J. Environ. Sci. & Natural Resources, **14(1&2): 65-71, 2025** ISSN 1999-7361

Food Irradiation Technology: An Overview of Practices and Status in the Globe and Bangladesh

K. S. Arefin[*1,2], M. Hassan[1], M. S. H. Suny[1], M. M. H. Sohag[1] and M. A. Farukh[2]

[1]Electronics and Health Physics
Bangladesh Institute of Nuclear Agriculture, Mymensingh – 2202
[2]Department of Environmental Science
Bangladesh Agricultural University, Mymensingh – 2202
[*]Corresponding author: arefin.241214902@bau.edu.bd

Abstract

The agricultural food industry is giving priority to the development of technologies that guarantee product quality and safety as customers grow more conscious about food safety and health. Conventional thermal preservation techniques, such pasteurization and sterilization, frequently degrade food's nutritional value and texture. Alternative methods that preserve the stability and freshness of food items are becoming more popular in response. Among these technologies is food irradiation, which has been used for more than a century. Ionizing radiation is applied to packaged or bulk goods in the form of gamma rays from Cobalt-60 or Cesium-137, X-rays up to 5 MeV, or accelerated electrons up to 10 MeV. Without causing radioactivity in food or packaging, this technique improves microbiological safety, increases shelf life, and conforms to quarantine regulations. Conducted in shielded environments, food irradiation is recognized globally for its ability to ensure hygienic quality and reduce post-harvest losses. This paper provides an overview of food irradiation practices and their status in the Americas, the European Union, Asia, and Bangladesh, underscoring the technology's evolution, bene-fits, and widespread acceptance.

Keywords: Consumer acceptance, Food irradiation, Food preservation, Ionizing radiation, Irradiated food

Introduction

Currently, individuals are aware of the health risks and benefits associated with food consumption. The food industry is allocating substantial resources and expertise to produce safe and wholesome products in order to meet consumer expectations. Food contamination can be prevented by thoroughly assessing the materials introduced into the food chain, chilling the food, processing it to avert post-processing contamination, and reducing or eliminating the microbial load (Barba et al., 2016; Chemat et al., 2017). The aspect of the activity focused on microbial destruction is crucial for assessing the safety and stability of foods. Traditionally, food undergoes pasteurization and sterilization through heat treatments, which diminish its nutritional value and sensory qualities (Ramos et al., 2011). The food industry seeks alternative technologies to maintain the fresh attributes, safety, and storage stability of food, as consumers perceive fresh foods to be healthier than heat-treated options (Tiwari et al., 2009; Pereira et al., 2010).

Long-standing technology used for decades to improve food safety, increase shelf life, and lower post-harvest losses is food irradiation. Harmful microbes, pests, and pathogens are essentially eradicated by subjecting food to regulated doses of ionizing radiation, such gamma ray, X-rays, or electron beams, therefore ensuring the safety and quality of food products. Many international agencies, including the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the International Atomic Energy Agency (IAEA), have approved this procedure as a safe and efficient means of food preservation (WHO, 1981; FAO/IAEA, 2020).

Food irradiation has been rather popular worldwide; more than 60 nations have used the technology for different food products, including spices, cereals, fruits, vegetables, and meat products (Eustice, 2020). Food irradiation has been included into food safety procedures by nations including the United States, China, and members of the European Union realizing its ability to solve foodborne diseases and enhance food security (Farkas, 2006). Food irradiation has shown clear advantages, although its acceptance is still uneven due to public opinion, legal obstacles, and inadequate infrastructure that would allow its broad application (Roberts, 2014).

In Bangladesh, a nation struggling with food safety issues, post-harvest losses, and a rising population, food irradiation offers a viable answer. Adoption of this technology will help Bangladesh greatly since of its agricultural economy and sensitivity to food contamination (Hossain et al., 2018). But food irradiation has progressed slowly in Bangladesh, mostly due to low knowledge, inadequate laws, and little funding for irradiation facilities (Ahmed, 2020). With an eye toward the prospects and difficulties for its application in Bangladesh, this paper investigates worldwide methods and developments in food irradiation. Examining case studies and successful examples from other nations can help Bangladesh to better understand how to use food irradiation to improve public health, lower economic losses, and in-crease food security (Bhuiyan et al., 2021).

This review paper points out the growth, potential positive aspects, and general acceptance of food irradiation technology by giving a broad overview of food irradiation practices and their status in the Americas, the European Union, Asia, and Bangladesh.

