing the conveyor speed. E-beam irradiation can be useful for packages of foods such as fish fillets not more than 8-10 cm thickness with density of 1 gcm3. X-rays have maximum energy of 5 MeV and similar penetrating power as gamma rays. Despite good penetration power and dose rate, X-rays are not used in food irradiation due to poor conversion of accelerated electrons to X-rays. The effects of gamma rays and electron beams are however comparable (Acheson and Steele, 2001; Sadecka, 2007). Labeling is necessary, so that people can freely choose whether to use this safe and wholesome processed food (Akram and Kwon, 2010).

**Foods Suitable for Irradiation**

Food which are used for radiation decontamination are poultry meat, egg products, red meat, fishery products, spices, mushrooms and other dry ingredients. Doses of irradiation suitable for various types of products are tabulated in Table 1.

**Table 1. Irradiation levels for various kinds of food products**

|  |  |  |
| --- | --- | --- |
| **Food products** | **Irradiation level** | **References** |
| Poultry products and raw meat | 1.5 to 2.5 kGy for chilled and 3-5 kGy for frozen products | Lewis et al., 2002 |
| Mushrooms | 1-3 kGy | Akram and Kwon, 2010 |
| Egg Products | 0.5 kGy for Salmonella elimination | Serrano et al., 1997 |
| Red meat | 1 kGy to 6 kGy depending on the purpose | Kampelmacher, 1984 |
| Fish and fishery products | Up to 4 kGy for frozen fish and fishery products  1 kGy for elimination of *Vibrio vulnificus* in Oysters  9 kGy for raw shrimps | Nouchpramoul, 1985;  Ito et al., 1989  Mallett et al., 1991  Coleby and Shewan, 1965 |
| Spices | 3-10 kGy | Farkas, 1988 |
| Fresh fruits and vegetables | Up to 3 kGy | Farkas, 1998 |

**Radiation process for fish and fishery products**

Radiation process is categorized into 3 different categories as:

*Radurization*

Radurization is a technique for reduction of bacteria responsible for spoilage of fish during chilled or refrigerated storage. Food irradiated with 1 kGy, undergoes what is termed radurization (“rad” from irradiation and “dur” from the Latin hard or durable. It leads to shelf life extension of fish and fishery products (Arvanitoyannis et al., 2009). Organoleptic, biochemical and microbiological factors which are responsible for spoilage are considered while determining the dose of irradiation. Gram negative microbes are sensitive to radiation which is responsible for spoilage of fish and fishery products. Low level of radiation of 1 is used in radurization leading to reduction of microbial load by 1 to 3 log cycles. Shelf life extension by 2-3 times compared to unirradiated samples can be achieved with radurization. Radurization makes its effectiveness in shelf life extension of most of the marine and freshwater fish species when iced soon after catching. Non spore formers are eliminated causing bacterial load reduction leading to shelf life extension of fish and fishery products (Mansiyom, 2011).

*Radicidation*

Radicidation is meant for sanitization purpose in frozen fish and fishery products by elimination of pathogens. If the radiation dose delivered falls in the range of 1–10 kGy, food undergoes what is termed radicidation (“rad” from irradiation and “cid” from Latin “to kill” (Arvanitoyannis et al., 2009). Doses of 2 kGy were found effective for significant elimination of pathogens. Handling conditions, product type and nature, application of product, processing parameters are important while using radicidation for preservation.

*Radappertization*

This technique is used to achieve shelf stability of fish and fishery products at ambient temperatures. If food is irradiated above 10 kGy, it undergoes what is called radappertization (“rad from radiation and “appert” after the French scientist Appert who invented sterile canning). Radappertization results in the complete sterilization of a food, as all bacteria are eliminated (Arvanitoyannis et al., 2009). In this technique, higher irradiation doses are used from 10 to 70 kGy in order to eliminate all organisms for providing commercial sterility. This method is insufficient to inactivate autolytic enzymes. Heat treatment is also needed and seafood is packed in vacuum packs in metal or flexible containers. It is most severe among three techniques. It leads to textural and flavour changes which can be reduced by blanching and antioxidant addition.

**Use of hurdle technology: combining irradiation with other processing methods**

Effect of irradiation in combination with other methods of preservation is advantageous. It leads to cost saving and improved sensory and bacteriological quality. Preservative effects of combinations of treatments in controlling microbial growth and resulting spoilage is based on hurdle technology and involves the creation of series of hurdles in the foods for microbial growth. Such hurdles include heat, irradiation, low temperature, water activity, and pH, redox potential and chemical preservatives.

