Radiation in Food Processing

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Abstract

Food irradiation involves exposing food to a carefully controlled amount of ionizing radiation that include gamma rays emitted from radionuclides (Cobalt-60, Cesium-137), X-rays ($\leq$ 7.5 MeV) and the high energy ($\leq$ 10 MeV) electrons generated by machine sources. The technology has several uses such as disinfestation of pulses and food grains, inhibition of sprouting in tubers and bulbs, ensuring microbiological safety and extending shelf-life. It can also aid in overcoming quarantine barriers to international trade as it is a suitable alternative to fumigation that is being phased out due to adverse effects on human health and environment. The process also has applicability for sterilization and hygienization of non-food items including pet food, cut-flowers, aqua feed, cattle feed, ayurvedic herbs and medicines and packaging materials. The present chapter discusses the effects of radiation treatment on the microbial status and chemical and nutritional quality as well as the methods currently available for identification of such treated foods. Recent applications of radiation processing developed at Food Technology Division (FTD), BARC is described. The legislations enacted regarding approval of food irradiation by Food Safety and Standard Authority of India (FSSAI) are also detailed.

Keywords: *Radiation processing; Irradiation; Food preservation*

1. Introduction

Consumption of contaminated food leads to health problems and reduced economic productivity [1]. According to the World Health Organization, worldwide 550 million people fall ill and 230 thousand die yearly due to food borne illness [2]. Situation of foodborne illness is more worrying in children under the age of five years. Two hundred and twenty million children under the age of five years suffer from foodborne illness every year which results in over 96 thousand deaths. Apart from causing food borne illnesses, contamination of food products with pathogenic microorganisms have severe economic implications. Microbial contaminations can lead to food shipment rejections or even total ban on food imports from specific countries by importing nations [3]. In addition, pathogenic contaminations also result in food recalls leading to massive losses to food processing industry in form of product losses and decreased consumer confidence.

Apart from pathogenic contaminations, food losses and wastage are another major concern globally. Food losses take place at production, post-harvest, processing and at consumer level. In developed countries substantial amount of food is wasted at final consumption stage. That means it is discarded by end consumers even when it is not spoiled and is good for human consumption. On the contrary, in the developing nations most of the food is spoiled during production, post-harvest and processing stage [4]. According to Food and Agriculture Organization, one third of food produced for human consumption is lost or wasted annually, amounting to about 1.3 billion tons [4].Losses in case of cereals, pulses and oilseeds is up to 20-30 percent of produce while in case of fruits, vegetables, roots and tubers higher amount of wastage up to 50 percent was noted.

The global population is presently over 7.2 billion and according to UN estimates is expected to rise beyond 9 billion in 2030. Food security is now prime concern around the world because without adequate food availability, natural disasters and emergencies can lead to economic and political instability [5]. In view of above, there is significant need for adoption of food processing technologies which can prevent pathogenic microbial contamination and simultaneously extend shelf life of food products thus reducing wastage.

At present widely employed technologies for food preservation are, thermal processing, canning, freezing, refrigeration and use of chemical preservatives [6]. Although, thermal processing is very good technique for processing of liquid and semi-solid foods, it is not suitable for solid foods and dry ingredients [7]. Fresh fruits, vegetables and nuts cannot be processed using heat treatment. Similarly, chemical fumigation technology (using sulfur dioxide, potassium nitrate or methyl bromide) although extensively used to preserve various food products, has now been banned in several countries because of apprehensions about their ozone depleting and carcinogenic properties [5]. Therefore, there is a need for technology which can preserve food while maintaining high nutritional and sensory properties without using harmful chemical preservatives. Food irradiation technology can fulfill most of these requirements.

Food irradiation is a non-thermal technology which involves exposing food to carefully controlled amounts of ionizing radiations generated from either natural radionuclides (Cobalt-60, Cesium-137) or from machine (X-rays ($\leq$ 7.5 MeV; ($\leq$ 10 MeV) electrons) sources [7]. The amount of radiation dose given to a food material is denoted by Gray (Gy) which is defined as the energy in Joules absorbed per unit mass (kg) of the irradiated product.

$$1\ \text{Gy} = 1\ \text{J/kg},\ 1000\text{Gy} = 1\ \text{kGy} = 238.9\ \text{cal kg}^{-1} = 6.2418 \times 10^{18}\ \text{eV kg}^{-1}$$

Dose rate of a source is defined as the absorbed dose per unit time (Gy sec^{-1}, kG min^{-1} or kGy h^{-1})

The technology is suitable for disinfestation of pulses and food grains, inhibition of sprouting in tubers and bulbs, ensuring microbiological safety and extending shelf-life. It can also aid in overcoming quarantine barriers to international trade as it is an effective alternative to fumigation that is being phased out due to adverse effects on environment and human health. The process can also be used for sterilization and hygienization of non-food items including pet food, cut-flowers, aqua feed, cattle feed, packaging materials, ayurvedic herbs and medicines.

2. The process

Irradiators are commercial facilities where radiation processing of food products is carried out. The food irradiator consists of a concrete bunker, inside which products are given desired radiation dose by carefully exposing them to a source of ionizing radiation. Radiation source used for this purpose are either gamma ray source such as Cobalt-60 or machine sources such as electron beam or X-rays.

2.1 Radiation sources

The Codex Alimentarius General Standard for Irradiated Foods [8] describes the following sources of ionizing radiations for the radiation processing of food products:

(a) Gamma radiation from ^{137}Cs (Cesium-137) or ^{60}Co (Cobalt-60);

(b) Accelerated electrons (forming electron beams) with a maximum energy of 10 MeV

(c) X-rays with a maximum energy of 5 MeV.

Characteristics of different types of radiations are summarized in Table 1. Gamma rays and X rays have higher penetration power of up to 40-50 cm into the product depending upon density whereas electrons can penetrate only up to depth of 5 cm. Therefore, gamma and X-rays result in more uniform dose distribution in product as compared to electron beam. But electron beam can provide very high dose rate in the order of kGy/s and therefore truckload of product can be processed in few hours using e-beam while it can take few days in gamma irradiators.

