


Food irradiation: an effective but under-utilized technique for food preservations

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Abstract While food borne pathogens constitute a major public health problem world-wide, food post-harvest losses is considered to be the leading cause of hunger and malnutrition globally. Food irradiation is a process of preserving food in which food are exposed to appropriate doses of ionizing radiation in order to kill insects, molds and other potentially harmful microbes and allergens. The process involves carefully exposing food to a measured amount of ionizing radiation in a special processing room on a conveyor belt for a specified duration. The radiation sources could be gamma ray, electron beam or X-ray. The radiation doses could be high, low or medium depending on the products to be irradiated and the target organism to be eradicated. Irradiation technology has various applications including sprout inhibition in root and tubers, disinfestation in cereals and pulses, reduction or elimination of food borne pathogens in vegetables and animal products and delayed ripening of fruits. All these applications are intended to increase shelf life and eliminate food allegenicity. Despite consumer concern on the safety and quality of irradiated foods, it is gradually gaining acceptance due to increased awareness and the perceived safety and quality as symbolized by the Radura symbol. With the increasing acceptance and commercialization of food irradiation, it could play an important role in solving the problems of food insecurity and food borne illnesses in the world.

Keywords Irradiation · Ionizing radiation · Preservation · Disinfestation · Sprout inhibition

Abbreviations

CCR	Centre for Consumers Research
DNA	Deoxyribonucleic acid
FOA	Food and Agriculture Organization
IAEA	International Atomic Energy Agency
kGy	Kilo gray
MeV	Milli-electron volt
WHO	World Health Organization

Introduction

The growth and advancement in farm machineries and hybridoma technology have led to a global increase in food production. This has led to an increased demand in food preservation techniques for effective large scale storage and processing of food (Singh and Singh 2019). About 25% of agricultural products are lost annually world-wide during post-harvest storage, marketing and transportation (Singh and Singh 2019). While sprouting accounts for most of losses in bulbs and tubers, microbial contamination and pest infestation are responsible for the spoilage and reduced quality of grains, spices, fruits, vegetables and meat products (Farkas 1998; Mostafavi et al. 2012). Food preservation involves different processes, methods and technologies to prevent food spoilage and decay, preserve food quality and extend shelf-life. The conventional methods for food preservation includes drying, freezing, use of chemicals, smoking, pickling and canning among others (Nunmer 2002; Prakash 2020). While some of the methods are specific to certain food types, others may be applied on two or more products (Kim et al. 2022). The seasonal nature of production, long

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distances between the production sites and consumption centers and the rising gap between demand and supply have posed great challenges to the conventional methods of food preservation (Kalyani and Manjula 2014). Despite the different methods of food preservation, food borne illness still constitute a global public health problem affecting over 600 million people every year (WHO 2020).

Foodborne illnesses (FBI) result from the consumption of food contaminated with micro-organism, chemicals or toxins. Some of the contaminants are constituents of food while others are added during production, processing and/or storage (Hoffmann and Scallan 2017). The World health organization (WHO) estimated that one in every ten people get ill from microbial or chemical contaminated food in 2010, resulting in about 420,000 global deaths (Havelaar et al. 2015). The burden of FBI is more in underdeveloped and developing countries with about 1300 disability-adjusted life-years (DALYs) per 100,000 people in low-income countries of Sub-Saharan Africa. However, the burden is low in developed countries with 35 DALYs per 100,000 people in high-income countries of North America (WHO 2015). Despite the efforts by many countries to study the national burden of FBI for proper intervention and control, several low and middle-income countries still lacked the political willingness, technical expertise and financial resources to estimate the burden of FBI (Pires et al. 2021).

Food irradiation is a process of exposing food to appropriate doses of ionizing radiation in order to kill insects, molds and other potentially harmful microbes for the purpose of preservation and safety (Mohamed 2016; Pan et al. 2021). The radiation sources could be gamma ray, high energy electron beam or X-ray (Olszyna-Marzys 1992). Irradiation does not significantly affect the chemical composition of food. However, the process may lead to the reduction of some vitamins which is also applicable in the other traditional methods of food preservation such as drying, smoking and canning (Singh and Singh 2019). The United Nations Food and Agriculture Organization (FAO) in collaboration with the WHO and International Atomic Energy Agency (IAEA) has been working to ascertain the quality and safety of irradiated food items. Their report showed that, irradiation alone or supplemented with other methods of food preservation could prevent insect infestation and microbial growth in food thereby extending their shelf-life (IAEA 2015). Irradiation is an old technique with a wide range of applications in food preservation. It has not been widely accepted due to fear of food quality and safety with regards to possible mutation of insects and pathogens that might produce radiation-resistant strains (Farkas 1989; Andrews et al. 1998). Other factors affecting the commercial implementation of food irradiation in many countries include; consumer advocacy and the risk of radiation accident. In recent times, irradiation technology is gradually gaining acceptance due to the increasing

