7. APPLICATION OF ELECTRON BEAM IRRADIATION FOR FISH AND FISHERY PRODUCTS

A. Jeyakumari, L. Narasimha Murthy, Laly S.J., Abhaykumar

Mumbai Research Centre of ICAR-Central Institute of Fisheries Technology, Navi Mumbai

jeya131@gmail.com

Irradiation process has been used in industry for many years. Electron beam irradiation is very similar to gamma radiation in terms of ionizing energy but is different in terms of dosage rates and penetration. Three principal types of radiation source can be used in food irradiation according to the Codex Alimentarius General Standard (Food and Agriculture Organization, WHO, 1984). Radiation processing involves precise exposure of food and agricultural commodities to ionizing radiations such as gamma rays (cobalt-60 and caesium-137) or machine generated X-rays (5 Mev) and high-energy electrons (8-10 Mev). Ionizing radiation in EBI technology is provided through electrons, while mainly by photons in X-rays and gamma rays. The amount provided by the source is known as dose and measured in kilo Grays (kGy) (1 kGy = 1,000 kJ or MR; 1 MR = 1,000,000 ergs/gram). Depending on the technical specifications, radiation processing is broadly classified into three categories:

1. Low dose (<1kGy) mainly used for sprout inhibition of vegetables, for disinfestation of storedgrains, dry fruits and spices and for delayed ripening in fruits.
2. Medium dose (1-10 kGy), for hygienisation of whole spices, spice powders, spice mixtures and for elimination of spoilage microbes in fruits and seafoods. This range of dose is employed for shelf life improvement during long-term storage.
3. High dose (10-45 kGy), necessary to make foods sterile, wherein no refrigeration is required. Some spices recommended for export has been given clearance for this dose range. This dose is used to produce sterile foods in hospital diets for patients with compromised immune systems. This dose also employed for foods used by astronauts during space flight.

Gamma irradiation Vs Electron beam irradiation technology

Gamma irradiation technology:

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.

Electron beam irradiation technology:

Electron beam irradiation (EBI) is a process for treating materials with energetic electrons that are produced by an accelerator. The electron beam accelerators cover a wide range of beam currents and energies to produce a large scale of products. Electron beam accelerators in industrial applications. 0.15 to 10 MeV energy ranges of electron beams are used for processing of various applications. Low energy electron accelerators having energies 0.15 to 0.5 MeV are generally used for treatment of surfaces and irradiation of coatings and polymeric films. Medium energetic ones produce electrons that have energies of 0.5-5 MeV. High energetic ones have energies between 5-10 MeV and they are used for sterilization of medical products and processing treatment of food. The principal of acceleration is the basic system to produce an electron beam and accelerated them in the electron accelerator. Tungsten filament is heated at the negative cathode and electron is then emitted as a free electron called by thermionic emission. The free electron flow is accelerated by electric field and gain energy in electron volt. The accelerated electrons escape through the window and proceed towards the target material. Electrons are accelerated and given energy to be irradiated to target material by electron beam processing system. The processing system is consisting of power supply unit, accelerator tube, scanning system, irradiation window, vacuum system, product handling system and safety system.

The EBI technology offers a fast, effective and environmentally safe alternative to fumigation. A standard source of electricity (AC) is sufficient to generate electrons for irradiation. The EBI allows nonnuclear and accelerated generation of radiation, is available when required and the machine can be switched 'on' or 'off', as necessary. Machine sources employed provide constant output without radioactive decay and waste generation normally associated with isotope sources. Energy of the beam and amount of radiation can be manipulated to suit the size of packages to be irradiated. The penetration depth can be predicted and the product can be irradiated from one or from both sides. Machine sources are economical and useful for high throughput and high dose applications. Radiation shielding is required only when the machine is on. No radioactive materials need to be transported, which minimizes the risks of occupation hazards. There is no change in the radiation dose due to decay of the source. Thus, the EBI technology is safe, cost effective and could be installed in places like airports or harbors for quarantine treatments of imported commodities. Electron beams are commonly used in industry for medical, environmental and material processing applications. In medical industry, electron beam processing system is used for medical equipment sterilization, water treatment, food preserving and pollution prevention for environmental industry .