Table 1: Different types of ionizing radiation, their penetration and characterization

	Isotope sources ^{137}Cs or ^{60}Co	**Machine sources**	
Type of radiation	Gamma rays	X-rays	Electron beam
Particles	Photons	Photons	Electrons
Charge	None	None	Yes (-1)
Penetration Capacity	Very good	Very good	Limited
Source Characteristics	Cannot be switched off	Can be switched off	Can be switched off
Radiation Characteristics	Isotropic and direction cannot be controlled	Unidirectional and direction can be controlled	Unidirectional and direction can be controlled
Dose rate	kGy/h	kGy/min	kGy/s
Type of products that can be treated	Products of low and medium density can be treated in cartons, drums or pallets	Products of low and medium density can be treated in cartons, drums or pallets	Suitable for products of low density only
Overall process	Since emission cannot be stopped so non-stop (24/7) operation to optimize source usage	Emission can be stopped. Large quantities of products can be treated in short time	Emission can be stopped. Large quantities of products can be treated in short time

2.2 Gamma irradiator

Radionuclide used in gamma irradiators is either cesium-137 (^{137}Cs) or cobalt-60 (^{60}Co). Most commonly used source of gamma irradiation is Cobalt-60. The half-life of ^{60}Co is 1925.2 days, this means that activity will reduce to half the initial activity at the end of this period. ^{60}Co disintegrates to stable nickel with emission of gamma radiation (1.17and 1.33 MeV) and beta radiation (0.31 MeV). Strength of the source used in gamma irradiator is measured by activity. SI unit of measuring the activity of source is Becquerel (Bq), which is the number of radioactive decays per second. Activity is also measured in Curies (Ci), which is the activity of one gram of ^{226}Ra. Due to the fact that radionuclides decay continuously, their activity decreases in time dependent manner. Therefore, the activity value of the source needs to be related with a date. The initial value of the activity written in the source certificate provided by the supplier should be used as a reference.

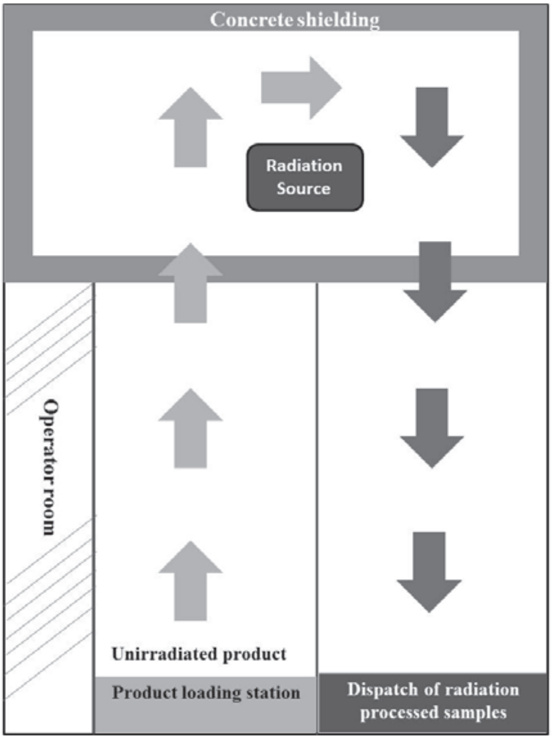


Figure 1: Schematic of food irradiation plant (Redrawn with suitable modifications from [24])

Schematic diagram of a typical food irradiation plant or facility is shown in Fig. 1. As shown in figure commercial food irradiation plant consists of a concrete (1.518 m thick) shielded radiation chamber. The thick concrete shield prevents gamma radiation from coming out of radiation chamber. Generally, radiation source is stored under water pool having a depth of about 6 m [9]. Food materials are moved inside the radiation chamber using a conveyor system for getting exposure to radiation. Source rack is lifted from water storage tank to start radiation processing. Conveyor mechanism is designed to ensure that food products receive equal dose of radiation from both sides. The radiation dose absorbed by the food material is determined by the strength of the cobalt source, i.e., by the number of Curies or Becquerels, and the length of time product spends in irradiation chamber. Working of gamma irradiators is on the fail-safe principle.

Any unusual occurrence such as jammed conveyor, fire alarm, power outage or timer failure results in the source returning to the safe storage position. The source rack reaches back to the bottom of the storage pool by gravity and the irradiation stops.

2.3 Electron beam and X-ray irradiators

Electron beam (e-beam) technology involves the use of compact equipment, termed linear accelerators, to generate high energy electrons which are ionizing, and are used to achieve the desired end result [5]. High-energy electron beam accelerators produce electrons with energies above 1 MeV. For purposes of food irradiation 10 MeV is the upper limit. A 10-MeV electron beam can thus be used for irradiation of thicknesses up to 5 cm if irradiated from one side, or 10 cm if irradiated from two sides [9].The high energy electron beam produced by accelerators has a diameter of only a few millimeters or centimeters. Therefore, to uniformly provide radiation dose to food products, electron beam coming out from accelerator tube is rhythmically deflected by a scanning magnet attached to the end of the accelerator tube. The beam is moved to and fro like a pendulum with a frequency of 100-200 Hz. To achieve uniform dose distribution in material, the electron beam is scanned continuously and the product is moved perpendicular to the scanning line of the electron beam (Fig. 2).

