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Mini Review

Food Processing by Irradiation——An effective technology for food safety and security

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Radiation processing of food involves controlled application of energy from ionizing radiations from radioisotopes (Cobalt-60 and Caesium-137), electron beam (≤10 MeV) or X-rays (≤5 MeV) in an irradiation chamber shielded by 1.5 - 1.8 m thick concrete walls. Food, either pre-packed or in-bulk, placed in suitable containers is sent into the chamber through an automatic conveyor. Major benefits achieved by radiation processing of food are inhibition of sprouting of tubers and bulbs, delay in ripening and senescence of fruits and vegetables, disinfestations of insect pests in agricultural commodities, destruction of microbes responsible for food spoilage, and elimination of food pathogens and parasites of public health importance. Irradiation produces very little chemical changes in food, and the changes are similar to those by other preservation methods like heat. The radiolytic products and free radicals produced are identical to those present in foods subjected to treatments such as cooking and canning. None of the changes known to occur have been found to be harmful. Radiation processing of food has been approved by various international statutory bodies and organizations to ensure 'Food Security & Safety', and overcome 'Technical barrier to International Trade' and currently is being practiced in more than 60 countries worldwide.

Keywords: Gamma ray, Food losses, Food borne outbreaks, Phytosanitary treatment, Radiation, Radicidation, Radurization

Introduction

Radiation processing of food utilizes controlled application of energy from ionizing radiation such as γ-rays, electrons and X-rays on food. γ-Rays and X-rays are short wavelength radiations of the electromagnetic spectrum. The approved sources of γ-radiation for food processing are radioisotopes (cobalt-60 and caesium-137), electron beam (up to 10 MeV) and X-rays (up to 5 MeV) wherein the latter two are generated by machines using electricity[1]. Gamma-radiation can penetrate deep into the food materials inside their final packaging causing the desired effects. Irradiation works by disrupting the biological processes that leads to decay. While interacting with water and other biomolecules that constitute the food and living organisms, radiation energy is absorbed by these molecules. The interactions of radiation and radiolytic products of water with DNA impair the reproduction of microorganism and insects, and thus help in achieving the desired objectives pertaining to food safety and security[1-2]. The radiation sensitivity differs among the microorganisms depending on their structural properties and their ability to recover from the radiation injury. The amount of radiation energy required to control microorganisms thus varies according to the resistance and number of organisms present. Several other factors such as composition of the medium, the moisture content, the temperature during irradiation, presence or absence of oxygen, the fresh or frozen state, influence radiation resistance[3]. The radiation response in microbes can be expressed by the decimal reduction dose (D_{10} -value), the dose required to kill 90% of the total number of that microorganism[3]. The process of radiation, depending on the absorbed dose, helps to improve the hygienic quality of food. The actual dose employed is the balance between what is required and what can be tolerated by the product without any unwanted physical and chemical changes. Furthermore, the food processing by ionizing radiation is also governed by regulations and standards of Codex Alimentarius Commission and the principles of the Hazard analysis

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Abbreviations: MeV, megaelectron volt; USDA, United States Department of Agriculture; UN-FAO, Food and Agriculture Organization of the United Nations; FSSAI, Food Safety and Standards Authority of India; RTE, Ready-To-Eat; IAEA, International Atomic Energy Agency; CRP, Coordinated Research Project and critical control point (HACCP), a preventative food safety management system that is mandated in meat, poultry and seafood processing plants in many countries.