Irradiation doses used for various food applications vary. Dose required for seafood disinfection is 0.2 to 0.8 kGy whereas prevention of food borne parasite reproduction, 1 to 3 kGy dos is required. Shelf life extension of fish and fishery products need dose between 0.5 to 5 kGy whereas, dose of 1 to 7 kGy is required for eliminating non-spore forming pathogens other than viruses (Sadecka, 2007).

**Use of ultraviolet (UV) irradiation**

Use of Ultraviolet in the wavelength of 2000-2950 is permitted. Due to its poor penetrating ability, only surface irradiation is possible for example packaging or transparent liquids. It exhibits bactericidal effect. Water purification systems use this. In fisheries sector, UV cleansing systems for purifying water uses UV irradiation system (Skowron et al., 2014).

**Application**

Radiation is useful for destruction of microbial load causing seafood poisoning, keeping seafood fresh for longer period of time by reducing microbial load causing spoilage. It is also use for seafood safety and for waste reduction purposes. Expansion of market for fish and fishery products is possible with application of irradiation process. It produces better quality fish compared to iced fish. Spoilage losses may be reduced as a result of use of radiation processing. Irradiation enables easier distribution and handling and reduces spoilage loss (Farkas, 2006).

**Irradiated seafood and consumer acceptance**

Radiation of seafood being effective method of food preservation faces the problems such as consumer advocacy (Ashley et al., 2004; Sadecka, 2007). It is not fully accepted by consumers (Board, 1991).

**Changes in properties of fish and fishery products in Irradiation**

Irradiation of seafood is non-thermal method of processing as the process does not elevate temperature however, product temperature is also important in fixing irradiation doses. General data on the same aspect is limited. It varies depending on species and processing conditions.

*Changes in amino acids and proteins*

Changes in proteins depend on the conditions of irradiation. Solid proteins absorb radiation energy producing free radicals. Methionine and cysteine forms volatile compounds during irradiation such as sulfane and mercaptan. Deamination, decarboxylation and peptide chain break may be observed in peptides. Acid or ketone formation takes place as a result. Radiation splitting of hydrogen and -S-S- bridges leads to development of protein molecules and loss of their organized structure (Grolichova et al., 2004). In general, irradiation destructs cysteine, thiamine as per the reports but it does not alter biological value of proteins or net protein utilization pattern as well as lipid components (Desrosier and Rosenstock, 1960). Free amino acids and amino acids of proteins are sensitive to irradiation. Radiolysis of water forms hydroxyl, hydrogen, aqueous electron radicals in free form which further undergo deamination or decarboxylation process leading to formation of ammonia and pyruvic acid. Deamination may be oxidative or reductive depending on the presence or absence of oxygen. Phenyl alanine and tyrosine which are aromatic amino acids undergo hydroxylation to form isomers of tyrosine and 2, hydroxy phenyl alanine (DOPA). Melanin pigmentation is observed due to oxidation and polymerization of DOPA.

*Changes in carbohydrates*

Changes in carbohydrates occur in solid as well as liquid state. They are more prone to irradiation. Melting point reduction and optical rotational changes occur in carbohydrates post irradiation. Radiolysis leads to develop hydrogen, carbon monoxide, methane, formaldehyde, acetone and malonaldehyde (Grolichova et al., 2004).

*Changes in lipids/ fats*

Lipids are regarded as very sensitive to the irradiation treatment which may cause oxidative and hydrolytic damage (Wills, 1980a,b) leading to fatty acid loss and changes in sensory properties. Changes depend on the fatty acid composition and amount of unsaturated fatty acids.

*Textural changes*

Radiation process influences textural quality of fish which can be enhanced by dip treatments with sodium tri poly phosphate or NaCl. Decreased gelation behaviour was observed in red hake mince at low doses of irradiation.

*Changes during processing of seafood*

Processes such as heating, cooking, drying of seafood may lead to loss of nutritional parameters. Irradiated food does not contain such carcinogenic materials produced during thermal processing (Sadecka, 2007). No loss of carbohydrates, proteins, fat and micronutrients was observed during irradiation below 10 kGy, however, irradiation above 10 kGy degraded carbohydrate and lipid structure (Miller, 2005). Lipid oxidation can be significantly reduced by freezing and/or removing of oxygen prior to irradiation (Miller, 2005; Sadecka, 2007). Fish quality parameters such as various intrinsic, extrinsic and microbial quality parameters are also important parameters to fix the irradiation dose (Ashie et al., 1996; Erkan et al., 2014). Irradiation of seafood destructs non-spore forming pathogens leading to protection of seafood consumers from microbe related complications such as salmonellosis, gastroenteritis, etc. (Thayer, 1990).