Sources of irradiation

Gamma rays

Cobalt-60 and Caesium-137, which are produced by neutron bombardment of co-balt-59 and as a byproduct of nuclear sources, respectively, are the radioisotopes from which gamma irradiation is produced (Fellows, 2018). Typically, Cobalt-60 is used to irradiate food. It is a stainless steel-encased metal source that is doubled encapsulated. The source is kept in a pool of radiation-absorbing deionized water or a shielded container when it's not in use. Since the decayed source is given back to the supplier for retention or replenishment, there is no waste produced. Due to its in-solubility in water and consequent low risk of environmental contamination from leakage into water systems, Cobalt-60 is the most often used source of gamma irradiation in food in commercial facilities (Fellows, 2018; Ashraf et al., 2019). To ensure compliance with the International Atomic Energy Act's Regulations for Safe Transport of Radioactive Materials, and to avoid any radiation leakage, Cobalt-60 must be transported in trucks specially designed to withstand extreme safety requirements and rigorous testing before being authorized for shipping radiation sources. Cesium-137 is more soluble in water than Cobalt-60 and can contaminate the environment.

Electron beam

It is produced when high-energy electrons in an accelerator—which is powered on and off—become electrons accelerated to 99% the speed of light. Although electron beams are less expensive and have a higher throughput, they have a lower penetration depth and poor dose uniformity. As a result, foods with less thickness are treat-ed with it (Fellows, 2018).

X-rays

The technique of producing X-rays (this process is known as bremsstrahlung-conversion) by bombarding dense target material with high-energy accelerated electrons, results in a continuous energy spectrum (Fellows, 2018). To generate X-rays Because of their high atomic numbers and melting temperatures, tantalum and tungsten are used as the anodes of X-ray tubes; however, tantalum is preferred for industrial, large-area, high-power targets because it has a higher threshold energy for induced reactions and is more practical than tungsten (Marshall and Stilchelbaut, 2009). Similar to electron beams, x-rays can be turned off when not in use and do not require the use of a radioactive source. Only 8% of incident energy is converted into X-rays, making X-rays a very expensive source of radiation despite their high penetration depth and dose uniformity (Fellows, 2018; Ashraf et al., 2019).

Gamma irradiation facilities

Cobalt-60 emits the gamma rays with the energies of 1.17 and 1.33 MeV while as ce-sium-137 emits gamma rays with the energy of 0.66 MeV. The Cobalt-60 is a radio-active metal that decays with a half-life of around 5.3 years. Gamma radiation with energies of 1.17 and 1.33 MeV is released by Cobalt-60, and gamma radiation with an energy of 0.66 MeV is released by cesium-137. Cobalt-60 is a radioactive metal that decays in about 5.3 years. Few commercial gamma facilities use cesium-137 as a gamma ray source despite the element's longer half-life of about 30.1 years. This is due to the element's low energy of emission, which is about half that of Cobalt-60 (Suresh et al., 2005). Because gamma rays have a higher penetration depth than electron beams, they are better suited for treating large bulk packages of food. One major drawback of gamma irradiation is that the radiation cannot be turned off. Thus, they need to be kept in a lead shielding chamber called a sealed source, stored in a water pool to absorb radiation energy when not in use, and shielding facilities are needed to protect workers from exposure if they must enter the irradiation room (Hvizdzak et al., 2010).

Electron beam facility

Electron beams are produced mechanically by accelerating an electron stream and concentrating it into a small beam spot. This spot of incident electrons is scanned across the food because it is perpendicular to the direction of the beam (Suresh et al., 2005). Three key benefits of e-beam over gamma rays are as follows: The first step is to stop using radioactive elements. They can be switched off when not in use, which brings us to our final point: their high dosage rates and low penetration depth. As a result, it can be applied to the surface of the slices to effectively and minimally harm food borne pathogens (Hvizdzak et al., 2010).

X-ray facility

X-rays can be turned off and are produced by machines. An X-ray beam is produced by accelerating machine-generated electrons toward a metallic target, such as gold or tungsten. Heat is lost during this process, but the atomic number of the target material and the E-beam energy can both raise the X-ray efficiency. Large bulk produce can be processed using X-ray facilities without the need for radioactive material, although these days, very few products are exposed to radiation from X-rays (Follett, 2004). As X-ray technology advances, its applications will grow diverse. How-ever, it looks like gamma rays may be used for a very long time in commercial food irradiation facilities (Kume et al., 2009).

Collection of data

Food irradiation data worldwide is sourced from multiple publications, data that has been published, and reports from the Commission to the European Parliament and the Council on food and food ingredients treated with ionizing radiation. This review paper discusses the current status of food irradiation facility and irradiated agricultural products in Bangladesh with statistical data on the irradiation of food in North and Latin American regions, the European Union, and Asian countries.