Radiation food processing facility

Radiation processing of food is carried out in an irradiation chamber shielded by concrete walls of 1.5-1.8 m thickness[4]. Food, either pre-packed or in bulk in suitable containers is sent into the irradiation chamber on an automatic conveyor that goes through a concrete wall labyrinth to prevent radiation from reaching the work area and operator room. The radiation sources Cobalt-60 (gamma energy 1.17 MeV, and 1.33 MeV) or Caesium-137 (gamma energy 0.66 MeV) is stored under 6 m deep water when the facility is not in use[4]. The water shield does not allow radiation to escape into the irradiation chamber, thus permitting free access for personnel to carry out plant maintenance. For the irradiation of food, the source is brought to the irradiation position above the water level after activation of all safety devices and restricting human entry. The goods in carriers or tote boxes are mechanically sent inside, positioned around the source rack and turned around their own axis, so that the contents are irradiated on both sides as the dose uniformity depends on the lateral dose distribution in the product on a plane parallel to that of the radionuclide source. The depth-dose uniformity is determined by the product density, thickness, radiation energy and type. The absorbed dose is determined by the residence time of the carrier or tote box in their radiation position. The absorbed dose is checked by placing the dosimeters at various positions in a tote box or carrier[1]. Food irradiators are designed to provide absorbed dose within the minimum (D_{min}) and maximum (D_{max}) dose limits in accordance with the government regulatory requirements. For research applications the ratio D_{max}/D_{min}, termed the dose uniformity ratio should be close to 1, in order that the experimental results clearly demonstrate the dose-effect relationship[4] while food product applications can tolerate a higher uniformity ratio of 2 or even 3. Depending on the source storage arrangement, irradiators are categorized as: (i) Category-I in which the sealed source is completely contained in a dry container constructed of solid materials; (ii) Category-II which has controlled human access and the sealed source is in dry container; (iii) Category-III containing the sealed source in storage pool (usually containing water), human access is physically restricted to the sealed source; and (iv) Category-IV that allows controlled human access irradiator, however, the sealed source remains in storage pool[4]. The sealed source is classified and tested in accordance with Atomic Energy Regulatory Board [AERB/SS-3 (Rev-1) 2001], Department of Atomic Energy, Government of India.

Safety of food irradiation facility

Gamma irradiator does not undergo meltdown, as cobalt-60 is not a fissile material and no neutrons are produced unlike in a nuclear reactor[1-2]. Also, no environmental contamination due to leakage of the radioactivity can occur because the radioisotope is doubly encapsulated in stainless steel tubes to form source pencils such that gamma radiation can come through but not the radioactive material itself. Laws and regulations enacted by the Atomic Energy Regulatory Board govern operations of irradiators in India. The plants must be approved by the Government of India before construction, and are subject to regular inspection, safety audits, and other reviews to ensure that they are safely and properly operated. Cobalt-60 and Caesium-137 which are used as the source of radiation energy decay over many years to non-radioactive nickel and barium, respectively[4]. When the radioactivity falls to a very low level, the source pencils are returned to the supplier who has the provision of storing them. Probabilistic safety assessment of food irradiation facility has earmarked that the risk of fatal exposure is 4.76E-07/year[5]. This frequency of the fatal exposure is below the numerical acceptance guidance for the risk to the individual and is thus considered acceptable[5].

Food production and post-harvest losses in India

As per the United States Department of Agriculture (USDA) database, India is ranked second in rice (approx. annual production 104 million tons) and wheat production (approx. 95 million tons) after China. India is the major producer of maize after USA, China, and Brazil, and also the leading producer of spices (approx. 6.1 million tons) (UN, FAO). Similarly, India is ranked second in production of fruits and vegetables following China. Food losses can be quantitative as measured by the decreased weight or volume, or can be qualitative, such as reduced nutrient value and unwanted changes to taste, color, texture, or cosmetic features of food. Food loss takes place at production, postharvest and processing stages in the food supply chain. In developing countries where the supply chain is less mechanized, larger losses are incurred during drying, storage, processing and in transportation. According a report published by Ministry of Food and Civil Supplies, Government of India, every year, about 21 million tons of wheat (~22% of its total production) rots in India. Close to 40% of India's fresh fruit and vegetable produce perishes before it reaches the consumers (FAO). Cold storage facilities are available for only 10% of India's perishable produce which are mostly used for the potato storage. In the developing countries, about 40% loss of the agricultural produce occurs at the post-harvest and processing stages while in the industrialized countries almost similar extent of loss is encountered at the retail marketing and consumer procurement. Thus, application of post-harvest technologies would enable small holders and larger producers to improve the quality and quantity of food/grains during postharvest handling and storage.