**Irradiated fish and fishery products: Quality aspects and extension of shelf life**

Biochemical quality parameters such as total volatile base nitrogen, tri methyl amine nitrogen, pH, salt, and moisture content had no significant impact by irradiation however, significant reduction in phenolic content was observed in cold smoked salmon (Badr, 2012). Irradiation and sodium acetate treatment of refrigerated stored rainbow trout at 1, 3 and 5 kGy affected H2S forming bacteria and enterobacteria as well (Moini et al., 2009). Somfug which is Thai fermented product of fish mince exhibited higher TBARS values, lower level of colour changes and gradual pH decrease (Riebroy et al., 2008). Irradiation of seabass at 2 and 5 kGy during ice storage exhibited lower TVB-N and TBARS when compared with non-irradiated control samples (Ozden et al., 2007). Atlantic horse mackerel (*Trachurus trachurus*) irradiated using 1 and 3 kGy gamma irradiation exhibited shelf life extension by 4 days compared to non-irradiated sample which exhibited shelf life of 8 days (Mendes et al., 2005), whereas irradiation in the range between 1 to 10 kGy had no significant effect on proteins of horse mackerel (Silva et al., 2006). Fish cutlets with 5 kGy irradiation exhibited shelf life extension up to 14 days (Bari et al., 2000).

**Table 2-QUALITY OF IRRADIATED FISH AND FISHERY PRODUCTS AND SHELF LIFE EXTENSION**

|  |  |  |  |
| --- | --- | --- | --- |
| **Fish and Fishery Product** | **Irradiation Dose** | **Shelf life** | **References** |
| **Haddock fillets** (*Melanogrammus aegleﬁnus*) at 5-6°C | 1.5-2.5 kGy | 22-25 days | Rosnivalli et al., 1968 |
| Bombay duck (*Harpodon nehereus*) under refrigeration | 1.0-2.5 kGy | 18-20 days | Kumta et al., 1973 |
| **Chilled scallops** (*Amusium balloti*) | 0.5, 1.5 and 3 kGy | 28 days (raw) and 43 days (cooked) | Poole et al., 1990 |
| Herring (*Clupea herring*) | 1 – 2 kGy | 10-14 days shelf life in ice | Snauwert et al., 1977 |
| Ocean perch (Sebastodes alutus) | 1-2 kGy | 25-28 days shelf life at 0.6 °C | Reinacher and Ehlermann, 1978 |
| Mackerel (Rastrelliger kanagurta) and White pomfret (Stomateus cinereus) | 1.5 kGy | - | Arvanitoyannis et al., 2009 |
| Black pomfret (Parastromatus niger) | 1 kGy | - | Arvanitoyannis et al., 2009 |
| Sole (Parophyrs vetulus) | 2-3 kGy | - | Arvanitoyannis et al., 2009 |
| Bombay duck (Harpodon nehereus) | 1.5-2.5 kGy | Shelf life extension up to 15-20 days | Kumta et al., 1970 |
| whiteﬁsh (Coregonus clupeaformis) | 0.82 and 1.22 kGy | Shelf life extension up to 17-21 days at 3°C | Chuaqui-Offermanns et al. (1988) |
| Silage sihama | 2-3 kGy | Shelf life of 19 days at 1-2°C | Ahmed et al. (1997) |
| Atlantic Horse mackerel (Trachurus trachurus) | 1 and 3 kGy | 0 ± 1°C for 23 days | Mendes et al. (2005) |
| breams | 2.5-5 kGy | Shelf life extension up to 15 days | Özden et al. (2007a;b) |
| Threadﬁn bream (Nemipterus japonicus) dipped in NaCl | 1 and 2 kGy | Shelf life extension up to 14-28 day | Jeevanandam et al. (2001) |
| Vacuum packed trouts | 0.5 to 2 kGy | 14 to 24 days shelf life | Savvaidis et al. (2002) |
| Sardines (Sardina pilchards) | 2-3 kGy | 21 days shelf life | Kasımoglu et al. (2003) |
| Squid (Doryteuthis sibogae) | 3 and 5 kGy | 10 days shelf life | Manjanaik et al., 2018 |
| chub mackerel (Scomber japonicus) | 1.5 kGy | 14 days shelf life | Mbarki et al., 2009 |
| Salted, seasoned and fermented oyster | 1, 2 and 5 kGy | 4 weeks shelf life at 10°C | Song et al., 2009 |
| Litopenaeus vannamei headless shell on | 2.5, 5, 7.5 and 10 kGy | 15 days shelf life of 2.5 and 5.0 kGy and 19 days shelf life of 7.5 and 10 kGy under chilled storage condition | Visnuvinayagam et al., 2017 |
| rainbow trout (*Oncorhynchus mykiss*) fillets | UV-C irradiation and modified atmospheric packaging | Shelf life extension to 22 days | Rodrigues et al., 2016 |
| Surimi seafood | Electron beam irradiation at 4 kGy | 7 log reduction in *Staphylococcus aureus* | Park and Jackzynski, 2003 |
| Glazing, nisin treatment and radiation processing of seer fish fillets | 2 and 5 kGy | 2 kGy 34 days shelf life  5 kGy 42 days shelf life in chilled storage conditions | Kakatkar et al., 2017 |
| Headless vannamei (*Litopenaeus vannamei)* | Electron beam irradiation at 2 kGy, 5 kGy and 7.5kGy | 15–23 days with respect to dose level in chilled storage conditions | Jeyakumari et al., 2020 |
| Tilapia fish (*Oreochromis niloticus)*  chunk | Electron beam irradiation at 2 kGy and 5 kGy | 28-38days with respect to dose level in chilled storage conditions | Jeyakumari et al., 2023 |