Food Irradiation around the World

Scientific and technical growth in irradiation of food and agricultural products began in 1958 (Ic and Cetinkaya, 2021). According to the Institute of Food Science & Technology (IFST), more than 50 countries have given approval for over than 60 products to be irradiated in the world (IFST, June 2015). In Asia the use of irradiation for food decontamination and phytosanitary purposes was estimated to 285,223 tons per year in 2010. In the European Union, the quantity of irradiated foods was estimated to 9264 tons, especially for spice decontamination. In the USA the total was estimated at 103 tons (Kume and Todoriki, 2013). The USA, China, The Netherlands, Belgium, Brazil, Thailand, and Australia are the major countries that have adopted the technology commercially (IFST, June 2015). The use of irradiation for phytosanitary purposes is important around the world. More than 18,446 tons of food are irradiated worldwide for phytosanitary purposes, representing 5734 tons in Hawaii, 493 tons in Australia, 100 tons in India, 951 tons in Thailand, 850 tons in Vietnam, and 10,318 tons in Mexico, mostly for export to the USA (Kume and Todoriki, 2013). Australia was the first user of irradiation for phytosanitary purposes in 2004, especially to export to New Zealand. India started to export to the USA in 2007, followed by Thailand and Vietnam. Mexico started to ship irradiated foods to the USA in 2008 and the export increased from 257 tons in 2008 to 3521 tons in 2009, making it now the most important exporter to the USA.

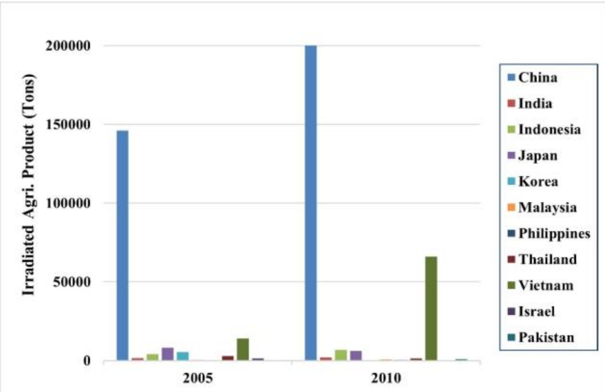

Fig. 1. Irradiation of agricultural products (in tons) in Asian nations during the years 2005 and 2010.

Food Irradiation in Asian regions

Currently, the world's most developed commercial food irradiation center is found in Asia. The data on food irradiation in Asia was studied by Kume (Kume and Todoriki, 2013; Kume et al. 2009). In Asia, 183109 tons of food were irradiated overall in 2005 and Five years later, it was seen that 285223 tons of agricultural and hu-man-consumption food products were irradiated in Asia. Kume et al. found that in Asia, the amount of irradiated food and agricultural products increased by 55.77% (Kume and Todoriki, 2013). The percentage of food that has been irradiated is growing continuously in Asia. Facilities for gamma irradiation are found in several Asian countries, such as China, India, Indonesia, Japan, Korea, Malaysia, Pakistan, Philippines, Thailand, Vietnam, and so on. In the last fifty years, the largest producer of irradiated food in the world right now is China (Wang et al. 2023). This country has achieved a tremendous achievement, from working on food irradiation at the laboratory scale to producing, implementing, and exporting irradiated food as well as building a facility outside of the country. In 2005, China irradiated 14,600 tons of agricultural products and food items (Mahera-ni et al., 2016; Kume et al. 2009). It is clearly seen from "Figure 1" that the quantity of irradiated food in China in 2010 was more than 200,000 tons, which increased by about 37% compared with 2005 (Kume and Todoriki, 2013). In 2016, the estimated total amount of food irradiation in China was close to 1 million tons per year. At the end of 2019, there were over 120 γ-irradiation installations in China with a design capacity of over 300 kCi, totaling ~176 MCi. Additionally, there were more than 50 10-MeV high-energy e-Beams in operation or under construction, with a total power of around 1,200 kW (Ic and Cetinkaya, 2021). According to incomplete statistics, the total actual capacity of γ-irradiation installations used for food irradiation is about 49.35 MCi (actual loading is 70 MCi, accounting for 23% of the world's total) with a total of 45 10 MeV e-beams expected to be completed by the end of 2022. Items including cereals, garlic, dried veggies, spices, health meals, and functional foods were irradiated in China.

