



An overview of irradiation as a food preservation technique

Ola Joshua Ajibola

Department of Microbiology, Faculty of Life Sciences, Kebbi State University of Science and Technology, Aliero
Kebbi State, Nigeria

Corresponding author E-mail: joshuaajibola5@gmail.com

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Abstract

Food irradiation is a process whereby food is exposed to a carefully measured amount of intense radiant energy, called ionizing radiation. The ionizing radiation has the ability to break the chemical bonds. Irradiation can kill harmful bacteria and other microorganisms in meat, poultry and seafood. Moreover, it can disinfest spices, extend shelf-life of fresh fruits and vegetables, and control sprouting of tubers and bulbs such as potatoes and onions; thus, can be used as a food preservation method. It is a safe process that has been approved by the U.S. Food and Drug Administration (FDA), and more than 60 of other national food control authorities for many types of foods. There are three types of ionizing radiation that can be potentially used in food irradiation including; Gamma rays from Cesium 137 (^{137}Cs) or Cobalt 60 (^{60}Co), X-rays generated from machine sources operating at or below energy level of 5 MeV; and Electrons generated from machine sources operating at or below an energy level of 10 MeV (also known as E-Beam). During the radiation processing of foods, the doses are generally measured in kilograys ($\text{kGy} = 1,000 \text{ Gy}$). The DNA is very sensitive to irradiation; therefore, food irradiation cause damage to the microbial cells through direct or indirect action on the DNA molecules. However, the accurate dose of food irradiation process is essential to ensure food preservation and safety. This review aimed to provide information on the principles of food irradiation, effect of irradiation on food contaminating microorganisms, and some limitations to its greater use as food preservation method in Nigeria.

Keywords: Food preservation, Food irradiation, Ionizing radiation, DNA, Nigeria

1. Introduction

Food preservation usually involves preventing the growth of bacteria, fungi (such as yeasts), or other microorganisms (although some methods work by introducing benign bacteria or fungi to the food), as well as retarding the oxidation of fats that cause rancidity. Food preservation may also include

processes that inhibit visual deterioration, such as the enzymatic browning of apples after they are cut during food preparation ([Akinloye et al., 2015](#)).

A recent study conducted by [Shafia et al., \(2019\)](#) highlighted that consumers expect that the food they

eat must be safe, and also wants it to have high nutritional value with minimal preparation times, as evidenced by the increase in using several products such as ready to eat food, and minimally processed fresh produce. In order to meet these demands, food manufacturers are looking for new methods and technologies for preserving it.

For many centuries, great effort has been devoted to finding ways of preserving food and protecting it from microorganisms, insects and other pests. Drying was most likely one of the first techniques developed. Heating, fermentation (acid or alcohol preservation), salting and smoking also have long histories of use in food preservation ([Audia, 2010](#)). Later recent techniques involve the use of preservatives other than salt including; heat pasteurization, canning, freezing, refrigeration, ultrahigh hydrostatic pressure, electrical conductivity heating, pulsed electrical fields and crop-protecting chemicals. [Paisan, \(2003\)](#) reported that all these methods have played a major role in improving the quality, quantity and safety of food supplies, through protecting it from destruction, microbial contamination and spoilage.

Food irradiation is a technology that can be used to enhance food safety and quality. According to [Farkas, \(2004\)](#), irradiation of food is the process of exposing food to a carefully controlled amount of energy in the form of high-speed particles or rays. This occurs widely in nature, which involve the energy reaching the earth from the sun. The various applications of food irradiation are presented in Table (1), in reference to [Fellows, \(2016\)](#).

[Paisan, \(2003\)](#) demonstrated that food irradiation, being a cold process, can be used to inactivate spoilage and disease-causing bacteria in solid foods such as meat, poultry, seafood, and spices. Moreover, it can also kill insect eggs and larvae in fresh fruits and vegetables without changing the foods' quality. Its ability to inactivate pathogenic bacteria in frozen food is unique. Since irradiation is a cold pasteurization process, foods remain in the same physical state after irradiation as before. The public acceptance of food

irradiation has been less than enthusiastic in some countries ([Shafia et al., 2019](#)). Fears of the thermonuclear war and accidents have made many people apprehensive about the use of nuclear energy for any purpose, even if desirable such as improving the quantity and quality of food. Such apprehension is attributed to the lack of information, and confusion between irradiation and contamination with radioactivity.