**IDENTIFICATION OF IRRADIATED FISHERY PRODUCTS**

Ionizing radiation does not cause any changes in the identity of the product from non-irradiated produce. Irradiated and non-irradiated products are visually and organoleptically identical (IAEA, 2000). Irradiated foods undergo less chemical modifications compared to other treatments such as heating (Marchioni, 2006).

**Future Developments**

Irradiation is being used at present in food preservation. In processing and preservation of fish and fishery products, experiments pertaining to extension of shelf life of fish in various forms, packaging material suitable for irradiated fish and fishery products and their usefulness need to be conducted.There is a need for extensive education in relation to broad acceptance by public sector targeting professional and lay man public. Labelling of irradiated fish and fishery products for safe and wholesomeness of food is needed. Compliance confirmation in relation to food irradiation and study of various reliable techniques for their detection are required in detail.

**CONCLUSION**

Radiation for preservation of seafood is gaining importance day by day due to its effectiveness and low cost. Irradiation can effectively reduce or eliminate pathogens of public health significance, spoilage causing microorganisms, insects and parasites. It is an effective, non-nuclear, quick and cost effective technique with high potential. Fish and fish products exhibited shelf life extension even 3-5 times longer than traditional methods. Radiation can be used as a method of preservation of fish and fishery products in combination with other preservation techniques making it a hurdle technique of processing of fish and fishery products. Its use in fish and fishery product preservation can be beneficial for reducing post-harvest losses in fisheries sector as well as for quality enhancement of fish and fishery products. Safety and wholesomeness of irradiated fish and fishery products can be achieved by optimum irradiation doses and standard sanitation operating procedure and good manufacturing practices which can be beneficial for further extending the supply of fresh fish and fishery products. In general, shelf life prolongation by 50 to 75% in fish and fishery products either in raw or processed and packaged form is observed which is much higher compared to present method of fish and fishery product preservation. In addition, higher rate of elimination of food borne pathogens can be achieved when irradiation is used as method of food preservation.

**References**

Acheson, D., Steele, J. H. 2001. Food irradiation: A Public Health Challenge for the 21st Century Clin. Infect. Dis. 33(3): 376 - 377. DOI: <https://doi.org/10.1086/321899>

Ahmed, I. O., Alur, M. D., Kamat, A. S., Bandekar, J. R., Thomas, P. 1997. Inﬂuence of processing on the extension of shelf-life of nagli-ﬁsh (*Silago sihama*) by gamma irradiation, International Journal of Food Science and Technology, 32: 325-332. DOI: 10.1046/j.1365-2621.1997.00409.x

Aram, K., Kwon, J. 2010. Food irradiation for mushrooms: A review. J. Korean Soc. Appl. Biol. Chem. 53, 257–265, <https://doi.org/10.3839/jksabc.2010.041>

Arvanitoyannis I S (Ed.) 2010. Irradiation of Food Commodities: Techniques, Applications, Detection, Legislation, Safety and Consumer Opinion. Academic Press.