Food irradiation in Vietnam expanded rapidly and is placed at second in Asia (**Fig. 1**). Commercial food irradiation was implemented at the Ho Chi Minh Irradiation Center (VAEC) and Son Son Electron Beam Irradiation Co. Frozen sea-food (mainly prawns) totaling 14,200 was irradiated and exported to Russia and other countries. Vietnam saw overall increases of 51,800 tons for the 5 years from 2005 to 2010 (Kume et al. 2009). After China and Vietnam, Indonesia (6923 tons) and Japan (6246 tons) irradiated the largest quantity of food. India irradiated 1600 tons in 2005 and 2100 tons in 2010. For India, 2010 data were available only for the Bhabha Atomic Research Center's KRUSHAK (275 kCi) and Vashi (400 kCi) facilities where sprout inhabitation, fruit disinfestation, and spice sterilization have been carried out. At the KRUSHAK facility, 2,000 tons of spices (including turmeric, red pepper, and coriander) and dehydrated vegetables were ir-radiated; at the Vashi facility, 100 tons of fresh fruit were irradiated. However, there were 7 Cobalt-60 private sector facilities in India (each comprising 250-540 kCi) for which the data were unavailable. In Indonesia, 6923 tons of food were irradiated in 2010; this was carried out at a private gamma irradiation facility (300 kCi) installed in 1992. The irradiated items comprised cocoa (80%), frozen foods (7%), spices (5%), and other foods including dehydrated vegetables, sea weed and honey. The only irradiation permitted in Japan is that on potato for sprout inhibition, and commercial irradiation has been performed at the Shihoro irradiation center in Hokkaido since 1974 for more than 30 years. The initial quantity of over 15,000 tons of irradiated potatoes had decreased to 8096 tons in 2005. It dropped to 3300 tons in 2006 because of new retail labeling regulations, but had gradually recovered to 6246 tons by 2010 after concerted efforts from businesses. In South Korea, 300 tons of hydrated vegetables were irradiated. This represented a significant drop from the 5,400 tons in 2005 because of the introduction of rules that had mandated the labeling of ingredients for various products. Despite research conducted by the Korea Atomic Energy Research Institute on food irradiation for allergy sufferers and food irradiation appropriate for astronauts and military personnel. In Malaysia, 785 tons of spices and herbs were irradiated in 2010; the products included curry powder, coriander, and pepper. Commercial irradiation started in 1997 at the Co-60 irradiation facility (SINAGAMMA) of the Malaysian Institute for Nuclear Technology Research. This plant has processed 700-800 tons every year since 2006. In Pakistan, a private-sector company initiated commercial food irradiation in 2010. A total of 940 tons of legumes, spices, and fruits were processed in that year. In 2011, permission was given for the development of 3 new food irradiation facilities, and the export of irradiated mango was started. In the Philippines, 445 tons of spice and dehydrated vegetables were treated at the Philippines Nuclear Research Institute. Food irradiation is still in the pilot stage in this country, but fruit irradiation for quarantine processing to export to the US is expected to take place. In Thailand, 1484 tons of agricultural products, herbs, frozen foods, and processed foods were irradiated at the irradiation center of the Thailand Institute of Nuclear Technique and at a private sector facility. Although the 2010 total had decreased compared with the 3 000 tons processed in 2005, it is presumed that the actual total amount is increasing because private-sector data for 2010 was obtained only for fruits. The export of irradiated fruits to the US was 951 tons in 2010. In Sri-lanka, Agricultural products irradiation has not yet been carried out. However, a multipurpose irradiator center (300 kCi) was opened in 2012.

Food irradiation in the European regions

The European Union (EU) implemented standardized food irradiation regulations that permit the irradiation of specific food categories, the majority of which are agricultural products and food items. However, the actual use of food irradiation in the EU is very limited, with around 10 countries performing commercial irradiation of food.

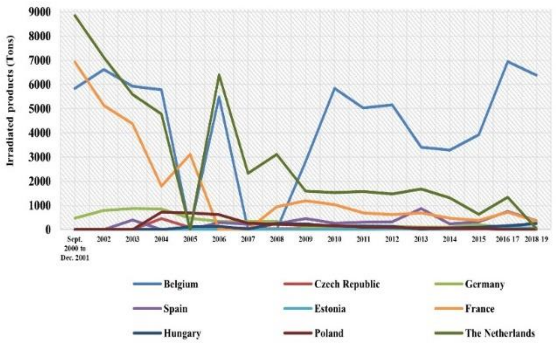

Fig. 2. EU countries' annual irradiation of agricultural food products (in tons) from 2001 to 2019.

The main products irradiated in the EU are spices, herbs, and dehydrated vegetables, with a total amount of about 189955.071 tons from September 2000 to December 2019 (EC Annual Report-Food Irradiation).