The Food and Drug Administration (FDA) approved irradiation as an effective food quality technique for preservation and increasing the storage life of many food products such as; meat, fresh fruits, vegetables and spices ([Ganguly et al., 2012](#)). A previous study revealed that irradiation is also used for delaying and/or inhibiting sprouting and ripening processes of certain fruits and vegetables. The effects of irradiation on the food and on the animals and people eating these irradiated foods have been studied extensively, and results showed clearly that irradiation process is approved for application on foods. Categories and names of foods permissible to be irradiated are presented in Table (2), according to [NAFDAC. \(2019\)](#).

The objectives of this review were to provide information on food irradiation, sources, effect on food borne microbial pathogens, and some limitations of its excessive use as a food preservation process.

2. Food irradiation

The process of food irradiation is called “cold pasteurization” because it kills harmful bacteria without the use of heat ([Inabo, 2006](#)). Similar to the other microbial inactivation processes such as heat pasteurization, irradiation cannot reverse the spoilage of food. Accordingly, safe food handling and good manufacturing practices are required for managing the irradiated food just as for other foods, as highlighted by [Paisan, \(2003\)](#).

[Margaret, \(2005\)](#) reported that from the microbiological point of view, food irradiation can be used to reduce the number of pathogens and spoilage

Table 1: Applications of food irradiation ([Fellows, 2016](#))

	Application	Dose (kGy)
Low dose (up to 1 kGy)	Inhibit sprouting (potatoes, onions, yams, garlic)	0.06 - 0.2
	Delay in ripening (strawberries, potatoes)	0.5 - 1.0
	Prevent insect infestation (grains, cereals, coffee beans, spices, dried nuts, dried fruits, dried fish, mangoes and papayas)	0.15 - 1.0
	Parasite control and inactivation (Tape worm, Trichina)	0.3 - 1.0
Medium dose (1 kGy to 10 kGy)	Extend shelf-life (raw and fresh fish, seafood, fresh produce, refrigerated and frozen meat products)	1.0 - 7.0
	Reduce risk of pathogenic and spoilage microbes (meat, seafood, spices, and poultry)	1.0 – 7.0
	Increased juice yield, reduction in cooking time of dried vegetables	3.0 – 7.0
High dose (above 10 kGy)	Enzymes (dehydrated)	10.0
	Sterilization of spices, dry vegetable seasonings	30.0 max
	Sterilization of packaging material	10.0 - 25.0
	Sterilization of foods (National Aeronautics and Space Administration, NASA, and hospitals)	44.0

Table 2. Categories and names of foods permissible to be irradiated, according to [NAFDAC. \(2019\)](#) (National Agency for Food and Drug Administration and Control) regulations

Classes of Food	Purpose	Required Dose (kGy)
Class 1: Bulbs, roots, and tubers (Onions, Yams and Potatoes).	To inhibit sprouting during storage	0.2
Class 2: Fresh fruits and vegetables (other than class 1) i.e. Plantains and mangoes.	(a) to delay ripening (b) insect disinfestations (c) Shelf-life extension (d) Quarantine control	1.0 1.0 1.0 1.0
Class 3: Cereals and their milled products, nuts, oil seeds, pulses and dried fruits. Beans, maize, millet, sorghum, cocoa and kola.	(a) Insect disinfestations (b) Reduction of microbial load	1.0 5.0
Class 4: Fish, seafood, and their product (fresh and frozen).	(a) Reduction of Pathogenic microorganisms (b) Shelf-life extension (c) Control of infection by parasites	5.0 3.0 2.0
Class 5: Raw poultry and meat, their products (fresh and frozen), Chicken, Turkey, Beef etc.	(a) Reduction of pathogenic microorganisms, (b) Shelf-life extension (c) Control of infections by parasites	7.0 3.0 2.0
Class 6: Dry vegetables, spices and condiments, animal feeds, dry herbs, and herbal teas, pepper.	(a) Reduction of certain pathogenic microorganisms (b) Insect disinfestations	10.0 1.0
Class 7: Dried food of animal origin, smoked fish, dried meat, stockfish.	(a) Insect disinfestations (b) Control of mould	1.0 3.0
Class 8: Miscellaneous food including but not limited to; honey, space foods, hospital foods, military rations, spices, liquid eggs and thickeners.	(a)Reduction of microorganisms; (b) Sterilization; (c) Quarantine control	< 10 < 10 < 10

microorganisms; leading to an extended shelf-life and reduction in waste food due to spoilage. [Inabo, \(2006\)](#) added that irradiated foods are not radioactive as the rays do not remain in the food.