Arvanitoyannis, I. S., Tserkezou, P. 2014. Irradiation of Fish and Seafood. In: Seafood processing: technology, quality and safety. Ioannis S. Boziaris (eds.) pp. 83–127. doi:10.1002/9781118346174.ch5

Arvanitoyannis, I. S., Stratakos, A., Mente, E., 2009. Impact of irradiation on fish and seafood shelf life: A comprehensive review of applications and irradiation detection, Critical Reviews in Food Science and Nutrition, 49: 68-112. doi: 10.1080/10408390701764278

Arvanitoyannis, S. I., Stratakos, A. and Mente, E. (2009). Impact of irradiation on fish and seafood shelf life: a comprehensive review of applications and irradiation detection. Critical Reviews in Food Science and Nutrition, 49: 68–112

Ashie, I., Smith, J., Simpson, B. 1996. Spoilage and shelf-life extension of fresh ﬁsh and shellﬁsh, Critical Review in Food Science and Nutrition, 36: 87-121. doi: 10.1080/10408399609527720

Ashley, B. C., Birchfield, P. T., Chamberlain, B. V., Kotwal, R. S., McClollan, S. F., Moynihan, S. 2004. Health Concerns Regarding Consumption of Irradiated Food In. Journal of Hyg. and Envir. Health. 207(6): 493-504 DOI: 10.1078/1438-4639-00321

Badr, H. M., 2012. Control of the potential health hazards of smoked fish by gamma irradiation., Int J Food Microbiol. 154(3): 177-186. doi: 10.1016/j.ijfoodmicro.2011.12.037

Barbosa-Canovas, G. V., Pothakamury, U. R. and Palou, E. 1998. Non-thermal Preservation of Foods, New York: Marcel Dekker, Inc..

Barbosa-Canovas, G. V., Pothakamury, U. R., Palou, E. (1998). Nonthermal Preservation of Foods, Marcel Dekker, Inc., New York, USA.

Bari, M. L., Sabina, Y., Kusunoki, H., Uemura, T. (2000). Preservation of Fish Cutlet (*Pangasius pangasius*) at Ambient Temperature by Irradiation. Journal of Food Protection, 63(1), 56–62. doi:10.4315/0362-028x-63.1.56

Bhat, R. and Karim, A. A. 2009. Impact of Radiation Processing on Starch, Comprehensive Reviews in Food Science and Food Safety, 8(2): 44-58, <https://doi.org/10.1111/j.1541-4337.2008.00066.x>

Board, R. 1991. Consumer acceptance of irradiated foods in the United State. In: Thorne, S. (ed.): Food Irradiation. Elsevier Applied Science, London, New York: 61-86.

Chapiro, A. 2004. Radiation Effects in Polymers In: Encyclopedia of Materials: Science and Technology (Second Edition), Elsevier, pp. 1-8. https://doi.org/10.1016/B0-08-043152-6/01918-5

Chuaqui-Offermanns, N., Mc Dougall, T. E., Sprung, W., Sullvan, V. 1988. Raduriation of commercial freshwater ﬁsh species, Radiation Physics and Chemistry, 31: 243-252.

Coleby, B. and Shewan, J. M. 1965. The radiation preservation of fish. In: Borgstrom, G. (Ed.), Fish as Food. Academic Press, New York, Vol. 4, 419.

Desrosier, N. W. and Rosenstock, H. M. 1960. Radiation technology in food. Westport, Connecticut: Avi Publishing Company, 401 pp.

Erkan, N., Gunlu, A., Genc, I. Y. 2014. Alternative seafood preservation technologies: Ionizing radiation and high pressure processing. Journal of fisheriessciences.com, 8(3): 238-251. DOI. 10.3153/jfscom.201430

Farkas J. 1998. Irradiation as a method for decontaminating food - A review International Journal of Food Microbiology 44 189–204.

Farkas, J. 1988. Irradiation of Dry Food Ingredients. CRC Press, Boca Raton, 153.

Farkas, J. 2006. Irradiation for better foods. Trends in food sci technol. 17: 148-152

Genç, İ.Y., Diler, A., 2013. Elimination of foodborne pathogens in seafoods by irradiation: Effects on quality and shelf-life, Journal of Food Science and Engineering, 3: 99-106.