Food Safety

The microbial contamination of food takes place at every stage of food processing including the (i) primary production stage (due to manure, soil, irrigation-water, worker, etc.); (ii) processing stage (worker, conveyer belt, washing water); and (iii) retail marketing or consumption stage (cross-contamination, cutting bed, improper storage). Several microbes including the bacteria (*Clostridium botulinum*, *E. coli* O157:H7, *L. monocytogenes*, *Salmonella spp*., *Shigella spp*., *Staphylococcus spp*., *Vibrio cholerae and Yersinia enterocolitica*), viruses (Norovirus and Hepatitis A) and protozoa (*Cryptosporidium* spp. and *Cyclospora* spp.) have been reported to be associated with major fruits and vegetables leading to the outbreaks worldwide[6-9]. The leafy greens including spinach are the most likely agricultural produce causing the food-borne illnesses as the internalization of pathogenic bacteria has been reported in such produce. In order to address the safety concern of the microbial contaminated leafy greens, the US FDA has issued the Final Rule on the Approval of Irradiation of Spinach and Iceberg Lettuce (Food Chemical News, February 25, 2014). The proposition that *E. coli* testing of the imported fresh fruits and vegetables should be mandatory was unanimously opined by the scientific panel on Contaminants or Biological Hazards of the Food Safety and Standards Authority of India (FSSAI) in New Delhi. Recently, the US FDA (2013) has also released a draft on risk assessment of the levels of contaminants in spices. Nearly, 12% of the spices imported by the US were found to be contaminated with insects and rodent excrement and ~6.6% of the spices were contaminated with *Salmonella*. Other pathogens included *Clostridium perfringens*, *Shigella* and *Staphylococcus aureus*[10]. Considering the impact of microbial and parasitic contamination of foods on consumer's health, food safety needs to be ensured at the retail and also at the consumer level. Here, food irradiation can be a boon for consumers and have a phenomenal impact on the safety assurance in the global food supply. In conjunction with good manufacturing practices, food irradiation has well established safety potential. This provides a strong scientific background for implementation of radiation processing of foods as an effective means to improve their safety. So far, more than 60 countries have approved irradiation as a sanitary and phytosanitary method for many food products[11].

Applications of radiation for food processing

The major benefits achieved by radiation processing of food include (i) inhibition of sprouting of tubers and bulbs; (ii) disinfestation of insect pests in agricultural commodities; (iii) delayed ripening and senescence of fruits and vegetables; (iv) destruction of microbes responsible for spoilage; and (v) elimination of pathogens and parasites of public health concern (Figs. 1-4)[12,13]. Sprouting of potatoes, onions, garlic, shallots, yams, etc. can be inhibited by irradiation in the low dose range of 0.02-0.2 kGy. Physiological processes such as ripening of fruits can be delayed in the dose range of 0.2-1 kGy. These processes are possible consequence of inhibition of enzymatic activities in plant tissues induced by radiation. Radiation enhances the keeping quality of certain foods through a substantial reduction in the number of spoilage causing microorganisms. Fresh meat and seafood may be exposed to such treatments with dose range of 1-7 kGy depending on the product[4].

Fig. 1—Phytosanitary (quarantine) treatment of fruits (Mango, Pomegranate and Litchi) for export at the minimum absorbed generic dose of 0.4 kGy.

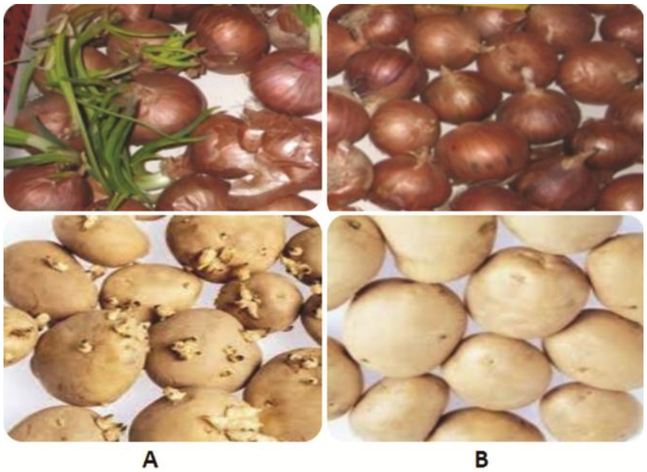

Fig. 2—Sprout inhibition in bulbs and tubers. (A) Non-irradiated control (spoiled within 2 months); and (B) Irradiated [Minimum absorbed dose ≤0. 2 kGy, 6 months stored at 15±1°C)].