The irradiation facility consists of a room with concrete walls that has the radiation source (Co-60 or Cs-137) in an industrial layout. The gamma radiation source consists of Cobalt-60 rods in stainless steel tubes. These tubes are raised into the concrete irradiation chamber to treat the food. Gamma rays have short wavelengths and high frequencies, thus penetrate the food so rapidly with little or no produced heat ([Inabo, 2006](#)).

In 1981, the Food and Agricultural Organization (FAO), the International Atomic Energy Agency (IAEA), and the World Health Organization ([WHO, 1999](#)), and the Joint Expert Committee on the Wholesomeness of Irradiated Food (JECFI) concluded that "irradiation of food product up to an overall average dose of 10 kiloGray (kGy) has no toxicological hazard; thus toxicological testing of

treated foods is no longer required". Moreover, the expert committee demonstrated that irradiation of food up to 10 kGy" causes no nutritional or microbiological problems ([Margaret, 2005](#)).

3. Principles of food irradiation

3.1. Radiation sources

In accordance with the General Standard for Irradiated Foods (CODEX STAN 106-1983), there are three types of ionizing radiation (Fig. 1), which can potentially be used in food irradiation, according to [NAFDAC. \(2019\)](#):

1. Gamma rays from the radionuclides of Cesium 137 (^{137}Cs) or Cobalt 60 (^{60}Co);
2. X-rays generated from machine sources operated at or below energy level of 5MeV; and
3. Electrons generated from machine sources operated at or below an energy level of 10 MeV (also known as E-Beam).

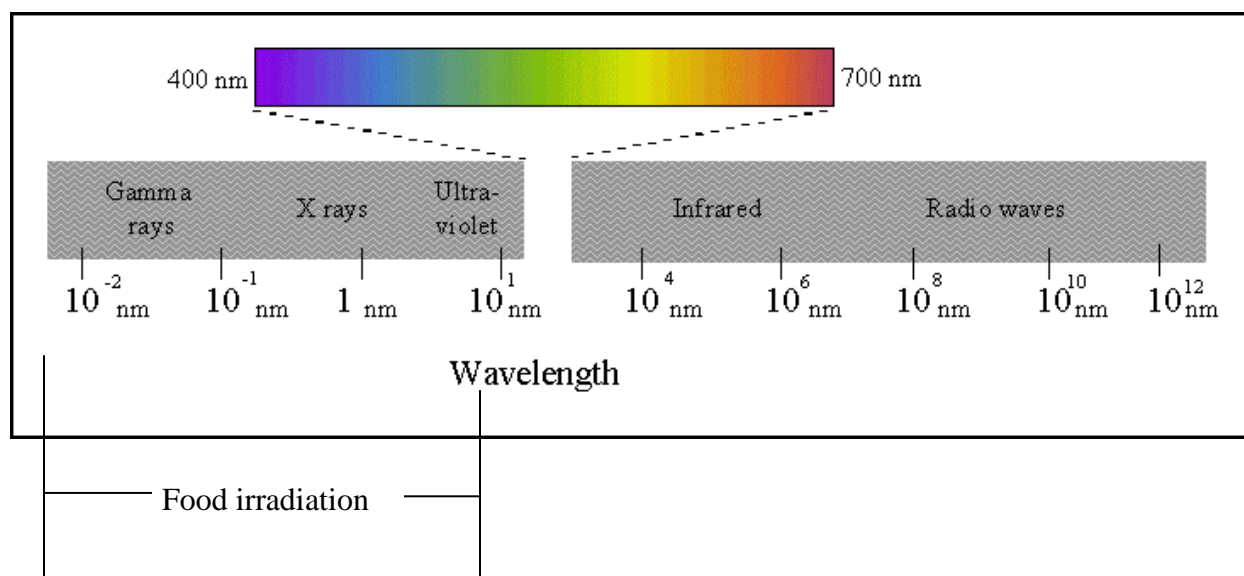


Fig. 1: Wavelength spectrum of the electromagnetic waves

3.2. Dosage of irradiation

In reference to [Ganguly *et al.*, \(2012\)](#), the dose of radiation is measured using the International System of Unit (SI Unit) known as the gray (Gy). One gray of radiation is equal to 1 joule of energy absorbed per kilogram of food material. In processing of radiated foods, the doses are generally measured in kilograys (kGy = 1,000 Gy). The average dose of the absorbed radiation by a processed food should be less than 10 kGy. However, the maximum permissible dose of an irradiated food should not exceed 150% of the minimum dose, to achieve the desired effect and avoid overdose ([NAFDAC. 2019](#)).