Grolichova, M., Dvorack, P and Musilova, H. 2004. Employing Ionizing Radiation to Enhance Food Safety – a Review. ACTA VET. BRNO 2004, 73: 143-149

IAEA. 2000. Irradiation of fish shellfish and frog legs, A comparison of technical data for editorization and control IAEA-TECDOC-1158

Ito, H., Adulyatham, P., Sangthong, N., Ishigaki, I. 1989. Effect of Gamma irradiation on frezen shrimps to reduce microbial contamination. Radit. Phys Chem. 34, 1009-1011.

Jeevanandam, K., Kakatkar, A., Doke, S. N., Bongirwar, D.R., Venugopal, V., 2001. Inﬂuence of salting and gamma irradiation on the shelf-life extension of threadﬁn bream in ice, Food Research International, 34: 739-746. doi: 10.1016/S0963-9969(01)00100-4

Jeyakumari A, Sivam V, Unnikrishnan P, Kuppa Sivasankara S, Kaushlesh Pansingh R, Shaik Abdul K, Lakshmi NM, Chandragiri Nagarajarao R. 2020. Effect of electron beam irradiation on the biochemical, microbiological and sensory quality of *Litopenaeus vannamei* during chilled storage. J Food Sci Technol. 57(6):2150-2158. doi: 10.1007/s13197-020-04250-7.

Jeyakumari A, Narasimha Murthy L, Visnuvinayagam S, Sarma K. S. S., Rawat K. P. and Shaikh Abdul Khader.2023. Effect of electron beam irradiation on the qualityof vacuum- packed, chilled-stored tilapia fish chunks. Indian Journal of Fisheries Science. Fish., 70 (2): 109-115,

Josephson, E. S., Peterson, M. S. 2000. Preservation of food by ionizing radiation (II), 102–103. Boca Raton, FL: CRC.

Kakatkar, A.S., Gautam, R.K., Shashidhar, R. 2017. Combination of glazing, nisin treatment and radiation processing for shelf-life extension of seer fish (*Scomberomorous guttatus*) steaks. Radiation Physics and Chemistry, 130: 303-305. <https://doi.org/10.1016/j.radphyschem.2016.09.017>

Kampelmacher, E. H., 1984 Low dose y-irradiation of raw meat II. Bacteriological effects on samples from butcheries. Int. J. Food Microbial. 1, 25-31.

Kashiwagi, M., Hoshi, Y. 2012. Electron beam Processing System and Its Application. SEI Technical Review, 75: 47-54

Kasımoglu, A., Denli, E., Ic, E. 2003. The extension of the shelf-life of sardine which were packaged in a vacuum stored under refrigeration, and treated by d-irradiation, International Journal of Food Science and Technology, 38: 529-535. doi: 10.1046/j.1365-2621.2003.00697.x

Kumta, U.S., Mavinkurve, S. S., Gore, M. S., Sawant, P. L., Gangal, S. V., Sreenivasin, A., 1970. Radiation pasteurization of fresh and blanced tropical shrimps, Journal of Food Science, 35: 360-363. doi: 10.1111/j.1365-2621.1970.tb00930.x

Lewis, S. J., Vela´squez, A., Cuppett, S. L., and McKee, S. R. 2002. Effect of Electron Beam Irradiation on Poultry Meat Safety and Quality. Poultry Science 81:896–903.

Lima, F., Vieira, K., Santos, M. and Mendes de Souza P., 2018. Effects of Radiation Technologies on Food Nutritional Quality, Descriptive Food Science, Antonio Valero Díaz and Rosa María García-Gimeno, IntechOpen, DOI: 10.5772/intechopen.80437.

Mahapatra, A. K., Muthukumarappan, K. and Julson, J. L. 2005. Applications of ozone, bacteriocins and irradiation in food processing: A review. Critical Reviews in Food Science and Nutrition, 45: 447–461.

Mallett, J. C., Beghiam, L. E., Metcalf, T. G., Kaylor, J. D. 1991. Potential of iradiation technology for improved shellfish sanitation. J. Food Safety. 11, 231245.http://cst.ur.ac.rw/library/Food%20Science%20books/batch2/Novel%20Food%20Processing%20Technologie s/dk1128ch18.pdf

Manjanaik, B., Kavya, N., Shetty, V., Somashekarappa, H., Rajashekar, P. 2018. Influence of gamma irradiation and low temperature storage on the quality and shelf life of squid (*Doryteuthis sibogae*). Food Research 2 (1): 39 – 45

Mansiyom, P. 2011. Deterioration and shelf-life extension of fish and fishery productsby modified atmosphere packaging. Songklanakarin J. Sci. Technol. 33 (2), 181-192.