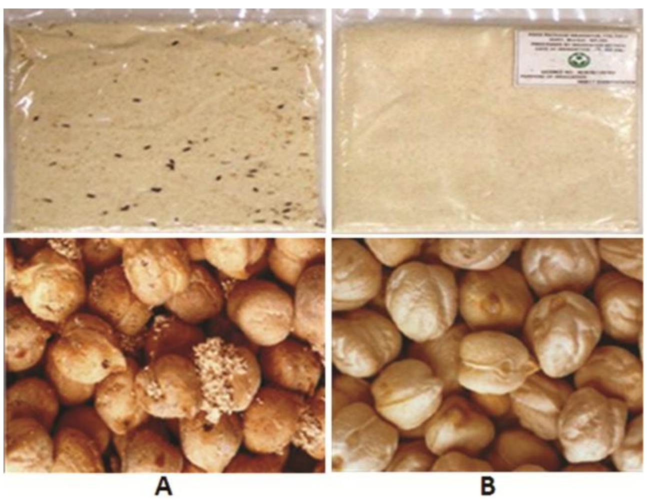

Fig. 3—Insect disinfestations of cereals and legumes. (A) Non-irradiated control; and (B) Irradiated [Minimum absorbed dose ≤1 kGy, one year stored at ambient (26±2°C) temperature].

Fig. 4—Microbial hygienization and insect disinfestations of spices. (A) Non-irradiated control; and (B) Irradiated [Minimum absorbed dose 10 kGy, one year stored at ambient (26±2°C) temperature].

This process of extending the shelf life is called radurization. The process of improving the hygienic quality of food by inactivation of foodborne pathogenic bacteria and parasites is called radicidation. This utilizes medium dose of 2-8 kGy and is similar to heat pasteurization, and hence called radiopasteurization. Irradiation at high doses of 10-30 kGy is an effective alternative to the chemical fumigants like ethylene oxide for microbial decontamination of dried spices, herbs and other dried vegetable seasonings. This is achieved by reducing the total microbial load present in such products including pathogenic organisms[2]. Radiation sterilization is achieved by the reduction of the number and/or activity of all organisms of food spoilage or public health significance including their spores to such an extent that none are detectable in the treated product by any recognized method. This process is analogous to thermal canning in achieving shelf-stability (long term storage without refrigeration) and is called radappertization. The detailed dose description as per the Atomic energy (Radiation processing of food and allied products) rules, 2012, has been included in Tables 1 & 2.

Effect of radiation processing on food quality

Irradiation produces little or no chemical changes in food. The physical properties of food are also not affected by irradiation. The majority of changes due to radiation processing of food are similar to those by other preservation methods such as the thermal (heat) food processing. The radiolytic products and free radicals produced in the irradiated food are identical to those present in the foods processed by cooking and canning. None of these changes known to occur have been found to be harmful[14,15]. The highly sensitive scientific tests/techniques utilized for the past 50 years have not revealed any new chemical product in the radiation-processed foods. The safety and wholesomeness of the technology was endorsed in the early nineties by the international organizations including the WHO, FAO, IAEA, and the Codex Alimentarius Commission[1,2]. The FSSAI has also endorsed this technology. The irradiation process involves passing of food through a radiation field allowing the food to absorb the desired radiation energy restricting the irradiated food never to come into direct contact with the radioactive material and keeping the food radioactive-free. There is no evidence to suggest that free radicals or radiolytic products jeopardize safety of the radiation-processed

Table 1—Classes of Food Products and Dose Limits for Radiation Processing. [Generic approval of radiation processing of food. Atomic Energy (Radiation processing of food and Allied Products) Rules, 2012]

Class	Food	Purpose	Dose limit (Kilo-Gray)	
			Minimum	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 2—Dose limits for radiation processing of Allied products— (Radiation processing of food and Allied Products) Rules, 2012]

Allied products	Purpose	Dose limit (Kilo-Gray)	
		Minimum	Maximum
Packaging materials for food or allied products	Microbial decontamination	5.0	10.0
	Sterilization	10.0	25.0
Food additives	Insect disinfestation	0.25	1.0
	Microbial decontamination	5.0	10.0
	Sterilization	10.0	25.0
Health foods, dietary supplements and nutraceuticals	Insect disinfestation	0.25	1.0
	Microbial decontamination	5.0	10.0
	Sterilization	10.0	25.0

food. Irradiation is quite effective against living organisms but does not cause any significant loss of macronutrients in foods. Proteins, fats and carbohydrates undergo little change in nutritional value, however, the use of higher doses of radiation may induce some changes in the sensory properties depending upon the nature of food which limits the radiation dose employed[2]. Other trace components such as essential amino acids, minerals, essential fatty acids, trace elements remain unaffected under practical irradiation, but in some cases vitamins such as vitamin C and vitamin B1 get partially lost. However, very little change in vitamin content is observed in food exposed to doses up to 1 kGy[2]. The WHO maintains, in a statement to the 19th Meeting of the International Consultative Group on Food Irradiation held in Vienna from 12-14 November 2002, that "*today there is no credible scientific evidence to change the findings of an FAO/WHO/IAEA Study Group that food irradiated at any dose is wholesome and nutritionally adequate when produced under established Good Manufacturing Practice*".