knowledge of the process and the perceived safety and quality of the products. In 2019, it was reported that irradiation of agricultural products is carried out in more than 60 countries of the world and more than 200,000 tons of irradiated products are produced annually in Europe (Obodovskiy 2019). In spite of the increasing acceptance of irradiation technology across the globe, irradiated food products are still not available in many low and middle-income countries due to lack of awareness and low standard of living. Therefore, there is need for more awareness on the principles and applications of food irradiation using different techniques and how it can be applied in the control and prevention of foodborne illnesses. The review highlights the principles and applications of irradiation technique in food preservation. It addresses the process of food irradiation using gamma ray, electron beam and X-ray including a schematic representation of the whole process. It also, states the benefits and limitation of food irradiation and explains the Radura symbol as a mark of quality and safety of irradiated food.

Radiation sources

Radiation is the energy that travels through space or matter in form of electromagnetic or particulate wave (Okafor et al. 2021). It is often referred to as “ionizing radiation” because it produces rays or particles strong enough to dislodge electrons from atoms and molecules, converting them to electrically charged ions (Ashfaq et al. 2020). In food irradiation, three principal types of ionizing radiation source can be used;

- (i) Gamma radiation: They are electromagnetic radiation emitted from radioactive forms of the element cobalt (Cobalt-60) or from Cesium (Cesium-137). Unlike cesium-137, small amount of Cobalt-60 is required. In addition, Cobalt-60 is insoluble in water and constitute less or no environmental hazard. Hence, it is commonly used in food irradiation and applicable on all agricultural products (Fellows 2018). Gamma radiation is recognized as the only energy efficient means for cold pasteurization (O’Bryan et al. 2008). Due to the extensive shielding to prevent radiation and the possible hazards on human health associated with gamma radiation, electron beam and X-rays are gaining more acceptance as an alternative (Zehi et al. 2020).
- (ii) Electron beams: This is a stream of high-energy electrons propelled from an electron accelerator with energies up to 10 MeV. Electron beams are cheap and has low penetrating depth. In addition, it does not require a radioactive source and can be switched off when not in use (Ashraf et al. 2019). Electron

beam irradiation is preferred to gamma irradiation because it poses little or no health hazard, consist of a non-nuclear energy source that can generate radiation when needed and its application in high-flow and high-dose radiation (Clemmons et al. 2015). Electron beam irradiation can be applied on all kinds of food including fruits and vegetables, cereals, meat, seafood and dairy products (Praveen et al. 2013; Kim et al. 2014; Nemtanu et al. 2014; Lung et al. 2015).

- (iii) X-rays: They are produced by reflecting a high-energy stream of electrons off a target substance with electron energies up to 5 MeV. X-rays have high penetrating power. Just like electron beams, they are not from a radioactive source and can be switched off when not in use but they are very expensive (Abdulkadir 2019). Recently, the X-ray has proven to be viable in microbial reduction due to its minimal environmental impact, efficacy and possibilities of direct installation in commercial processing lines. Additionally, the ability to switch off the machine when not in use allows for more effective large-scale processing and better regulation (Moosekian et al. 2012). The X-ray has been applied for microbial reduction in vegetables, seafood and dairy products (Jeong et al. 2010; Moosekian et al. 2012).

Process and principles of food irradiation

The processes involved for irradiating foods in all the three sources of radiation are the same. As it involves carefully exposing the food to a measured amount of ionizing radiation. This is done in a special processing room (Irradiation room) on a conveyor belt for a specified duration. The food to be irradiated is placed on a conveyor belt at the loading site. The conveyor belt moves the food to the irradiation room where it passes through a measured amount of ionizing radiation for a specific time frame after which the conveyor belt moves the food to the unloading site (Fig. 1). The radiation source, level and time of exposure depend on the type of food, the target pest/microorganisms and how long the food will last before consumption (Ehlermann 2014). The radiation beam (electrons, gamma rays, or X-rays) that passes through the food breaks chemical bonds, kills pest and damages the DNA of microorganism rendering them inactive and incapable of reproducing. These prevents spoilage and extend shelf life maintaining the flavor and texture of most agricultural products (Bisht et al. 2021). Most agricultural products are irradiated in gamma facilities. The principle involves the use of Cobalt-60 to emit rays with energy up to 1.33 MeV. When not in use, the sources of radiation are stored under water to absorb energy and prevent exposure (Greenwood 2017). In electron beam facility, electron beams are generated by accelerating a stream of electrons focused on a narrow beam-spot. Due to the low penetrating depth and high dose levels of electron beams, they are mostly used to inactivate pathogens in food (Ashraf et al. 2019). In X-ray facilities, a machine generated