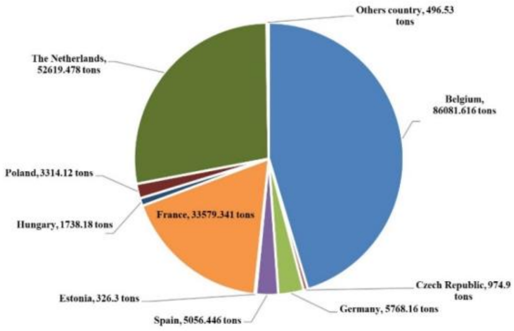

Fig. 3. Proportion of total irradiated agricultural products by EU country from 2001 to 2019.

Three principal European nations Belgium, the Netherlands, and France have irradiated about 90.70% of agricultural and human consumable items over the past two decades, according to the EC Annual Report on Food Irradiation (**Fig. 2** & **Fig. 3**). Ionizing radiation is an efficient way to decontaminate food; however, its use in treating agri-food is less common across EU member states due to its limited diffusion. People in Italy, for instance, have historically been afraid of nuclear technology, and customers are frequently misinformed about the technique used to irradiate food. But in 1976, the Italian people liked irradiation potatoes despite their worse quality and poorer capacity to store, despite popular belief to the opposite. In Poland, irradiated foods (potatoes and onions, 1987–1988) sold well, with 90% of people accepting them overall and 95% accepting them; in France, irradiated strawberries sold well in 1987, even bringing in an additional 30% above the standard price, indicating a good acceptance (only 2% of people rejected strawberry irradiation) (Marcotte and Kunstadt, 1993; Frenzen et al., 2000; Maherani et al., 2016; Kume et al. 2009). In the EU, consumer acceptability of irradiated food is low and is influenced by a number of variables, including awareness, information, trust, risks, ethics, and preferences.

In European regions, the highest amount of agricultural and human-consumable food items has been irradiated in Belgium [see "Figure 3"]. According to the official re-port of the European Commission, which is published every year about food irradiation, Belgium irradiated around 45.32% (86081.616 tons) of agricultural and human consumable products in Europe during the period from September 2000 to December 2019. Herbs, spices, vegetable seasonings, dehydrated veggies, grilled onions, herbal tea, dried fruits, starch, papain, pâtes de fruits, frozen vegetables, prepared meals, rice meal, and gum arabic are among the items that are specifically treated with irradiation (4304 tons per year) in Belgium. In The Netherlands, irradiation is practiced for spices, herbs, dehydrated vegetables, food additives, dried fruits, flavorings, vegetable seasonings (dried), dried aromatic herbs, dried vegetables, dried fruits, cereals, mushrooms or mushrooms products (dried) and nuts (2631 tons/year). It is appeared from approximately 27.70% of the irradiated agricultural and human consumable items in Europe have come from the Netherlands (**Fig. 3**).

Commercial food irradiation in France was active. Commercial food irradiation in France increased in the 1990s, with the 10000 tons irradiated in 1991 being doubled to 20000 tons in 1998 (Kume et al. 2009). However, the amount of irradiated food decreased rapidly afterwards, reaching a low of 3000 tons in 2005. France commercially irradiated about 33579.341 tons of agricultural and human consumable items from the time period of September 2000 to December 2019. In France, vegetable products (frozen & dried), spices, aromatic herbs, deep frozen aromatic herbs, dried fruits, gum arabic, vegetable seasonings, dried fruits, cereal flakes for milk products, herbal teas/infusions, instant noodles, mushrooms or mushrooms products (dried), avocado and sauces and soups (dehydrated) are treated by irradiation (1679 t/year). The first commercial food irradiation facility was established in Germany in 1957 (Diehl, 1995). Several papers reported that irradiated food is prohibited for domestic consumption, and some agricultural products and human consumable items were irradiated for export to third-world countries (Kume and Todoriki, 2013; Kume et al., 2009; Diehl, 1995). According to the European Commission report, between September 2000 and December 2019, Germany irradiated 5768.16 tons of agricultural products and human consumable items, which were 3.04% of the irradiated products in the European regions at this time. Spices, seasonings, fresh vegetables, dried aromatic herbs, spices, dried vegetables and vegetable powder, herbal tea, and oil seeds (poppy, sesame, and linseed) were irradiated in Germany and ex-ported to third-world countries.

In Spain, there are two facilities approved for the irradiation of food and food ingredients. Inspections by the competent authorities in 2007 confirmed the compliance of the irradiation facilities with the requirements of Directive 1999/2/EC (EC Annual Report-Food Irradiation). Throughout the years 2000–2005, with the exception of 2003, Spain did not irradiate any food or agricultural goods. Up to 2019, this country has irradiated dried aromatic herbs, spices, and vegetable seasonings with an average 8–10 kGy total dose in a total of 5056.446 tons of agricultural products, which is about 2.66% of the total irradiated products in European regions shown as "**Fig. 3**".