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.

Comparison of Gamma irradiation and Electron beam irradiation technology

Gamma irradiation (Co-60)	**Electron beam irradiation**
Well established technology	New technology
Permanent source of radiation emission	Radiation emission only on operation state
Simple to operate	Operating skills necessary
Limited options of operations	Numerous options of operation

No mass radiation penetrates deep into materials	Small mass, radiation penetration limited
Low dose rate (absorbed dose per unit time) required	Required dose rate is higher. Quick dose changes Reduced risk of product damage The only disadvantage faced by EB irradiators is the requirement of a steady and continuous power supply

Quality and Shelf life of Irradiated fish and fishery products

Effects on food products

Ionizing radiation produces chemical changes by primary and secondary radiolysis effects.The effect of chemical reactions depends on the absorbed dose, dose rate and facility type, presence or absence of oxygen and temperature. Generally, most food micronutrients (mainly water-soluble and fat-soluble vitamins) and macronutrients (carbohydrates, proteins, and lipids) are not affected by 10 kGy-range -range ionizing dose with regard totheir nutrient contents. But, with radiation doses above 10kGy, the properties of fibrous carbohydrates can be degraded structurally and lipids can become somewhat rancid (Miller, 2005; Brewer, 2009). The physical status of food (frozen or fresh, solid, liquid or powder) and also its composition influence the reactions induced by the radiation (IAEA, 2009). Direct absorption of energy by the irradiated food can produce chemical changes via primary and secondary indirect radiolysis effects. Irradiation effects water molecule to free an electron producing HO+. This product reacts with other water molecules to create a quantity of compounds, including hydrogen and hydroxyl radicals (OH.), hydrogenperoxide (HO), molecular hydrogen and oxygen. Because the hydroxyl radical is an oxidizing agent, and the hydrated electron is a reducing agent, free radical attack can be expected to cause oxidizing and reducing reactions in food (Black &Jaczynski, 2008; Calucci., 2003).

Some recent studies have shown, irradiation impartsundesirable organoleptic attributes to high-fat products. So, content of fat in the fresh meats and sea foods is a limiting factor (Norhana et al., 2010). These changes can be reduced by adapted atmosphere packaging and minimized fat levels and mainly prevented by irradiating in the frozen state.

Ready-to-eat foods are very various and their consumption has increased. These foods maycause a specific danger to consumers when they do not endure a process pathogen reduction (Sommers& Boyd, 2006). To improve microbiological safety of ready-to-eat foods by irradiation, extensive research has been devoted, specifically to eliminate non spore forming pathogens from ready-to-eat meat products. Irradiation is an effective treatment that can be used in many of these products after packaging (Romero et al., 2005). Also, Sommers and Boyd (2006) demonstrated that doses of 2 to 4 kGy inactivate food-borne pathogens including *Salmonella* spp., *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichiacoli*O157:H7 and *Yersinia enterocolitica*in a variety of ready-to-eat food products.

Application Irradiation in Sea Foods for Shelf Life Extension

Several diseases originated by pathogenic Vibrios, *Listeria monocytogenes,*parasitesandviruses are generally related to consumption of raw products (Venugopal, 2005). Irradiation of sea foods is proposed to extend shelf-life, inactivate parasites and decrease pathogen load (Norhana et al., 2010). Many studies indicated that irradiation at doses of 3 kGy, should yield 2 to 5 log10 reduction of pathogenic, non spore forming bacteria (Guinebretiere et al., 2003; Lim et al., 2007). The applicable dose to sea foods should be adapted to the pathogen reduction and the product (O'Bryan et al., 2008; Norhana et al., 2010). For example, Shrimp is separate from fish and shellfish given that certain pathogens (i.e*Listeria monocytogenes*) for several log10 reductions need doses in excess of 3 kGy. In frozen shrimp the dose required to reduce *Aeromonashydrophila*and*Vibrio* by 10-4 per gram was about 3 kGy, while 3.5 kGy was needed for *L. monocytogenes*and 1.0 kGy for Salmonella (Hatha et al., 2003; Pinu et al., 2007). Irradiation of fresh meat