Marchioni, E. 2006. Food irradiation research and technology Edited by: Sommers, H. S. and Fan, X. 85–103.

Mbarki, R., Miloud, Najla Ben, Selmi, S., Dhib, Soukeina and Sadok, Saloua 2009. Effect of vacuum packaging and low-dose irradiation on the microbial, chemical and sensory characteristics of chub mackerel (*Scomber japonicus*), Food Microbiology, 10.1016/j.fm.2009.05.008, 26, 8: 821-826.

McHugh, T. 2017. Illuminating E-Beam Processing. Food Technology Magazine, 71(1): 64-66.

McLaughlin, W. L. 1989. Reference dosimetry and measurement quality assurance, International Journal of Radiation Applications and Instrumentation. Part A. Applied Radiation and Isotopes, 40, (10–12): 945-951. <https://doi.org/10.1016/0883-2889(89)90021-X>.

Mendes, R., Silva, H. A., Nunes, M. L., Empis, J. M. A., 2005. Effect of low-dose irradiation and refrigeration on the microﬂora, sensory characteristics and biogenic amines of Atlantic horse mackerel (*Trachurus trachurus*), European Food Research and Technology, 221: 329-335. doi: 10.1007/s00217-005-1172-x

Miller, R. B. 2005. Electronic Irradiation of Foods. Springer US DOI.10.1007/0-387-28386-2, p. 296.

Moini, S., Tahergorabi, R., Seyed Vali, H., Rabbani, M., Tahergorabi, Z., Feas, X., Aflaki, F., 2009. Effect of Gamma Radiation on the Quality and Shelf Life of Refrigerated Rainbow Trout (*Oncorhynchus mykiss*) Fillets. Journal of food protection, 72(7), 1419- 1426.

Mollins, R. A. 2001. Introduction. In: R. A. Mollins. Food Irradiation: Principles and application. Pp. 1-21, New York Wiley Interscience

Morehouse, K. M. and Komolprasert, V. 2004. Irradiation of Food and Packaging ACS Symposium Series 875, Chapter 1, Pages 1-11.

Mundt JM, Rouse L, Van den Bossche J, Goodrich RP. 2014. Chemical and biological mechanisms of pathogen reduction technologies. Photochem Photobiol. 90(5):957–964. doi:10.1111/php.12311

Nouchpramoul, K. 1985. Elimination of Salmonella in frozen shrimp by radiation treatment. Food Irradiat. Newsl. 8 (1), 14-15

Özden, Ö., İnuğur, M., Erkan, N., 2007a. Preservation of iced refrigerated sea bream (*Sparus aurata*) by irradiation: microbiological, chemical and sensory attributes, European Food Research and Technology, 225: 797-805. doi: 10.1007/s00217-006-0484-9

Özden, Ö., İnuğur, M., Erkan, N., 2007b. Effect of different dose gamma radiation and refrigeration on the chemical and sensory properties and microbiological status of aqua cultured sea bass (*Dicentrarchus labrax*), Radiation Physics and Chemistry, 76: 11691178. doi: 10.1016/j.radphyschem.2006.11.010

Park, J.W. and Jackzynski, J. 2003. Microbial Inactivation and Electron Penetration in Surimi Seafood During Electron Beam Processing. Journal of food science, 68(5): 1788-1792

Pillai, S. D., Shayanfar S., 2015. Electron Beam Pasteurization and Complementary Food Processing Technologies (UK: Elsevier, 2015), p. 324.

Poole, S. E., Wilson, P., Mitchell, G. E., Wills, P. A., 1990. Storage Life of Chilled Scallops Treated with Low Dose Irradiation. J Food Prot. 53(9):763-766. doi: 10.4315/0362-028X-53.9.763.

**Rahman, M. S., Perera, C. O. 1999. Drying and food preservation. In: Handbook of Food Preservation. Rahman, M. S., Ed. Marcel Dekker, New York. pp. 173–216.**

**Rahman, M. S., Perera, C. O. 2007. Drying and food preservation. In: Handbook of Food Preservation. Second Ed., Rahman, M. S., Ed., Taylor and Francis, LLC, New York. pp. 403-432.**

Reinacher, E., Ehlermann, D., 1978. Effect of irradiation on board on the shelf life of red fish. 1. Results of the sensory examination. ArchivfürLebensmittelhygiene, 29: 24-28.