4. Labeling of irradiated food

With provisions of Recommended International code of practice for the operation of irradiation facilities used for the treatment of foods, The [Codex Alimentarius Commission \(CAC/RCP-19-1979, Rev. 1-1983\)](#): all irradiated foods, foods containing irradiated components, or processed foods prepared from irradiated materials to be imported, exported, advertised, distributed, stored, manufactured and sold, shall have label of the Food irradiation logo (Fig. 2) on the package. This logo is known as The RADURA symbol. The word "Radura" is derived from radurization, in itself a portmanteau combining the initial letters of the word "radiation" with the stem of "durus", the Latin word which means hard, lasting ([Ehlermann, 2009](#)). This is in addition to the inscription boldly written as "Preserved by irradiation" and "not to be re-irradiated".

5. Effect of irradiation on the food contaminating microorganisms

Microorganisms vary greatly in their response to irradiation. Viruses and spore forming bacteria are being the most resistant, followed by yeasts and



Fig. 2: The RADURA symbol ([NAFDAC. 2019](#))

mold fungi; however, the vegetative bacteria are being more sensitive ([Margaret, 2005](#)). Similarly, a previous study of [Forsythe, \(1998\)](#) demonstrated that any preformed bacterial or fungal toxins will be highly resistant to irradiation, as they do not contain any genetic materials.

The efficacy of a given dose of irradiation against microorganisms depends on:

1. The kind and species of the microorganism;
2. The numbers of the microorganisms (or spores) originally present, thus the more the number of these microorganisms, the less effective will be a given dose;
3. The composition of the food, some constituents such as; proteins, catalase, nitrites, sulfites and sulfhydryl compounds may be protective, but compounds which combine with the sulfhydryl (SH) groups would be sensitizing;
4. The presence or absence of oxygen, the effect of free oxygen varies with the type of the microorganism;
5. The physical state of the food during irradiation, both of the moisture content and the temperature affect the various microorganisms in different ways;

6. The growth conditions of the microorganisms including; the age, temperature of growth and sporulation and;

7. The state of growth (vegetative or spore), may affect the sensitivity of the microorganisms to the radiation.

The DNA is very sensitive to irradiation. Therefore, the use of irradiation causes detrimental damages to DNA of the microorganisms in the foods. [Forsythe, \(1998\)](#) documented that inactivation of bacteria, yeasts and mold fungi mainly results from damage to the DNA, accordingly the different sensitivities of these microorganisms to irradiation are a reflection of the efficiency of their DNA repair systems.

6. Mechanisms of action of irradiation

Damage of the microbial cell induced by irradiation may be attributed to the direct or indirect effects of radiation on the DNA molecules.

6.1. Direct action

[Omar et al., \(2015\)](#) reported that in the direct mode of action, the radiation hits the DNA molecule directly, thus disrupting its molecular structure (Fig. 3). Such structural change leads to cell damage or even cell death.

6.2. Indirect action

In the indirect action, the radiation hits the water molecules; which is the major constituent of the microbial cell and other organic molecules inside the cell, thus free radicals such as hydroxyl ion (OH^\cdot) and hydrogen atoms (H) are produced. [Saha, \(2013\)](#) study demonstrated that free radicals are characterized by the presence of an unpaired electron in its structure, which is very reactive, and therefore reacts with the DNA molecules and causes structural damage to their molecules (Fig. 3). The result of this indirect mode of action of radiation on the DNA molecules is the impairment of the cell function or its death. The number of free radicals produced by the ionizing radiation depends on its total dose. [Omar et al., \(2015\)](#)

added that the majority of the indirect cell damage induced by radiation is because water constitutes about 70% of the microbial cell composition.