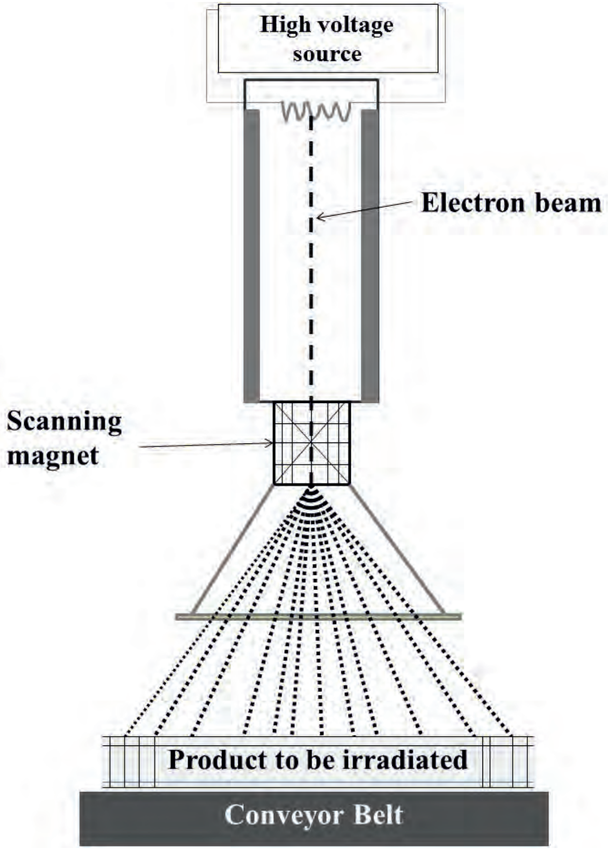


Figure 2: Schematic of electron beam machine (Redrawn with suitable modifications from [24])

3. Applications of food irradiation

Although radiation processing of foods has several applications but broadly they can be classified into three categories i.e. low dose applications (where dose required is < 1kGy), medium dose applications (dose delivered between 1 to 10 kGy) and high dose applications (dose required is beyond 10 kGy). Major applications in all the three categories are summarized in table 2.

Table 2: Applications of food irradiation

Dose range	Effects	Examples
Low dose (Up to 1 kGy)	Sprout inhibition	Onions, Potatoes
	Delay in ripening	Fruits
	Quarantine treatment	Fruits, fresh produce
	Insect disinfestation	Cereals, legumes and pulses
	Pest disinfestation	Fresh produce, dried products
	Parasite inactivation	Pork (Trichinella)
	Reduce spoilage organisms thereby extending shelf life	Fruits and vegetables
Medium dose (1-10 kGy)	Eliminating vegetative pathogenic micro-organisms	Meats, dried fish, meat products and spices
High dose (beyond 10 kGy)	Reduce micro-organisms to the point of sterility	Hospital diets, Spices, emergency rations, foods for severely immune compromised patients, foods for astronauts

3.1 Low dose applications (<1 kGy)

Sprout inhibition: Sprouting results in considerable post-harvest storage losses (10-20%) in onions and potatoes. Prevention of these post-harvest losses is necessary to maintain year-long supply of commodities such as onions, potatoes, garlic and yams to consumers. Using refrigerated storage or employing several chemicals for example hydrazide (pre-harvest) and isopropyl chlorocarbamate during postharvest storage is currently practiced to inhibit sprouting. Amongst these treatments, refrigeration is most expensive mainly in the sub-tropical and tropical environments. Chemical treatments have serious health concerns because they leave harmful residues after treatment [6]. Therefore, in view of the above reasons, radiation can be a suitable alternative for preventing damages due to sprouting. Radiation processing in the range of 50 -150 Gy had shown to result in sprout inhibition, reduced weight loss and rotting in garlic, onions, potatoes, sweet potato, turnip, carrot, sugar beet and yams [10,11].

Insect disinfestations: Insect pests cause damage of stored products such as grains, flour, coffee beans, pulses and nuts by direct feeding and thus reduce value of grains for marketing and consumption. Additionally, insect pests contaminate food products through dead bodies, molting, excretion and their own existence in the product. Damage due to insect pests enhances infection with bacterial and fungal diseases through transmission of their spores. Fumigants such as ethylene oxide or ethylene dibromide are highly effective and were widely used for control of insect pests. However, these chemicals are being banned or their usage is stringently restricted in most countries for environmental and health reasons. Other processing methods such as heat and cold treatments although capable of insect disinfestations could degrade the sensory quality of the produce [6]. Radiation processing could suitably provide an alternative to fumigation. Radiation treatment can prevent insect damage in stored pulses, grains, cereals, flour, dried fruits, coffee beans, nuts and dried fish [7, 12]. Required radiation dose for insect disinfestation is between 150 - 700 Gy. A dose of 250 Gy is effective for quarantine treatment of fruit flies. Higher dose of 500 Gy can eliminate all stages of most insect pests [13].

3.2 Medium-Dose applications (1-10 kGy)

Food borne pathogens: Meat, dairy products and eggs are major sources of food borne illnesses. The microbial pathogens of major concern are *E. coli, salmonella, campylobacter* and *listeria*. Tapeworm is another organism of concern for beef. Radiation treatment in dose range of 1-3 kGy can eliminate all these pathogenic microorganisms [3].

Shelf-life extension: Radiation dose required for controlling microbial pathogens (1-3 kGy) can also extend shelf life of treated foods. Shelf-life extension is mainly due to reduction in population of spoilage bacteria, molds and yeasts. Shelf life of meat products such as chicken can be extended by few weeks while shelf life extension of few days (10-20) can be achieved in case of fruits and vegetables using radiation treatment [6]. Similarly, radiation dose in range of 0.25 to 1 kGy can result in delayed ripening in case of climacteric fruits such as mango, banana and papaya when irradiated before onset of ripening [14].

Microbial decontamination: Spices are generally contaminated by soil microorganisms, by bird droppings and windblown dust and can have microorganism population beyond 10^6 CFU g^{-1} [15]. These contaminated spices could lead to swift food spoilage which can further cause food borne illness. Since fumigation is now banned in several parts of world, radiation treatment is the method of choice for spice manufacturers. Elimination of mold, bacteria, insects and spores can be achieved using doses between 5 -10 kGy without having any negative impact on chemical or sensory properties [16, 17].