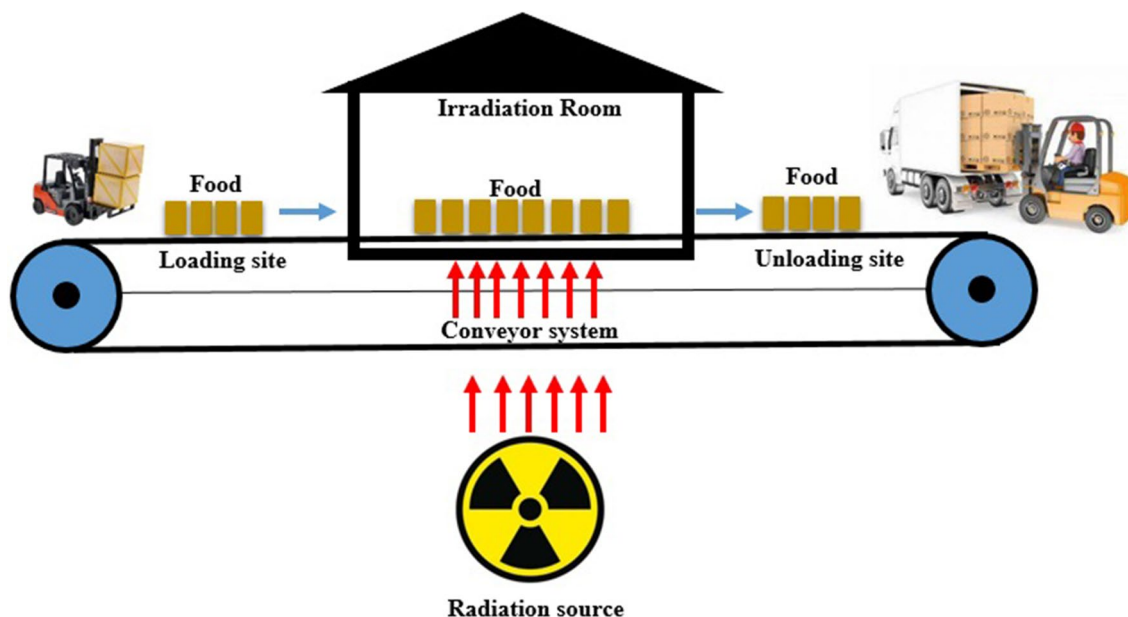


Fig. 1 Process of food irradiation: The food is loaded on a conveyor system which transport it to irradiation room where it is exposed to the required amount of radiation for a certain period of time after which the conveyor takes it to the unloading site for removal and onward storage

high velocity electrons bombards a heavy metal such as tungsten to generate streams of X-rays. X-ray can be used to irradiate large amounts of food items but few products are irradiated using this process (Follet 2014).

Applications of various ionizing radiation dose levels in food preservation

The use of ionizing radiation in food preservation employ three different approaches, these includes; low doses, ≥ 1 kilogray (kGy) to inhibit sprouting of bulbs and tubers and delay ripening of fruit, medium doses (1–10 kGy) to partially destroy food pathogens and increase shelf-life, and high doses (> 10 kGy) for complete destruction of microorganisms and sterilization of food products. For convenience, trade names have been given to these three range of radiation doses based on their desired function (Satin 1993).