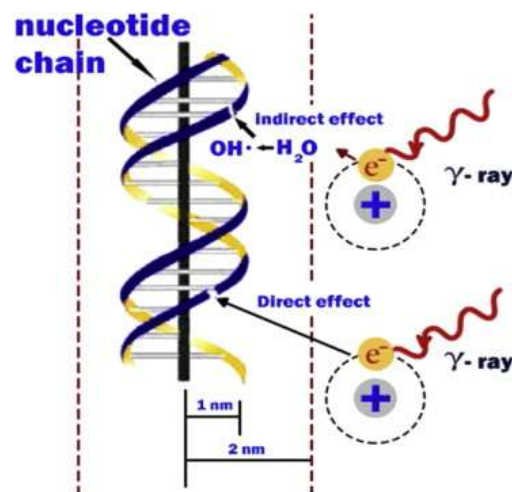


Fig. 3: Direct/ indirect effects of radiation on the microbial cell ([Omar et al., 2015](#))

The direct or indirect effects of radiation result in the development of biological and physiological alterations within the microbial cells, which may lead to abnormalities in these cells ([Omar et al., 2015](#)). Recently, [Shafia et al., \(2019\)](#) highlighted that food irradiation damage of the microbial cell is mainly associated with the formation of cross-linkages in the DNA, causing distortion of the molecule and thus suppression of its replication. The ionizing radiations cause breaks in the double stranded DNA with the same consequence. A previous study conducted by [Rajapakshe et al., \(2009\)](#) highlighted that all these abnormalities cause the microorganisms to loss of their ability to reproduce. [Shafia et al., \(2019\)](#) added that the principal lesions induced by the ionizing radiation in intracellular DNA are chemical damage to the purine and pyrimidine bases and to the Deoxy-ribose sugar. This is in addition to the physico-chemical damage of the molecule, resulting in breaking the phospho di-ester backbone in one strand of the molecule (single-strand break), or in both strands at

the same place (double-strand break). Generally, the double-strand breaks are produced by the ionizing radiation at 5- 10 % of the rate for the single-strand breaks. However, most microorganisms can repair their single-strand breaks. A previous study of [Forsythe, \(1998\)](#) reported that for the microorganism to survive, it is imperative to be able to repair the DNA damage quickly. Thus there are a number of different repair mechanisms, some involving a whole battery of enzymes. If there are too many lesions on the DNA molecule for the microorganism to cope with, the replication will stop. Some of the more complex enzyme repair systems exist in all living organisms including humans; however, the repair mechanisms are less efficient in the higher animals. Thus, a human being would certainly die on exposure to a radiation dose of 0.005 kGy. However, [Shafia et al., \(2019\)](#) recently revealed that carcinogenesis or other abnormalities may be induced later in the cell, if this damaged cell survived. The approved dose of irradiation is that which causes breaking of the DNA strands and their cross linking, without serious effects on the irradiated food itself.

7. Factors affecting the process of food irradiation

7.1. The surrounding medium

A recent study of [Shafia et al., \(2019\)](#) demonstrated that the composition of the medium surrounding the microorganisms plays an important role in the dose required to achieve a given effect on them. In general, the more complex is the medium, the greater is the competition from the medium components to the free radicals produced by the radiation, thus protecting these microorganisms. A previous study of [Buchanan et al., \(1999\)](#) reported that prior decrease of the pH of the growth medium increased the resistance of *Escherichia coli* O157:H7 to the ionizing radiation. [Shafia et al., \(2019\)](#) revealed that it is impossible to predict the type of foods in which particular bacterial cells will be more sensitive or resistant to the radiation

7.2. Water content

Similar to heat treatment, a reduction in the moisture content of the food protects the microorganisms from the lethal effects of the ionizing radiation. [Shafia et al., \(2019\)](#) reported that under drier conditions, the yield of free radicals from water by treatment with radiation is lower, and thus the indirect damage of the DNA in the microbial cell is decreased.

7.3. Temperature

The temperature at which a food product is treated may influence the radiation resistance of microorganisms ([Shafia et al., 2019](#)). For the vegetative cells, elevated-temperature treatments in the sub lethal range ($\geq 45^{\circ}\text{C}$), synergistically enhance the lethal effect of radiation. This enhancement is because the microbial repair systems that normally operate at ambient temperatures and/or slightly above become damaged.