Only two establishments in Poland are authorized to irradiate food: the Institute of Applied Radiation Chemistry at the Lodz University of Technology and the Institute of Nuclear Chemistry and Technology in Warsaw. The country has irradiated 3314.12 tons of dried aromatic herbs, vegetable seasonings, dry spices, vegetables, and roots with an average dosage of 5–10 kGy between 2004 and 2019.

Since 2004, the Czech Republic has irradiated 974.9 tons of dry vegetable seasoning, aromatic herbs, and spices at dosages ranging from 2.49 to 10 kGy. An average of 61 tons of agricultural goods are irradiated annually; of them, around 0.51% have been irradiated in this country in European areas. Herbs, spices, and vegetable seasoning have been irradiated in Bulgaria, Estonia, Romania, Croatia, Norway (EFTA country), and Italy (about 401.8, 326.3, 38.6, 26.7, 27.03, and 2.4 tons, respectively), according to European Commission reports from September 2000 to December 2019. Some European states, such as Denmark, Portugal, and the United Kingdom, equipped with irradiation facilities, did not irradiate any foodstuffs from September 2000 to December 2019, as covered by the European Commission report.

Status of food irradiation in Bangladesh

Bangladesh has taken radiation processing programs in a big way, right from its inception through Bangladesh Atomic Energy Commission (BAEC).

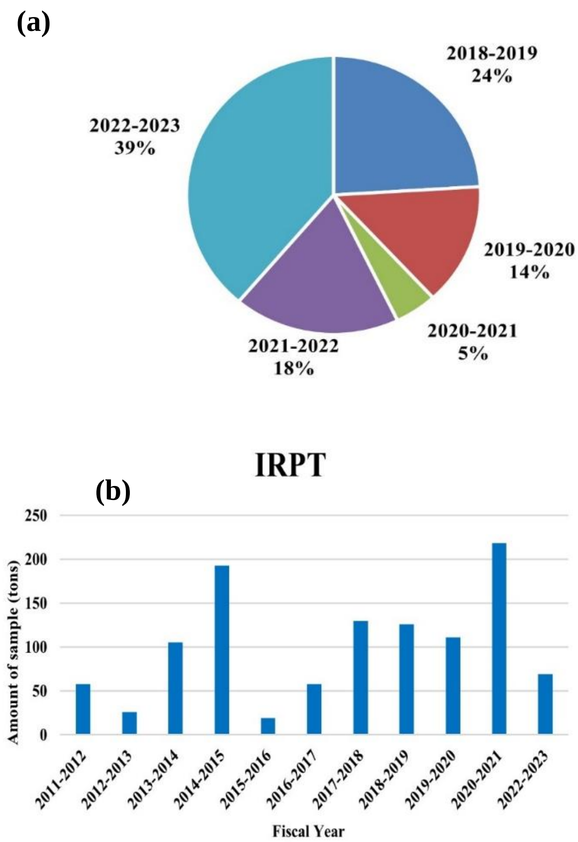

Fig. 4. (a) Irradiated products at IFRB (2018-2023) & (b) Agricultural products irradiated at IRPT.

With tremendous efforts by the government of Bangladesh, in 1983, irradiation of 12 food items was issued by the Bangladesh Standards and Testing Institute (BSTI) in 1983 which was a great decision to facilitate this technology in Bangladesh. Subsequently, in 1995, Bangladesh adopted a "Specification for Authorization of Irradiation by Groups/Classes of Foods" in line with the guidelines framed by ICGFI. This authorization for irradiation by groups/classes of foods is essentially similar to the final draft of the Harmonized Regulations for Food Irradiation in Asia and the Pacific adopted by RCA Member States in Seoul, Korea in April 1998 (Maherani et al., 2016; Kume et al. 2009; Kume et al. 2009; IAEA TECDOC-1219, 2001).