Codex Alimentarius Commission that sets standards for food worldwide and the World Trade Organization (WTO) have also recognized the suitability of radiation processing of foods[16].

Methods to detect irradiated food

There are certain analytical methods that can discriminate between irradiated and non-irradiated foods. Such analytical methods detect physical, chemical and microbiological changes occurring as a consequence of food irradiation. The most useful and widely used methods include electron spin resonance spectroscopy (ESR), luminescence methods (thermo-luminescence TL), and photo stimulated luminescence (PSL)[11]. These analytical methods have been adopted as standard methods for detection of irradiated foods by Codex Alimentarius Commission.

Irradiated fruit available nationwide in USA

In the USA approx. 0.1 million tons of irradiated food is consumed annually which includes ~0.07 million tons of spices, 8200 tons of ground beef (fresh and frozen), 18000 tons of other irradiated produce. Nearly 15000 tons of irradiated fruits are marketed in the USA annually which include mangoes from India; purple sweet potatoes from Hawaii; litchis, mangosteens and rambutan from Thailand; guavas and mangoes from Mexico; dragon fruit from Vietnam; and grapes from South Africa. Many food companies are using irradiation of foods in USA. Some of these include Dairy Queen (Minnesota), Wegman's, Huisken's of Minnesota, Schwan's home delivery, Omaha Steaks, Tyson, Excel, Emmpak, Colorado Boxed Beef, WW Johnson Meat Company, Kenosha Beef International, Hamburgers, Nation's Pride, and Rochester Meat. Hawaiian papayas deal with irradiation of the plant foods[17].

Economics of setting up of the radiation food processing facility and cost of food processing

The estimated cost for setting up of a commercial radiation food processing facility is in the range of Rs. 10-12 crores excluding the land cost. However, the processing cost is quite inexpensive. Irradiation costs is in the range of approx. Rs.0.50-1.00/kg of the produce for a low-dose application such as the sprout inhibition of potato and onion and insect disinfestation in cereals and pulses and Rs.3-5/kg for a high-dose application such as the treatment of spices for microbial decontamination. The costs could be further brought down in a multipurpose facility irradiating a variety of produce around the year. In many cases, extended shelf-life offsets the extra cost. Processing also brings benefits to the consumers in terms of availability, storage life, distribution, and improved hygiene of food. Irradiation can have a stabilizing effect on the market price of commodities by reducing the storage losses resulting in increased availability of the produce.

Recent R&D findings in India indicating additional applications of radiation processing

The shelf-life extension of 10 d was achieved for the button mushroom (*Agaricus bisporus*) by γ-irradiation (2 kGy) and low temperature (10°C) storage[18]. Sugarcane juice was preserved for 35 d by addition of the permitted preservatives, γ-irradiation (5kGy) and storage at 10°C[19]. Safety of the leafy vegetables can be ensured by radiation processing with extended shelf-life of more than two weeks. A combination process including radiation treatment can ensure safety and also extend the shelf-life of sweet corn kernels more than one month. Dried water chestnut can be preserved by radiation processing for more than one year. Safety of herbals and tea can also be ensured by radiation treatment. The misconceived notion about the safety concern of the irradiated food has remained a stumbling block in wider adoption of this technology worldwide. Enormous research efforts have been directed towards biological testing of irradiated foods for the evaluation of their safety and wholesomeness. Some recent studies included long term exposure studies with irradiated foods and meat products in bacterial and human cell line models, which have shown that there is no genotoxic effect of irradiated foods and such foods, are safe for consumption.

Shelf-stable special purpose foods developed in India using radiation processing

Several new ready-to-eat (RTE) shelf-stable food products have also been developed for the benefits of the special groups of consumers such as the persons affected by natural calamities, defense personnel, and immune-compromised patients. Many food items were developed in India using the radiation processing during IAEA CRP (D6.20.09) on "The Development of Irradiated Foods for Immuno-Compromised Patients and other Potential Target Groups". Also the radiation doses, treatment and storage conditions were standardized for these products. The products include Naso-Gastric Liquid Feed formulation (NGLF), Low Cost Enteral Food (LCEF), Intermediate Moisture (IM) Papaya Cubes, Irradiated honey, Stuffed Baked Food (SBF, Local name: Litti), Methi Paratha, Puran Poli, Vegetable pulav, and RTE meat products (Chicken tikka, Chicken pahadi kabab, Chiken paratha, Chikenpulav, and Baked chiken dumpling)[20-24]. The products have been reported to retain wholesomeness and quality attributes. Two of these products (NGLF, and LCEF) have been developed by Food Technology Division, BARC in association with the Tata Memorial Hospital mainly for the immune-compromised patients. Other products are for use during natural calamities and by the defense personnel deployed to remote places. These products are equally good for routine consumption by other individuals.