3.3 High Dose (> 10 kGy) applications

Foods can be commercially sterilized as in canning by using radiation treatment in the dose range of 25-45 kGy [18]. But not all foods are amenable for such radiation sterilization procedures [19]. Fresh fruits and vegetables will deteriorate, while products with excellent quality can be obtained from meat, poultry and sea foods by employing high dose of radiation. Generally, products subjected to high dose radiation are preheated to inactivate enzymes, vacuum packed to exclude oxygen and irradiated at low temperatures (-20 to 40 °C). These products have very long shelf life at room temperature. These sterilized products are useful for immune compromised patients, in natural disasters, military rations and for special group such as astronauts [9, 20, 21]. Irradiation has definite advantages over other processing technologies as summarized below:

A) Radiation used for treating foods has high penetration, which helps in treating foods in their final packaging without affecting the process efficiency. Treating pallet loads is also possible

B) Radiation processing is a versatile technology i.e. it can be used for microbial safety, shelf life extension (food security) and for quarantine applications.

C) Irradiation is a cold process and therefore advantageous to several products

D) Extremely effective as it has a broad spectrum effects against microbes including bacteria and fungi, insects and pests.

E) Radiation processing is a residue free technology. No harmful chemical residues are left in foods processed with radiation technology.

F) Food irradiation process is simple to control as dose delivered will only be dependent on source activity and conveyor speed.

G) Food treated with radiation can be immediately distributed in food supply chain.

H) Solid and raw foods which are not possible to process by thermal treatment can also be readily processed using radiation treatment.

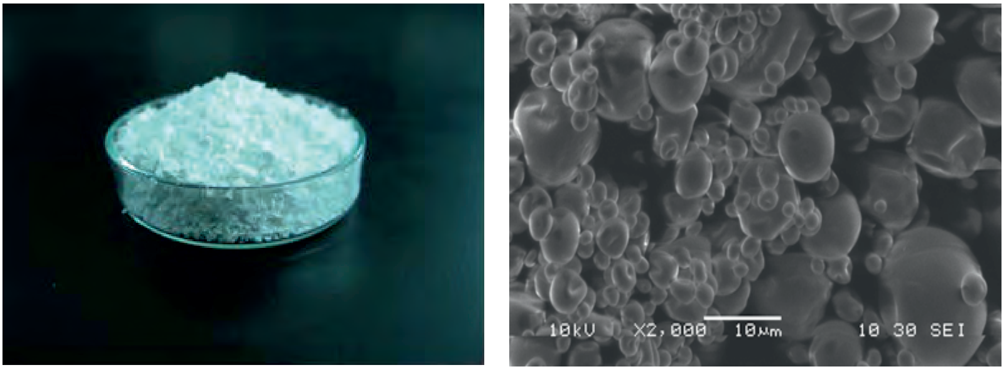
3.4 Other applications

Apart from these applications, recent research in the area of food irradiation at Food Technology Division, Bhabha Atomic Research Centre has shown some very interesting applications of radiation processing such as enhancing aroma quality, antioxidant status and shelf life extension of minimally processed products. Some of these recent applications are as follows:

3.4.1 Quality improvement in food products by radiation processing

Radiation processing can be employed for quality improvement in several food commodities. It was demonstrated that radiation processing increased aroma in case of spices such as nutmeg. Radiation was also shown to increase antioxidant activity in soybeans. Wine prepared with irradiated grapes had higher antioxidant activity and darker red color as compared to wine prepared with control grapes. Irradiated cabbage has higher content of glucosinolates, known anticancer compounds.

Radiation was used for value addition of guar gum. Guar gum is a biopolymer which is extracted from endosperm of legume plant *Cyamopsis tetragolonoba*. Chemically, it has a mannose backbone and galactose side chains as every alternative mannose. India is the largest producer of guar gum accounting for 80% of total world production. Guar gum when dissolved in water results in solutions of very high viscosity even at a very low concentration (1% w/v). Due to this property it is widely used in several industries as gelling agent, thickener and stabilizer. Apart from above mentioned uses, it can also be used as wall material for flavor encapsulation and soluble type of dietary fiber. But for these purposes guar gum of low viscosity is required. Currently in industry, to prepare low viscosity guar gum it is subjected to depolymerization by various means such as acidic hydrolysis, enzymatic hydrolysis and thermal hydrolysis. These methods are time consuming, labor intensive and expensive. Moreover, getting desired viscosity characteristics is difficult by employing these methodologies. Radiation processing can provide a suitable alternative for depolymerizing guar gum. Depending on radiation dose, it is possible to prepare guar gum with different viscosities suitable for several different purposes. Guar gum suitable for dietary fiber applications was successfully prepared by radiation processing (Fig 3). It had better dietary fiber properties (higher glucose and bile acid dialysis index) when compared to commercial enzymatic hydrolyzed product. Suitability of radiation depolymerized guar gum



Radiation processed guar gum for dietary fiber

Microcapsules with guar gum

Figure 3: Soluble type of dietary fiber from guar gum and flavor microcapsules

was also shown for flavor encapsulation applications. Different essential oils (mint and nutmeg) were encapsulated in wall materials prepared from radiation depolymerized guar gum. Encapsulation efficiency was found to be similar to that to gum Arabic which is standard wall material used industrially. Guar gum resulted in better stability of essential oils in spray dried flavor. Essential oil had a half-life ($t_{1/2}$) of 25 weeks when encapsulated in gum Arabic alone which increased to 35 weeks with guar gum. Guar gum did not result in any change in size and structure of microcapsules formed as observed by scanning electron microscope (Fig 3).