- (i) Radurization is the use of ionizing radiation doses sufficient to increase shelf life by reducing the number microorganisms to the barest minimum. This amount depends on food type because spoilage varies from commodity to the other. The doses of < 2.5 kGy is used in this process and is considered low dose. This dose range is applied to delay fruit ripening, inhibit sprouting in tubers and for insect control in fresh vegetables and grains (Marapana and Wijetunga 2009).
- (ii) Radicidation is the irradiation treatment that is required to reduce the level of non-spore-forming pathogens, yeast and molds to an undetectable level, thereby reducing the risk of food borne disease to near zero. This level of irradiation is generally considered in the medium range between 2.5–5 kGy and may vary depending on the product and possible suspected pathogens. Food are usually stored at < 4 °C to prevent spore formation and can be applied on meat seafood and shell eggs (Erkmen and Bozoglu 2016).
- (iii) Radappertization is the highest level of radiation doses used, usually > 10 kGy targeted at eliminating spore forming pathogens. This doses are required to achieve sterility of agricultural products and shelf stability attainment (Andrews et al. 1998). This can be applied to sterilize frozen and packaged meat and for microbial control in herbs and spices (Oslon 1998).
- (i) Sprouting inhibition: Food irradiation technique can be used to reduce rotting and prevent sprouting in potatoes, garlic, onions, ginger and yam (Acheson and Steele 2001). This technique has advantage over refrigeration which is expensive especially in developing countries where there is poor source of electricity. It is also better than the relatively cheap chemical treatment which maybe hazardous (Kalyani and Manjula 2014).
- (ii) Disinfestations: Food irradiation technique is applied to prevent insect and pests infestation in cereals, pulses and dried fruits. This method does not leave chemical residue in food, therefore it is preferable to the use of chemicals that may pose health and environment hazards (Hallman and Blackburn 2016; Guclu 2022). It is also more effective than the conventional storage in air tight containers with may still harbor some insects.
- (iii) Food borne pathogens: Food irradiation technique is applied to destroy food pathogens in Spices, fruits and vegetables thus reducing the incidence of food borne diseases (Bintsis 2017). While overcooking vegetable destroy some vital vitamins, spices are exposed to micro-organisms during processing and drying. Irradiation will prevent the nutrient deficiency in overcooked vegetables and destroy microbes in spices.
- (iv) Shelf-life extension: Shelf life of various food items can be extended significantly with irradiation. This is applicable in fruits, meat, chicken and fish. It was reported that irradiating fruits before ripening further extent their shelf-life (Mostafavi et al. 2010).
- (v) Irradiation does not kill viruses. However, it can inactivate viruses when supplemented with heat (Koopmans and Duizer 2004).
- (vi) Quarantine: Irradiation technique can be applied on fruits and vegetables using low dose to reduce the number of microorganism.

Applications of food irradiation on different food items

Food irradiation technique is applied to different agricultural products for sprout inhibition, insect disinfestation, pathogen reduction and shelf life extension among others (Fig. 2).

Packaging and labelling of irradiated foods

If the process is intended to control microorganism or pest infestation, the products are packaged before irradiation to prevent recontamination or re-infestation. Since the materials used for packaging are exposed to radiation during the treatment, these materials must be radiation resistance and should not transmit toxic substances into food nor affect the products flavor and texture. The materials used for packaging depends on the level of radiation doses (Verde et al. 2013).

Labelled irradiated food allow consumers to choose between irradiated and non-irradiated products. It may also prevent the irradiation of already irradiated product and

Fig. 2 Different applications of food irradiation: shelf life extension; disinfestation; pathogen reduction; quarantine and sprout inhibition



control the export of irradiated foods to countries that ban irradiation (Barkai-Golan and Follet 2017). The ‘‘Radura’’ symbol indicates irradiation (Fig. 3). The Radura symbol is usually green in colour and consist of a plant-like structure within a circle. The lower half of the circle is complete while the upper half has broken lines. The plant-like structure represents agricultural products while the broken lines in the upper half of the circle indicates penetrating ionizing radiation. Complementary information may be added to indicate the benefits of irradiation or supplementation (FDA 2008).



Fig. 3 The Radura symbol of irradiated food

Benefits of food irradiation technique

- (i) Irradiation does not induce any radioactivity in food and does not leave any harmful or toxic radioactive residues on foods as is the case with chemical fumi-

gants. Therefore, irradiation can replace chemical fumigants for disinfestation and microbial control in many agricultural products especially grains.

- (ii) Irradiation does not change food texture, flavor or color. Therefore, Irradiated foods cannot be identified by sight, smell, or taste (Barkai-Golan and Follet 2017).
- (iii) Irradiation use one process for different commodities which is not applicable with the other methods of food preservation. In other food preservation techniques, the process depends on the type of food while in irradiation, the same process using different radiation doses is applied.
- (iv) Irradiation can supplement other methods of food preservation for better quality and safety of products.
- (v) Irradiation does not significantly affect the nutritional content of food. The chemical and physicochemical properties of cowpea, almond, millet and sunflower were reported to be preserved following irradiation (Friday 2020). The technique can also be applied on packed foods to prevent recontamination.
- (vi) Irradiation can increase the shelf life of fruits, root, bulbs and tubers by delaying ripening in fruits and preventing sprouting in root, bulbs and tubers.
- (vii) Irradiation can eradicate harmful food borne bacteria such as *Shigella*, *Escherichia coli*, staphylococcus and *Salmonella* (Yousefi and Razdari 2015).
- (viii) The radiation processing facilities are environmental friendly, safe to workers and the general public (Anki 2019). Everyone can have access to the radiation protection regulations and the principles and/or processes involve in irradiation.
- (ix) Considering the allergenic properties of sulphur compounds, irradiation is considered as an alternative to sulphurization for yeast elimination in wine. An irradiation dose of 2.5 KGy was reported to eliminate 99.9% of yeast with slight reduction of polyphenols content and little influence on wine colour compared to Ozonation that cause a significant reduction in

polyphenols with negative impact on wine colour and organoleptic properties (Blaszak et al. 2019).