In March 1993, the Bangladesh Atomic Energy Commission, in partnership with BEXIMCO, a prominent private corporation in the country, established a demonstration/commercial Co-60 irradiation plant (80kCi) in the port city of Chittagong under the name Gammatech Ltd. Gammatech Ltd. has radioactively treated more than 1300 tons of various foods and these products have been effectively marketed both domestically and overseas. Gammatech Ltd. has irradiated 1377 tons of different food items from 1995 to 1998, and these items have been marketed successfully both domestically and overseas (IAEA TECDOC-1219, 2001). Bangladesh's first provider of irradiation services is Institute of Food and Radiation Biology (IFRB). Gamma Source Division (GSD) of Institute of Food and Radiation Biology (IFRB) has been rendering irradiation services since 1979 to different institutes/organizations and private companies using Co-60 panoramic gamma irradiator (IFRB, BAEC-Annual Report, 2011-2023). The main objectives of IFRB are to provide irradiation services in research and commercial sectors and to develop and utilize gamma irradiation technology for better quality products. IFRB has a semi-commercial irradiator. In 2014, this irradiator was refilled, and at that time, the radioactivity was 90 kCi (IFRB, BAEC-Annual Report, 2011-2023).

Bangladesh has another irradiator at the Institute of Radiation and Polymer Technology (IRPT), Savar, that is providing commercial gamma irradiation services for the quality improvement of food items and contributing to the socio-economic development of the country. The 350 kCi Co-60 gamma irradiator of IRPT is used to irradiate food items, medical products, and pharmaceutical products. Generally, 25 kGy is used for sterilization purposes, and up to 10 kGy is applied to food items. In this institute, different private companies take food irradiation services for export. The irradiated foods are mainly spices such as chili, turmeric, coriander, zinger, nuts, spirulina, pet food, mushrooms, etc. (IRPT, BAEC-Annual Report, 2018-2023). According to Figure 4(a), in the last five fiscal years, it appears that the amount of irradiated products at IFRB has over-all increased, and in fiscal year 2022-2023, it is the maximum at 39% (IFRB, BAEC-Annual Report). Figure 4(b) shows that in the last fiscal year 2022-2023, quantities processed at IRPT were generally lower due to IRPT being planned to re-fill the Co-60 isotope (IFRB, BAEC-Annual Report, 2011-2023). Bangladesh is an agriculturally based country, so there is a tremendous chance to earn foreign currency by exporting agricultural products to the EU, Middle East, Australia, Japan and North America. Australia, Japan, and most European countries have regulations that require imported agricultural products to be irradiated. A huge amount of agricultural product is spoiled due to postharvest losses; this can be solved by utilizing proper irradiation technology. But irradiation facilities in Bangladesh are not well enough for exporting huge amounts of agricultural items and preserving domestic agricultural products. A pilot project is being undertaken by the Bangladesh Institute of Nuclear Agriculture (BINA) to build up food irradiation facilities to reduce postharvest losses, and BINA also plans to adopt X-ray and e-Beam facilities in the near future. Positively educating stakeholders and the public about the safety of irradiated agricultural products and the fact that no radiation remains after irradiation remains a significant challenge.

References

Ashraf, S., Sood, M., Bandral, J.D., Trilokia, M., Manzoor, M. 2019. Food irradiation: A review. *Int. J. Chem. Stud*., 7, 131-136.

Ahmed, T. 2020. Food Safety and Security in Bangladesh: Challenges and Opportunities. *J. Food Sci. Technol.*, 57(5), 1234-1245.

Barba, F.J., Terefe, N.S., Buckow, R., Knorr, D., Orlien, V. 2015. New opportunities and perspectives of high pressure treatment to improve health and safety attributes of foods. A review. *Food Res. Int.,* 77, 725-742.

Bhuiyan, M.S., Hossain, M.A., & Rahman, M.M. 2021. Adoption of Food Irradiation in Developing Countries: A Case Study of Bangladesh. *Int. J. Food Sci.*, 2021, 1-10.

Chemat, F., Rombaut, N., Sicaire, A.G., Meullemiestre, A., Fabiano-Tixier, A.S., Abert-Vian, M. 2017. Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. *Ultrason. Sonochem.,* 34, 540-560.

Diehl, J. F. (1995). Safety of irradiated foods. *CRC Press.*

European Commission (EC) (2000-2019). Annual reports-Food Irradiation.

Eustice, R. 2020. Global Status and Commercial Applications of Food Irradiation. *Food Irradiation Research and Technology*, 2nd Edition, Wiley-Blackwell.

Eustice, R.F. 2011. Food Irradiation: A Global Perspective and Future Prospects.

Farkas, J. (2006). Irradiation for Better Foods. *Trends Food Sci. Technol.*, 17(4), 148-152.

FAO/IAEA. 2020. Food Irradiation: A Technique for Preserving and Improving the Safety of Food. *Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.*

Fellows P.J. 2018. Food Processing Technology: Principles and Practices, 79-280.

Follett, P.A. 2004. Irradiation to control insects in fruits and vegetables for export from Hawaii. *Radiat. Phys. Chem.,* 71, 161-164.