3.4.2 Novel shelf life extension applications

Shelf- life extension of fruits: The premium variety Indian mangoes are in high demand in many countries including USA. At present, mangoes after radiation treatment as per USDA guidelines are exported to USA by air route. Because of high air transportation cost and limitation of volume, share of Indian mango in the USA remains relatively small and result in low export earnings. Use of sea route for transportation would result in substantial cost reduction and enable export of larger volumes enabling deeper penetration in the USA market. A technology has been developed for processing Indian 'Kesar' mangoes for sea-route shipment to USA'. The SOP has been approved by the United States Department of Agriculture (USDA). Fig. 4 shows mangoes processed with the developed protocol.

Figure 4: Mangoes processed with protocol developed at FTD, BARC

'Litchi', a highly delicious and juicy fruit is extremely valued for its flavor and unique fruit appeal. The fruits are quite seasonal and also very perishable. Discoloration of fruit peel from pinkish-red to brownish colour and associated spoilage by microbes severely affects its keeping quality and this affects its trade including distribution to distant markets in India. A technology has been developed that maintains the freshness and keeping quality of litchi for up to 45 days (at 4-6°C) (Fig. 5). The processed fruits remain free from spoilage microbes and their color is also maintained during storage period. This patented technology is very useful for the farmers and traders involved in litchi trade. Radiation treatment is needed to fulfill the phytosanitary requirement for export to various countries including USA.

Figure 5: Litchis processed with the protocol developed at FTD, BARC

Fresh date palm fruits are very popular among consumers due to their high nutrition value and low calorie content. The fruits have a hard, crisp and crunchy texture with high moisture (50-85%). As the fresh fruit has short shelf-life of 5-6 days at room temperature storage, a study was initiated to extend the shelf-life of the fruit. A dip treatment with combination of US-FDA and FSSAI approved GRAS (generally recognized as safe) food preservatives has been optimized. After the treatment, fruits are subjected to gamma radiation with respect to the requirements of international trade. The untreated control fruits showed fungal contamination within 20 days of storage, while no visible contamination was observed in processed fruits (Fig. 6). The treated fruits showed both colour and texture retention up to 40 days.

Figure 6: Date palm fruits processed with protocol developed at FTD, BARC

Sprouts and sweet corn: Legume sprouts and shelled sweet corn kernels are consumed worldwide as a highly nutritive food. However, due to high moisture content these products are quite supportive of microbial and pathogenic growth and have poor shelf life of only up to 3 days. A combination process involving radiation has been developed which can ensure safety and extend shelf life of sprouts (mung, alfalfa and chickpea) and sweet corn kernels up to 15 days at 4-10ºC. The products were also nutritious, organoleptically acceptable and with reduced level of anti-nutritional factors (in sprouts) during storage (Fig. 7).

Mung Sprout Chickpea Sprout Alfalfa Sprout Sweet corn kernels

Figure 7: Sprouts and sweet corn processed by radiation

Bell paper Onion Tomato

Figure 8: Minimally processed vegetables processed by radiation technology

Ready to cook products: Ready to cook (RTC) products such as pre-cut vegetables / minimally processed vegetables are gaining consumer acceptance. These products provide convenience to consumers by substituting preparatory steps such as sorting, washing, peeling and chopping. Although convenient, these products have limited shelf life and are prone to microbial contamination. At, Food Technology Division, BARC shelf life extension of several minimally processed vegetables has been successfully carried out (Fig. 8, 9).

Figure 9: Minimally processed bitter gourd processed by radiation treatment

Besides, sensory attributes ('taste', 'flavour', 'colour', 'texture', and 'overall acceptability') of the irradiated products were found to be acceptable even after 20 days of storage. Nutritional quality of these products such as fat, carbohydrate, protein, vitamin content, minerals and total energy was also maintained. This study establishes the suitability of gamma radiation treatment in ensuring the quality and safety of minimally processed vegetables. In near future, utilization of chemical-residue free, gamma radiation treated pre-cut vegetables can contribute significantly in reducing post-harvest losses (30-40%) of these vegetables by helping their processing into convenient ready to cook/eat and shelf-stable products.

3.4.3 Ready to eat products

Preservative Free Jamun and strawberry product: 'Jamun' (*Syzygium cumini*) also known as 'Indian blackberry' is a highly perishable dark purplish colored underutilized fruit that is widely known for its different health benefits in India. However, the fruits are available for a brief period only during late summer season in India. Therefore, a convenient dietary product has been developed employing dehydration and radiation technology from the pulp portion of this fruit. This dehydrated product is shelf stable (best before 5 months from the date of manufacture) under ambient conditions and also hygienic. No external sugar and artificial flavoring substances have been added hence the product is 100% natural and completely chemical preservative free. This product is easily chewable, naturally low in fat, rich in minerals & dietary fibers and has excellent sensory properties (Fig. 10).

Figure 10: Shelf stable Jamun product developed at FTD, BARC

Strawberry (*Fragaria ananassa*) is highly delicious and healthy fruit but quite perishable due to its high moisture content and soft texture. Thus, to reduce post-harvest losses, a value added strawberry fruit product (sweet dehydrated roll) was developed employing radiation processing which has shelf life of 5 months during ambient temperature storage (Fig. 11). The product possessed desirable microbial, sensory, flavor, physical, surface topology, biochemical and functional (antioxidant and antimutagenic) qualities during storage.

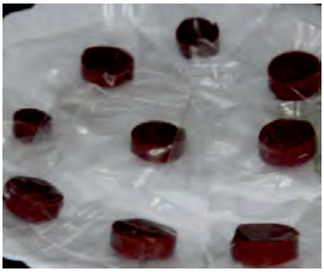


Figure 11: Shelf stable strawberry product developed at FTD, BARC

Figure 12: Stuffed baked product developed at FTD, BARC

Stuffed Baked Food (SBF; Litti): Availability of nutritious, safe and ambient storable meal during calamities is an earnest need. Unpredictable disasters like flood and earthquakes etc. may lead to failure of different logistics and worsen the food supply. A nutritious and safe ready-to-eat product 'Stuffed Baked Food (SBF)' was developed which upon radiation treatment can be stored for 8 months at ambient temperature (Fig. 12). This product was supplied for flood and land slide

Figure 13: Shelf stable puranpoli product developed by radiation processing

affected people at Himachal Pradesh, Bihar and also to various National Disaster Response Force (NDRF) units of the country.

