Review Article

iMedPub Journals
www.imedpub.com

Advances in Applied Science Research

2020
Vol.11 No.3:1

DOI: 10.36648/0976-8610.11.3.1

Irradiation: Utilization, Advances, Safety, Acceptance, Future Trends, and a Means to Enhance Food Security

Agbaka JI[1]* and Ibrahim AN[2]

1 College of Food Science and Nutritional Engineering, China Agricultural University, Beijing, P.R. China
2 Department of Food Science and Technology, Federal University Wukari, Wukari, Taraba State, Nigeria

***Corresponding author:** Agbaka JI

E-mail: jagbaka@gmail.com

College of Food Science and Nutritional Engineering, China Agricultural University, Beijing, P.R. China.

Tel: 18801147002

Citation: Agbaka JI, Ibrahim AN (2020) Irradiation: Utilization, Advances, Safety, Acceptance, Future Trends, and a Means to Enhance Food Security. Adv. Appl. Sci. Res Vol.11 No.3:1

Abstract

Adequate preservation of food has been a major objective of man over time. In the course of storage, marketing, and transportation, food and food products have been significantly taunted by pests and microorganisms. This has resulted in a significant loss of foods (15% for cereals, 20% for fish and dairy products, and up to 40% for fruits and vegetables). With the current global pandemic situation, there are possibilities that famine might be inevitable. Therefore, processes capable of long-term preservation of foods and food products should not only be practiced but readily available and acceptable. Irradiation of foods and food products is a measure that needs to be implemented all over the world, especially in the developing countries. Food irradiation is scarcely practiced in Africa, mostly due to the economy and lack of knowledge on the part of the people, hindering its acceptance as a method of food preservation. Common methods of food preservation have been found to deter nutritional and sensorial qualities of foods; however, irradiation not only keeps foods safe for a longer time, but causes little or no effect on the sensorial qualities. Food irradiation is one of a set of processing strategies that via the application of ionization energy, has been used in the preservation of foods and food products, in addition, improves safety. Gamma rays, eBeams, and X-rays have been applied and studied extensively. As a 'cold' pasteurization process, the application of irradiation does not compromise flavor, aroma, and color of foods and food products. Since the irradiation source in no time comes in contact with the food material, irradiation does not make foods radioactive. However, gamma and electron beam radiation have been implicated in several studies to affect the chemical and antioxidant profile of several food products, where exposure of mushrooms to 2 kGy gamma radiation lead to a reduction in sugar content while the antioxidant activity of *Arenania montana* L was significantly decreased. Moreover, as can be found in other processing techniques involving the application of heat, effects caused by irradiation are minimal. The present review tends to improve the knowledge of irradiation of food which has been practiced for decades. Subsequently, provide insights into the advances in irradiation technology, more so, highlights the safety as well as future trends, and create an awareness to facilitate its acceptance, since consumer acceptance tends to be a barrier to overcome.

Keywords: Food irradiation; Food losses; Microbiological safety; Shelf life; Consumer acceptance; Food security

Received: July 30, 2020; **Accepted:** August 13, 2020; **Published:** August 20, 2020

Introduction

It is expected to have the world's population grow over 8.5 billion by 2024. This growth has presented unavoidable challenge to food researchers and processors who must develop neoteric technologies that will ensure adequate and safe and portable water, food, and other basic needs for the teeming population. Food security had over the years being a problem for several countries, posing a serious difficulty for the population and hence, needs to be addressed. Growth of the middle-class population in several nations has been recorded in recent times. With the advancement of technology as well as the standard of living and a vast dynamic dietetic expectation, this teeming population expects to have foods of excellent quality- free of additives, limited pathogenic load, crops cultivated with the use of fewer pesticides, and several other harmful chemicals. In response to this urgent call for improvement, food processors have begun to adopt more consumer-friendly and advanced food processing technologies while instituting international supply chains and products sales [1].

Globally, to ensure adequate wellbeing of persons, it is fundamental to gain a certain level of guarantee in terms of food safety and security, reduce food wastage, and enhance feeding with a resulting decrease in nutrition-related sicknesses. Extreme weather conditions, for example, harsh and muggy temperatures, exposure of foods to potential hazards conditions during storage and handling, transportation and conditioning has unfortunately played a role in an increased loss of food [2]. Various processing technologies have employed to monitor and control food deterioration and further increasing food security. The conventional techniques employed in the preservation of foods have been comprehensively used [3] in combination with several preservation techniques such as with pasteurization [4], canning [5], freezing [6], refrigeration [7], Smoking [8], MAP [9] and chemical additives [10].

In recent times, the impact of processing techniques which do not require the use of heat has gained some form of interest amongst researchers who study the relationship between of these processing techniques and enzymes, biological cells, and food constituents [11,12]. DNA cells of microorganisms are disrupted when exposed to irradiation sources [13]. In positivity, an extension of shelf-life, improvement of food safety without causing any form of negative effect on the organoleptic and nutritional profile, however, the reverse could be the case when foods are exposed to doses higher than required [14-16] thereafter, provided a basis for a global interest in the increased application of ionising radiation as a form of food treatment.

The utilization of ionizing radiation (gamma rays, electrons and X-rays), preserves food. This treatment applied in the destruction of microscopic or pathogens or to deteriorate or to expand the shelf stability of fresh fruits by decreasing maturation and/or germination rate. There is no remarkable food heating so, in this sense, sensory and nutritional features are usually unchanged. It has been shown to improve microbiological safety or shelf life by irradiation used alone or with other methods [17].