Shelf life of irradiated fish and fishery products

Fish and Fishery Product	Irradiation Dose	Shelf life	Author/ Authors
Haddock fillets (*Melanogrammusaeglefinus*) at 5-6°C	1.5-2.5 kGy	22-25 days	Rosnivalli et al., 1968
Bombay duck (*Harpodonnehereus*) under refrigeration	1.0-2.5 kGy	18-20 days	Kumta et al., 1973
Chilled scallops (*Amusiumballoti*)	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 (Sebastodesalutus)	1-2 kGy	25-28 days shelf life at 0.6 °C	Reinacher and Ehlermann, 1978
Mackerel (Rastrelligerkanagurta) and White pomfret (Stomateuscinereus)	1.5 kGy	-	Arvanitoyannis et al., 2009
Black pomfret (Parastromatusniger)	1 kGy	-	Arvanitoyannis et al., 2009
Sole (Parophyrsvetulus)	2-3 kGy	-	Arvanitoyannis et al., 2009
Bombay duck (Harpodonnehereus)	1.5-2.5 kGy	Shelf life extension up to 15-20 days	Kumta et al., 1970
whitefish (Coregonusclupeaformis)	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 (Trachurustrachurus)	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 (Nemipterusjaponicus) dipped in NaCl	1 and 2 kGy	Shelf life extension up to 14-28 day	Jeevanandam et al. (2001)
Vacuum packedtrouts	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 (Doryteuthissibogae)	3 and 5 kGy	10 days shelf life	Manjanaik et al., 2018
chub mackerel (Scomberjaponicus)	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
Litopenaeusvannameiheadlessshellon	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 (*Oncorhynchusmykiss*) 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

Regulation in Irradiated Food

The Codex Alimentarius Commission (Codex) is the body responsible for standards related to human health. Food irradiation must be conducted according to good management practice and comply with the Codex Alimentarius General Principles of Food Hygiene . The foundation for food irradiation was set with the adoption of the Codex World-wide General Standard for Irradiated Foods in 1983 and a significant revision in 2003. The General Standard states that the minimum absorbed dose should be sufficient to achieve the technological purpose and the maximum absorbed dose should be less than that which would compromise consumer safety of wholesomeness or would adversely affect the structural and functional properties or nutritional and sensory attributes. In 1983, the Codex Alimentarius Commission accepted that foods irradiated up to 10 kGy were safe and therefore toxicological testing was no longer necessary. In 1997, the United Nations confirmed that foods could be treated at any dose without any detrimental effect on the food's wholesomeness. The study group concluded that high-dose irradiation, conducted in accordance with good manufacturing and irradiation practices, could be applied to several types of foods to improve their hygienic quality, make them shelf stable, and produce special products

Identification of irradiated food:

In order to identify an irradiated product and alert consumers to its quality, the Pilot Plant for Food Irradiation at Wageningen, The Netherlands, created the symbol RADURA . This word is related to “radurization,” a word derived from radiation and the Latin word “durus” for “lasting.” The term is used for the process of exposing food to ionizing radiation to enhance and extend the shelf life. Thus, the product is irradiated at doses in the range from 0.4 to 1 kGy to decreased number of spoilage bacteria . Due to the fact that external microorganisms can also encounter the irradiated product, food packaging is part of the process. The “RADURA” symbol was established to represent the irradiation treatment. The symbol presents a plant (dot and two leaves), in a closed package (circle), irradiated with ionizing rays passing through the package to the food (dashed lines). Despite the fact that the use of the RADURA symbol is optional, according to the Codex Alimentarius standard, if the food or an ingredient product is treated with ionizing radiation a written statement shall be placed in proximity to the food to indicate that the treatment was done. This last requirement might change from country to country. For instance, in the United States, labeling is only required if the whole food has been irradiated and labeling is not required at restaurants/catering establishments. Canada requires labels and written statements such as “irradiated,” “treated with radiation,” or “treated by irradiation” when the whole product was irradiated or more than 10% of the ingredients that compose the final product.

****