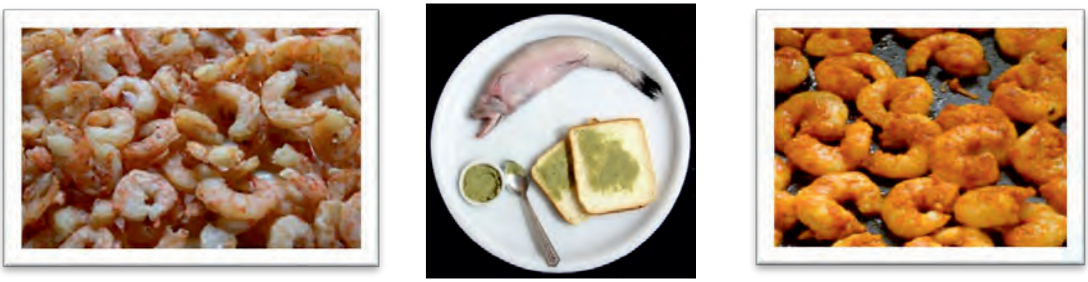
Puranpoli: Packaging and radiation conditions for puranpoli were optimized. This product had long shelf life of 12 months even at room temperature (Fig. 13).

Figure 14: Shelf stable meat products developed by radiation processing

Ready to eat meat products: Several ready to eat meat products such as chicken tikka, chicken pahadikabab, chicken pulao having long shelf life were developed employing radiation processing (Fig. 14).

Development of ready to eat sea food products: Ready to cook semidried prawns with moisture content of 28-30% was prepared on pilot and large scale in collaboration with ICAR-Central Institute of Fisheries Education which can be stored for 6 months with irradiation

(5 kGy) at ambient temperature. This technology has been transferred to industry. Ready-to-eat shelf-stable Jawala tikki, a nutritious and delicious snack, was prepared by microwave heating and irradiation (5 kGy) processing. Jawala tikki may serve as emergency food in natural calamities as well as regular consumptions by common public or military rations. Ready to Eat fish spread- a low calorie, high protein diet, suitable for health conscious, elderly and infants prepared using irradiated (5 kGy) Bombay duck, can be stored for 2 months in chilled condition. Instant fish soup prepared from Seer fish, is an excellent appetizer for every class of society which can be stored at ambient temperature for 6 months. Ready to Eat Barbequed (Tandoori) Prawns were developed using radiation processing (12 kGy) with a shelf-life of 1 month at 4 °C. Fig. 15 shows products developed from radiation processed sea food.



Ready to Cook semi-dried prawns

Ready to Eat Fish Spread from Bombay Duck

Heat & Eat Barbequed prawns

Ready to Eat Jawalatikki from Acetesspp (Paste shrimp)

Instant Fish Soup Powder

Figure 15: Shelf stable sea food products developed using radiation processing

4. Wholesomeness of Irradiated Foods

4.1 Nutritional Quality of Irradiated Foods

Macronutrients: Carbohydrates, lipids and proteins are major components of food which provide energy and building blocks for growth and maintenance of the body. Several animal feeding and human trials have successfully shown that radiation processing do not change energy value, nitrogen balance and digestibility of food products [22, 23]. Radiation processing does not affect biological value and digestibility of food proteins.

Micronutrients: Radiation processing does not significantly change vitamin and mineral composition of food products. Any nutritional losses due to radiation processing are not different from losses in other processing treatments. Traditional processing methods such as heating and drying may cause higher nutritional losses that irradiation.

5. Detection of irradiated food

Although irradiated food is safe and wholesome, detection methods for irradiated food products will help consumers to make a choice between irradiated and non-irradiated food. Availability of analytical methods to directly detect whether the product has been irradiated or not would also help authorities to regulate marketing of irradiated foods, accelerate approval of additional food irradiation applications, and enhance international trade in irradiated food. Techniques developed so far can be classified under three broad categories namely 1) physical 2) chemical and 3) biological. Table 3 summarizes the detection methods available till date for identifying irradiated food.

Table 3: Summary of detection methods irradiated food products

(a) Physical	1) Electron spin resonance (ESR) or Electron paramagnetic resonance (EPR) 2) Viscometry 3) Thermoluminescence 4) Photostimulated luminescence (PSL) 5) Nucleation Temperatures (NT) 6) Near Infra-red reflectance 7) Impedance
(b)Chemical	1) Gas evolution (e.g. H_2, CO and possibly H_2S and NH_3) 2) Hydrocarbons 3) Peroxides 4) Cyclobutanones 5) Proteins 6) Thymine glycol 7) o- Tyrosine (ortho-hydroxy phenylalanine)
(c) Biological	1) Germination 2) DNA (bacterial count, micro gel electrophoresis/comet assay, mitochondrial linear vs circular vs supercoiled) 3) DEFT (direct epifluorescent filter techniques)/APC (aerobic plate count) 4) LAL (limulus amoebocyte lysate test) 5) Immunological/ enzyme-linked immunosorbent assay (ELISA) for cyclobutanones, dihydrothymidine, DNA, proteins and thymidine glycol.

5.1 Detection methods developed at FTD, BARC

Extensive research has been carried out at FTD, BARC for development of detection methods for irradiated foods. The identification of irradiated food is a challenging task because the changes in food commodities are minimal after radiation processing of food. Research work was carried out on two physical methods, namely electron paramagnetic resonance (EPR) spectroscopy and thermoluminescence (TL) measurements. EPR spectroscopy determines different paramagnetic centers such as cellulosic radical, carbohydrate radical and axially symmetric CO_2^- radical ion as the markers of irradiation. Relaxation characteristics, spectral and thermal behavior of the radical during EPR are emerging as useful means to detect radiation treatment even after prolonged storage. TL measurements of the isolated minerals from the foods are being successfully employed to detect a wide spectrum of irradiated food. Detection methods were successfully established for different purposes of radiation treatment such as insect disinfestations, sprout inhibition and microbial decontamination etc. Fig. 16 shows picture of ESR equipment and demonstrates a representative ESR graph of control and irradiated ashwagandha powder.