7.4. Freezing

Freezing temperature causes an increase in the resistance of the vegetative cells to radiation. Generally, the microbial radiation resistance in frozen foods is about two or three folds higher than that at the ambient temperature. This is attributed to the immobilization of the free radicals, and prevention of their diffusion in the frozen medium. In the frozen state, the indirect damage of the DNA molecule by the OH⁻ radicals is prevented. This observed change in microbial resistance with temperature demonstrates the importance of the indirect action of the radiation in high moisture foods ([Shafia et al., 2019](#)).

7.5. Aeration

[Farkas, \(2007\)](#) demonstrated that the lethal effect of ionizing radiation on the microbial cells increases in the presence of oxygen. In the absence of oxygen and in wet conditions the radiation resistance increases by about 2-4 folds. However, under the dry conditions, the resistance to radiation might increase by 8-17 folds.

8. Advantages of food irradiation

A recent study of [Isabel, \(2018\)](#) demonstrated that food irradiation offers several advantages over the traditional heat-based or chemical food preservation methods including;

8.1. Terminal food processing: Due to deep penetration of the ionizing radiation, food products can be processed in their sealed or final packaging. This limits the risk of food contamination after sterilization treatment.

8.2. Chemical independence: During irradiation, no volatiles or toxic chemicals are required. Moreover, on using X-ray or e-beam irradiation, no end products are generated that may require the disposal.

8.3. Temperature independence: During irradiation, the increase in temperature is minimal. In addition, radiation sterilization does not depend on heat, as it efficient at the ambient and at the sub-zero temperatures. Food irradiation is compatible with the temperature sensitive materials including; the pharmaceuticals and the biological samples.

8.4. Flexibility: Radiation can sterilize food products of any of their phase's i.e. gaseous, liquid and/or solid materials. Moreover, it can sterilize products with variable size, thickness or density, and homogeneous or heterogeneous systems.

8.5. Sterility assurance level (SAL): Food irradiation procedure can yield a high level of SAL, ensuring that less than 10⁶ microorganisms survive the food sterilization treatment.

8.6. Ease of application: Only a single variable is monitored during food irradiation that is the exposure dose/time, thus making the process of sterilization simpler and easy to control.

9. Limitations of food irradiation in Nigeria

9.1. Lack of adequate sterilizing equipment

Currently, the fact that Nigeria has just one functional irradiation facility is a setback. A study conducted by [Akinloye et al., \(2015\)](#) reported that for the use of irradiation technology for commercial food preservation, Nigeria needs to begin setting up more irradiation facilities at several strategic locations, in order to enhance the ease of application from all regions of the country. To address these issues properly, a system must be used that brings public and private sectors of this country together for active interaction. Moreover, a cue could be taken from Food Corporation of India, which has played a significant role in promoting the Indian food economy. Active co-operation between the relevant governmental agencies and the private sectors will hasten the creation and/or construction of more irradiation facilities, in order to make this technology available to the potential users along this country.

9.2. High cost of food irradiation facility

[Akinloye et al., \(2015\)](#) highlighted that there is a need for favorable pricing linked with efficient marketing services. However, in Nigeria, incentives are generally minimal or do not exist. The problem of price assurance must be addressed, so that the farmers can increase their food production to levels that ensure stability of supplies, in order to meet the normal and emergency requirements.

9.3. Non-adequate sensitization

To solve the issue of inadequate sensitizations, there should be an active dissemination of the information about the improved food storage techniques to all farmers in the rural areas, through using the mass social media, and to farmers in the different groups.

[Akinloye et al., \(2015\)](#) added that the use of some modern food storage technologies requires more specialized skills, and technical know-how which the farmers are lacking. Farmers should be trained on the use of these improved food storage techniques such as storage by irradiation. The government, institutions

and all agricultural organizations should arrange regular workshops to train the farmers and all those who operate in this machinery, in order to educate them with this modern technology and encourage its adoption.

9.4. Transport of the food products

These must be a build of new suitable roads to convey the large amounts of food produce from the field, and to avoid wasting these products due to lack of transport facilities. [Akinloye et al., \(2015\)](#) suggested that this problem can be solved by setting up more irradiation facilities at several strategic locations, to enhance ease of accessibility.

Conclusion

Food irradiation is an improved technique of food preservation, which can reduce food-borne diseases, and also increases shelf life of the stored food. However, the suitable dose of irradiation is critical to maintain safety and stability of the treated food.

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