Current status

In countries, such as France, The Netherlands, South Africa, USA, Thailand and China, the radiation-processed foods such as strawberries, mango, banana, shrimp, frog legs, chicken, spices, and fermented pork sausage are sold on regular basis on the market shelf. More than 50 countries are irradiating food for processing industries and institutional catering. These radiation-processed food items are labeled with the Radura logo to indicate the irradiation treatment and its purpose. Recent development in the area of food irradiation in India includes the harmonization of food irradiation rules with the international regulation through adaptation of class wise clearance of irradiated food items through the Atomic Energy (Radiation processing and Allied Food Products) Rules, 2012 by the FSSAI (Table 1 and 2). These rules have recently gazette notified by the Government of India (F.No.1-120(2)/Standards/Irradiation/FSSAI-2015) on 23 August 2016.Thirteen food irradiation plants have been commissioned till date in the private sector (Table 3). Two plants set up by the Government of India (Radiation Processing Plant, Vashi, Navi Mumbai; and KRUSHAK, Lasalgaon, Nashik) are also operational (Table 3). Many more food irradiation plants are under construction or conception stages. The volume of food irradiated in India has been steadily increasing. As per the reports published by Department of Atomic Energy, a total of ~34000 tons of produce have been irradiated by the Radiation Processing Plant, Vashi, Navi Mumbai till 2015. Irradiated mango (approx. 300 tons per annum) is being exported to USA since 2007. In the year 2016 around 750 tons of irradiated mango has been exported to USA. Dabur, one of the leading companies in India dealing with the Ayurvedic herbals and churna (a complementary medicine) has started γ-radiation treatment of products for microbial decontamination. Many other herbals and food companies have also started irradiating their products.

Table 3—Food irradiation facilities and their locations in India (Till 2015).

Government Sector
Radiation Processing Plant, BRIT, Vashi, Navi Mumbai, Maharashtra
KRUSHAK Irradiator, Lasalgaon, Nashik, Maharashtra
MSAMB’s Food Irradiation Facility, Navi Mumbai
Private Sector
Agrosurg Irradiators (India) Pvt. Ltd., Mumbai, Maharashtra
Hindusthan Agro Co-op Limited, Rahuri, Ahmednagar, Maharashtra
STERICO facility, M/s A V Processors Pvt. Limited, Mumbai, Maharashtra.
Universal Medicap Ltd, Ranoli, Padrad road, Baroda, Gujarat.
Gujarat Agro Industrial Group's irradiator, Bavla, Gujarat
Innova Agro Bio Park Ltd., Bangalore, Karnataka.
MicrotrolSterlisation Services Pvt. Ltd, Bangalore, Karnataka
Jhunsons Chemical Private Limited (JCPL), Bhiwadi, Rajasthan
Gamma Agro Medical Processing Pvt. Ltd, Hyderabad
Shriram Applied Radiation Center (SARC), Shriram Institute for Industrial Research, Delhi.
Impartial Agrotech Pvt. Ltd.'s Irradiator, Unnao UP
Organic Green Foods Limited, Kolkata, WB.

Challenges

Despite all these developments, irradiation is still an issue of concern for consumers, particularly in food items. A greater effort is required to convince the consumers with scientific and accredited information about food irradiation. Expansion and strengthening the collaboration between various agencies viz., Food Corporation of India, Ministry of Food Processing, National Disaster Management Authority, Defense authorities, hospitals, and commercial as well as institutional food suppliers is necessary. This will ensure the eventual adoption and integration of the irradiated foods into the supply chains and will help promote commercialization and widespread use of the technology. It is also required to develop appropriate outreach and education materials for the targeted audiences including family members, medical professionals, private investors, community groups, NGOs, regulatory agencies, and financial and legal industries. The private entrepreneurs should be encouraged to establish more food irradiation facilities to ensure the large scale availability of the irradiated food in the market so that consumers will have an option.

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