Riebroy, S., Benjakul, S., Visessanguan, W. 2008. “Properties and Acceptability of Som-Fug, a Thai Fermented Fish Mince, Inoculated with Lactic Acid Bacteria Starters, Swiss Society of Food Science and Technology, 41(4): 569-580.

Rodrigues, B. L., Alvares, T. S., Sampaio, G. S. L., Cabral, C. C., Araujoa, V A A, Franco, R. M., Mano, S. B., Conte, C. A. 2016. Influence of vacuum and modified atmosphere packaging in combination with UV-C radiation on the shelf life of rainbow trout (*Oncorhynchus mykiss*) fillets Food Control 60: 596-605

Rosnivalli, L. J., King, F. G., Ampola, V. G., & Holston, J. A. 1968. A study of irradiated pasteurized fishery products. Report to U.S. Atomic Energy Commission on Contract No. AT(49-11)-1889 (No. TID-24256).

Sadecka J. 2007. Irradiation of spices – a review. Czech J. Food Sci., 25: 231–242.

Sampels, S. 2015. The Effects of Storage and Preservation Technologies on the Quality of Fish Products: A Review. Journal of Food Processing and Preservation 39(6): 1206-1215 DOI: 10.1111/jfpp.12337

Savvaidis, I., Panagiotisskandamis, Riganakos, K., Nikolaospanagiotakis, Kontominas, M. 2002. Control of Natural Microbial Flora and *Listeria monocytogenes* in Vacuum-Packaged Trout at 4 and 10 ° C Using Irradiation. Journal of Food Protection, 65(3): 515– 522

Serrano, L.E., Murano, E.A., Shenoy, K., Olson, D.G. 1997. D values of *Salmonella enteritidis* isolates and quality attributes of shell eggs and liquid whole eggs treated with irradiation Poultry Science, 76(1): 202-206, https://doi.org/10.1093/ps/76.1.202

Silva, H.A., Mendes, R., Nunes, M. L., Empis, J., 2006. Protein changes after irradiation and ice storage of horse mackerel (*Trachurus trachurus*). European Food Research and Technology, 224: 83-90.

Sioen, I., DeBacker, M. G., Van Camp J., De Henauw, S. 2007. Importance of seafood as nutrient source in the diet of Belgian adolescents. Journal of human nutrition and dietetics, 20(6): 580-589. <https://doi.org/10.1111/j.1365-277X.2007.00814.x>

Skowron K, Bauza-Kaszewska J, Dobrzański Z, Paluszak Z, Skowron KJ. UV-C radiation as a factor reducing microbiological contamination of fish meal. ScientificWorldJournal.

Snauwert, F., Tobback, P., Maes, E. and Thyssen, J., 1977. Radiation induced lipid oxidation in ﬁsh, Zeitscrift für Lebensmittel Untersuchung Forschung, 164: 28-30. doi: 10.1007/BF01135420

Song, H.P., Kim, B., Jung, S., Choe, J.H., Yun, H., Kim, J.Y., Jo, C. 2009. Effect of gamma and electron beam irradiation on the survival of pathogens inoculated into salted, seasoned, and fermented oyster. LWT - Food Sci Technol. 42(8): 1320-1324. <https://doi.org/10.1016/j.lwt.2009.03.018>

Thayer, D.W. 1990. Food irradiation: benefits and concerns. Journal of Food Quality, 13(3): 147-169, <https://doi.org/10.1111/j.1745-4557.1990.tb00014.x>

Venugopal, V., Doke, S.N., Thomas, P., 1999. Radiation processing to improve the quality of fishery products, Critical Reviews in Food Science and Nutrition, 39: 391-440. doi: 10.1080/10408699991279222

Visnuvinayagam S., Jeyakumari A., Murthy L.N., and Rawat K.P. 2017. Electron Beam Irradiation: A novel approach for shelf stable vacuum packed and chill stored vannamei shrimp. FISH Tech Reporter, 3(2): 22-23

WILLS, ED 1980: Effect of antioxidants on lipid peroxide formation in irradiated synthetic diets. Int J Radiat Biol 37: 403-414

WILLS, ED 1980: Studies of lipid peroxide formation in irradiated synthetic diets and the effects of storage after irradiation. Int J Radiat Biol 37: 383-401