Follett, P.A., Weinert, E.D. 2012. Phytosanitary irradiation of fresh tropical commodities in Hawaii: Generic treatments, commercial adoption, and current issues. *Radiat. Phys. Chem.,* 81(8), 1064-1067.

Frenzen, P.D., Majchrowicz, T.A., Buzby, J.C., Imhoff, B. 2000. Consumer acceptance of irradiated meat and poultry products (No. 1474-2016-120892).

Hallman, G.J. 2011. Phytosanitary applications of irradiation. *Compr. Rev. Food Sci. Food Saf.,* 10(2), 143-151.

Hossain, M. A., Bhuiyan, M. S., Rahman, M. M. 2018. Post-Harvest Losses in Bangladesh: A Critical Review. *J. Agric. Sci.*, 10(3), 45-56.

Hvizdzak, A.L., Beamer, S., Jaczynski, J., Matak, K.E. 2010. Use of electron beam radiations international review of food science and technology (winter 2004/2005) an international union of food science and technology (IUFOST).

Ic, E., Cetinkaya, N. 2021. Food safety and irradiation related sanitary and phytosanitary approaches-Chinese perspective. *Radiat. Phys. Chem.*, 181, 109324.

Institute of Radiation & Polymer Technology (IRPT), Bangladesh Atomic Energy Commission (BAEC) 2011-2023). Annual report.

Institute of Food and Radiation Biology (IFRB), Bangladesh Atomic Energy Com-mission (BAEC) (2018-2023). Annual report.

Institute of Food Science and Technology. Food irradiation. Available online: http://www.ifst.org/print/118 (accessed on June 2015).

International Atomic Energy Agency (IAEA). Consumer acceptance and market development of irradiated food in Asia and the Pacific. IAEA TECDOC-1219. In Proceedings of the Final Research Co-Ordination Meeting, Leuven, Belgium, 24–28 September 2001; pp. 17–19.

Kume, T., Furuta, M., Todoriki, S., Uenoyama, N., Kobayashi, Y. 2009. Quantity and economic scale of food irradiation in the world. *Radioisotopes*, 58(1), 25-35.

Kume, T., Furuta, M., Todoriki, S., Uenoyama, N., Kobayashi, Y. 2009. Status of food irradiation in the world. *Radiat. Phys. Chem.*, 78(3), 222-226.

Kume, T., Todoriki, S. 2013. Food irradiation in Asia, the European Union, and the United States: A status update. *Radioisotopes*, 62(5), 291-299.

Maherani, B., Hossain, F., Criado, P., Ben-Fadhel, Y., Salmieri, S., Lacroix, M. 2016. World market development and consumer acceptance of irradiation technology. *Foods*, 5(4), 79.

Marcotte, M., Kunstadt, P. 1993. Acceptance of irradiated food by North American consumers. *Radiat. Phys. Chem.*, 42(1-3), 307-311.

Marshall, R., Stilchelbaut, F. 2009. Radiation processing with high energy X-rays. *Association of Brasileria De Energia Nuclear*, 84, 91-99.

Molins, R. A. 2001. Introduction. In R. A. Molins (Ed.), Food irradiation: Principles and applications. New York: Wiley Interscience, 1, 1-21.

Pereira, R.N., Vicente, A.A. 2010. Environmental impact of novel thermal and non-thermal technologies in food processing. *Food Res. Int.*, 43(7), 1936-1943.

Ramos, B., Miller, F.A., Brandão, T.R.S., Teixeira, P., Silva, C.L.M. 2013. Fresh fruits and vegetables—An overview on applied methodologies to improve its quality and safety. *Innovative Food Science & Emerging Technologies*, 20, 1-15.

Roberts, P. B. 2014. Food Irradiation: Standards, Regulations, and World-Wide Trade. *Radiat. Phys. Chem.*, 105, 78-82.

Suresh, P., Leslie, A., Braby, L. 2005. Introduction to electron beam food irradiation. *Chemical Engineering Progress*, 112(11), 36-44.

Tiwari, B.K., O'Donnell, C.P., Cullen, P.J. 2009. Effect of non-thermal processing technologies on the anthocyanin content of fruit juices. *Trends Food Sci.Technol.*, 20(3-4), 137-145.

Wang, K., Pang, X., Zeng, Z., Xiong, H., Du, J., Li, G., Baidoo, I. K. 2023. Research on irradiated food status and consumer acceptance: A Chinese perspective. *Food sci. nutr.*, 11(9), 4964-4974.

WHO. 1981. Wholesomeness of Irradiated Food. *World Health Organization Technical Report Series*, 659.