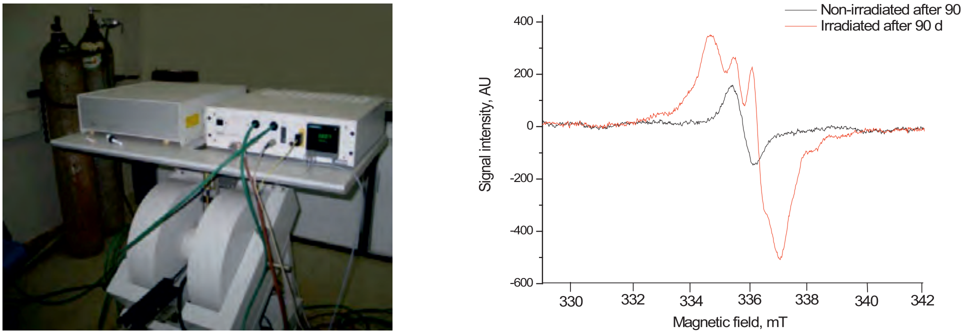


Figure 16: ESR equipment and a representative ESR spectrum of control and irradiated ashwagandha powder

6. International status

Independent research carried out worldwide for the last five decades by several countries including Canada, Denmark, France, India, Sweden, UK, European Union and US FDA has convincingly demonstrated the safety of irradiated food and confirmed that such processed foods are safe for human consumption. Several international bodies including the World Health Organisation (WHO), Food and Agriculture Organisation (FAO), International Atomic Energy Agency (IAEA) and Codex Alimentarius have also approved radiation technology as a safe food preservation technique. There has been a considerable increase in international trade in radiation processed foods in the last two decades. The quantity of various food groups irradiated worldwide in 2015 is shown in Table 4.

Table 4: Quantities of food irradiated world-wide in 2015

Food items and purpose	Quantity irradiated worldwide (tons)
Disinfection of spices and dry vegetables	186,000
Disinfection of grains and fruits	82,000
Disinfection of meat and fish	33,000
Sprout inhibition of garlic and potato	88,000
Other food items	17,000

According to a recent report on trade in irradiated food products, quantity of the irradiated foods increased by 100000 tons in Asia and 10,000 tons in the US in 2010 compared with 2005.A corresponding increase in the quantity of fruits and agricultural produce irradiated for phytosanitary purposes also increased during this period.

7. National status

India's first pilot plant radiation processing facility, The Food Package Irradiator was commissioned in 1967. The facility could process commodities right from requiring very low

Table 5: Class Wise Segregation of Food Products and Dose Limits for Radiation Processing

Schedule – I (see clause (b) of rule 6)

Class	Food	Purpose	Dose limit (kilo Gray) Minimum	Dose limit (kilo Gray) Maximum
Class 1	Bulbs, stem and root tubers, and rhizomes	Inhibit sprouting	0.02	0.2
Class 2	Fresh fruits and vegetables (other than Class 1)	Delay ripening	0.2	1.0
		Insect disinfestation	0.2	1.0
		Shelf-life extension	1.0	2.5
		Quarantine application	0.1	1.0
Class 3	Cereals and their milled products, pulses and their milled products, nuts, oil seeds, dried fruits and their products	Insect disinfestation	0.25	1.0
		Reduction of microbial load	1.5	5.0
Class 4	Fish, aquaculture, seafood and their products (fresh or frozen) and crustaceans	Elimination of pathogenic microorganisms	1.0	7.0
		Shelf-life extension	1.0	3.0
		Control of human parasites	0.3	2.0
Class 5	Meat and meat products including poultry (fresh and frozen) and eggs	Elimination of pathogenic microorganisms	1.0	7.0
		Shelf-life extension	1.0	3.0
		Control of human parasites	0.3	2.0
Class 6	Dry vegetables, seasonings, spices, condiments, dry herbs and their products, tea, coffee, cocoa and plant products	Microbial decontamination	6.0	14.0
		Insect disinfestation	0.3	1.0
Class 7	Dried foods of animal origin and their products	Insect disinfestation	0.3	1.0
		Control of moulds	1.0	3.0
		Elimination of pathogenic microorganisms	2.0	7.0
Class 8	Ethnic foods, military rations, space foods, ready-to-eat, ready-to-cook/ minimally processed foods	Quarantine application	0.25	1
		Reduction of microorganisms	2	10
		Sterilization	5	25

Table 6: Approved Dose Limits for Radiation Processing of Allied Products

Schedule – II (see clause (b) of rule 6)

Sr. No.	Allied product	Purpose	Dose limits (kilo Gray) Minimum	Maximum
1	Animal food and feed	Insect disinfestation	0.25	1.0
		Microbial decontamination	5.0	10.0
2	Ayurvedic herbs and their products, and medicines	Insect disinfestations	0.25	1.0
		Microbial decontamination	5.0	10.0
		Sterilization	10	25
3	Packaging materials for food/allied products	Microbial decontamination	5.0	10.0
		Sterilization	10	25
4	Food additives	Insect disinfestations	0.25	1.0
		Microbial decontamination	5.0	10.0
		Sterilization	10	25
5	Health foods, dietary supplements and nutraceuticals	Insect disinfestation	0.25	1.0
		Microbial decontamination	5.0	10.0
		Sterilization	10	25
6	Bodycare and cleansing products	Microbial decontamination	5.0	10.0
		Sterilization	10	25
7	Cut flowers	Quarantine application	0.25	1.0
		Shelf-life extension	0.25	1.0

dose (0.06- 0.1 kGy) e.g. onion and potato to products requiring very high doses (10-30 kGy) such as spices. Food Safety and Standards Authority of India (FSSAI) provided approval of radiation processing based on generic class (Atomic Energy [Radiation processing of Food and Allied Products] rules 2012). Class wise segregation of food products and doses approved for various applications is provided in Table 5 (Schedule I and II).