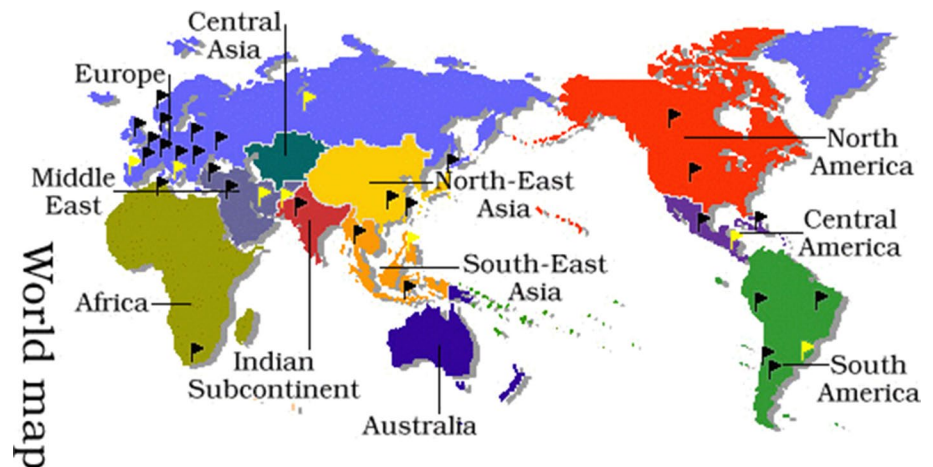
Limitations of food irradiation technique

- (i) Food irradiation is a highly controlled and regulated process. Therefore, only foods which specific benefits are achieved by irradiation using appropriate doses are permitted (Anki 2019).
- (ii) Some spore-forming bacteria such as *Bacillus* and *Clostridium* species are radiation resistant. Hence, radiation doses below 10 kGy can only reduce the number of spores. However, irradiation can be applied with freezing to prevent the growth of spores (Markland and Hoover 2016).
- (iii) Irradiation is not suitable for some fruits and vegetables such as tomatoes, grapes and cucumber due to reduction in some vitamins and possible loss of colour and texture (Hwang et al. 2015; Mohamed 2016).
- (iv) Irradiation of lipid products such as egg and dairies using high doses in an oxygen rich environment can lead to hydrogen peroxide formation. Thus, resulting to unpleasant odour and flavour (Feng et al. 2017; Ham et al. 2017).

Consumer concerns and acceptance of irradiated food

Consumers' perception could play an important role on the acceptance and use of irradiated food. Also, flavor, nutritional content and presence or absence of additives largely determines the acceptance rate of the products (Bruhn 2007; Maherani et al. 2016). With regards to novel food

Fig. 4 World map showing Countries with commercial food irradiation (black flag) and approval for food irradiation (yellow flag). *Source:* Centre for Consumers Research (2017)



preservation technologies like irradiation, nature of the resultant products as well as contextual and sociocultural attributes are the driving forces for consumer acceptance (Cardello 2003). The major consumer concerns on irradiated foods is the fear of possible mutation of pathogens and parasite resulting in a radiation resistance strain and the speculations that irradiated food may be radioactive (Andrews et al. 1998). The quality and safety of irradiated food can be properly assessed if irradiated foods are compared with food preserved using other methods of preservation. The comparison should focus on food irradiated at the dose level employed for commercial use. Many countries have accepted the irradiation technology and irradiated food are produced and sold in America, Europe, Middle East and some parts of Africa and Asia (Fig. 4).

Conclusion

Irradiation technique can be applied on a number of agricultural products in order to prevent spoilage and increase shelf life. The process involves exposing food to appropriate amount of ionizing radiation. Despite consumer concern on irradiated foods, it is gradually gaining acceptance globally. This was attributed to the increasing knowledge and the perceived safety and quality of the products. While food borne pathogens constitute a major public health problem worldwide, food post-harvest losses is considered to be the leading cause of hunger and malnutrition globally. Therefore, commercial food irradiation could play an important role in solving the problems of food insecurity and food borne illnesses in the world.

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Declarations

Competing interests The authors declare that they have no competing interests.

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Consent for publication Not applicable.

Ethics approval Not applicable.

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