KRUSHAK facility at Lasalgaon, Nashik district, Maharashtra state, India is the major facility in catering to irradiation of fresh horticultural produce. A total of 13000 tons of mango has been irradiated and exported from this facility from its inception in 2007 till 2015.Phytosanitarytreatment of other products such as litchi and pomegranate has also been demonstrated.

Processing spices and dry ingredients for microbial decontamination has been routinely carried out at the Radiation Processing Plant, BRIT, Vashi, Navi Mumbai that functions under the administrative control of the Department of Atomic Energy, Government of India. Since its inception in 2007 the facility has processed approx. 40,000 tones of these products fetching revenue of US $ 2.0 million. A total of 18 irradiation plants have also now been set up in the private sector (Table 7).

Table 7: List of food irradiation plants in India

Sr. No.	Facility Name & Location	Commissioning Year	Purpose of the facility
1	Demonstration Plant for Irradiation of Spices, BRIT, Vashi, Navi Mumbai	1999	Irradiation of spices
2	KRUSHAK Irradiator, Lasalgaon, Nashik	2000	Irradiation of Potatoes and Onions
3	Organic Green Foods Limited, Kolkata	2004	Multipurpose facility for Medical Products & food processing
4	A.V Processor, Ambernath, Mumbai	2005	Multipurpose facility for Medical Products & food processing
5	Universal Medicap Ltd , Ranoli , Padrad road , Baroda- 390 020	2005	Multipurpose facility for Medical Products & food processing
6	MicrotolSterlisation services Pvt. Ltd, Bangalore	2006	Multipurpose facility for Medical Products & food processing
7	Agrosurg Irradiators (India) Pvt. Ltd., Mumbai	2008	Multipurpose facility for Medical Products & food processing
8	Gamma Agro Medical Processings Pvt. Ltd, Hyderabad	2008	Multipurpose facility for Medical Products & food processing
9	Jhunsons Chemicals Pvt. Ltd., New Delhi	2009	Multipurpose facility for Medical Products & food processing
10	Innova Agro Bio Park Ltd., Bangalore	2010	Food Processing
11	HindusthanAgro Co-op Limited, Rahuri, Ahmednagar (M.S)	2012	Food Processing (Potatoes & Onions)
12	Impartial Agro biotech Pvt. Ltd. Lucknow	2014	Multipurpose facility for Medical Products & food processing
13	Gujarat Agro Industries Corporation Limited, Ahmedabad	2014	Multipurpose facility for Medical Products & food processing
14	Maharashtra State Agricultural Board, Vashi	2014	Food Processing
15	Align Industries, Bhiwadi	2015	Multipurpose facility for Medical Products & food processing
16	Electro Magnetic Industries, Vadodara	2018	Multipurpose facility for Medical Products & food processing
17	Pinnacle Therapeutics Private Limited, Vadodara	2018	Multipurpose facility for Medical Products & food processing
18	Avantee Mega Food Park Private Limited, Dewas, Madhy Pradesh	2018	Multipurpose facility for Medical Products & food processing
19	M/s Jamnadas Industries Limited (JIL), Indore	2020	Multipurpose facility for Medical Products & food processing
20	Akshar Gamma Steriles LLP, Ambernath,	2020	Under Commissioning

8. Future goals

In the earlier period~~s~~, substantial progress has been achieved on research and development of semi-commercial/pilot-scale radiation processing and storage facilities. This helped in transfer of technology to industry and optimization of process control procedures. Public acceptance of irradiated food was evaluated as well. Through actual retail sales and various market surveys it was clearly demonstrated that if food safety is ensured consumers are willing to pay a premium price. However, at present consumer choice is restricted in the market place due to limited availability of irradiated foods in the retail market. Further, lack of acceptance of irradiated food mainly due to misconceptions and irrational fear of nuclear related technologies and confusion by people to differentiate between irradiated foods from radioactive foods has hampered commercialization of irradiated food.

It is therefore necessary to overcome consumer's fear of buying irradiated food and device strategies so that they begin to realize the benefits of radiation processing. There is also a greater need for understanding of the potential advantages of irradiation by both consumers and entrepreneurs so that they will be in a position to evaluate the process in a rational manner. To expand the technology on a larger scale it is necessary to increase the understanding of the business community.

Building strong partnerships between government and private industry in order to expand the scope of the technology from the research laboratory to the market-place will be major focus in the coming years. Commercial exploitation of the technology in for increasing trade in irradiated food products on a wider scale by strengthening public acceptance and market development is another area of focus for FTD, BARC. As consumers and the food control authorities become increasingly cautious on the question of food safety, food irradiation technology is expected to have wider commercial acceptance.

Food irradiation either as an individual stand-alone process or in combination with others is effective to solve technical difficulties in the trade of several food and agricultural commodities, a prerequisite to gain a higher share of world trade that demands compliance with international food standards. In accordance with the guidelines framed by the International Consultative Group on Food Irradiation (ICGFI), for harmonization of regulation internationally, several countries have authorized food irradiation by groups/classes of food. Irradiation as a phytosanitary treatment for quarantine of horticultural produce to meet export market requirements can boost exports to international markets for which ethnic fruits with potential for export need to be identified. In the era of economies becoming global, only those food products which fulfill high standards of quality and quarantine will get access to international markets. Further, increasing demand for food supplies to serve the needs of ever increasing population and for improving the diets of the millions suffering from malnutrition, food irradiation technology could make a useful contribution to help alleviate world food problems.

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