For over nine decades, investigation has gone into the understanding of the successful utilization of irradiation as a safety strategy. National and worldwide organizations and administrative organizations have concluded that irradiated food is secure and wholesome. To confirm the safety and quality of foods treated by irradiation, global organizations including the Food and Agriculture Organization (FAO), the International Atomic Energy Agency (IAEA), WHO, and Codex Alimentarius Commission (CAC) have explore several approaches [16]. This endorsement is driven to various studies on an assortment of food irradiation applications. Irrespective of the massive gains made by this innovation, shockingly, acceptance of food and food products treated by irradiation has overtime gain less growth.

Therefore, this article provides crucial information about the science, innovation, and current applications, future trends of irradiation of foods and food products. We went further to discuss ways of determining the treatment dose received by a food or food product. We highlighted the application of food irradiation on packaged foods and also discussed the microbiological safety of irradiated with a view of convincing consumers on the safety of irradiated foods.

Literature Review

Historical background and development of irradiation over the years

Ionising radiation used in food irradiation includes gamma (Ɣ) – rays, X – rays, and electron beams. X-rays and Ɣ-rays were discovered in the 1890s and research showed that these kinds of irradiation can kill bacteria. The utilization of ionising radiation for food conservation started within the early 1920s. Not until the 1940s, where electron beam accelerators were created and ionising radiation was able to be produced at a much lower cost. However, the efficiency of x-ray machines and the availability of radioactive materials prohibited them from being used in the food industries. Gamma (Ɣ) – photons, x-rays, and electron beams are used in the ionizing radiation contained in food irradiation. In the 1890s, X-rays and Ɣ-rays was found and research showed that bacteria could be killed by these kinds of radiation. In the beginning of the 1920s, ionizing radiation was used for food preservation. Until the 1940s, accelerators were developed for electron beam and ionizing radiation was produced at a substantially less expense. However, they could not be used in the food industry by efficiently using x-ray machines or the availability of the radioactive material. In the production of nuclear fission radioactive elements such as cesium-137 and cobalt-60, substantial steady progress was made that preserved food irradiations mechanical applications. Several studies have since been conducted to assess the appropriate doses for treating a wide array of foodstuffs. Whilst a certain volume of ionizing radiation has begun to soften vegetables, which may become objectionable mushy as in strawberries, grapes, and certain cucumbers or to integrate undesirable tastes into dairy and meat products, to be required for the inactivation or killing of foodborne diseases, spoilage microorganisms, and insects. Amid the 1950s – the 1960s, the US armed force investigated low dosage and high dosage irradiation of military proportions. These tests provoked comparable studies in other nations, in this way, the intrigue in food irradiation picked up gigantic development. In 2017, the worldwide food irradiation market was esteemed at $200 million and was anticipated by coherent market experiences to develop at a 4.9% combined yearly development rate from 2018-2026. This projected the market size to rise to about $284 million by 2026, this high growth rate was envisioned due to increased consumer acceptance since the U.S. Food and Drug Administration (FDA) affirmed the phytosanitary treatment of fresh fruits and vegetables by irradiation. The food irradiation market in Asia is additionally developing exceptionally quickly owning to the endorsement of government offices in India and other nations. Directly over 50 nations have affirmed applications to irradiation over 60 distinctive foods [18]. More than half a million tons of food is irradiated around the globe annually. In Canada, irradiation is approved for onions, potatoes, wheat, flour, wheaten and whole or ground spices. Large amounts of seafood, vegetables, fish and frog legs are irradiated in France and the Netherlands. Irradiated hamburger patties are sold in all States in the United States. Papaya is irradiated and imported into the continent of Hawaii **(Tables 1 and 2).**

Sources of food irradiation

Many sources [19] describe details of the physical and chemical processes involving the decay of radioactive materials to produce alpha, beta and gamma radiation, X-rays and free electrons. In food processing applications, only gamma radiation and accelerated electrons (which can also be converted to X-rays) are used since other particles lead to induced radioactivity. That is why the electron energy is limited to the most legitimate 10 MeV and X-rays to 5 MeV for food irradiation.

Gamma (γ) rays: Theoretically, gamma rays have been studied to contain the simplest form of irradiation, where the radioactive isotopes emitting the photons are (^{60}Co) or caesium (^{137}Cs). The cobalt-60 radio-isotope (^{60}Co) with a half-life of 5.3 years produces 2 wavelengths of gamma rays with 1.17 and 1.33 MeV energies, respectively, while caesium-137 (^{137}Cs) with a half-life of 30.2 years emits gamma rays of 0.66 MeV in strength. However, because of the solubility of ^{137}Cs in water, its use in food irradiation has been disincentive, however, neither of these isotopes has the capacity to induce radioactivity in food.

Photons emitted by the gamma-ray isotopes are comparably higher in frequency and energy (shorter wavelength) than X-rays **(Figure 1).** Since penetration depth can be several feet, microorganisms can be targeted within range. Conceptually, gamma (γ) rays are simple, practically, it could be more complex. The emitted photons are produced by proximity to the nuclear core reactor and after the source has been identified, the exercise becomes complicated logistically as it is not feasible to shut down the source. In addition, the steering or intensity controls are not provided. The source is usually dissolved in water in order to absorb gamma (α) rays **(Figure 2)** and separated by reinforced layers of concrete [20]. In the U.S., gamma irradiation has been widely used for decontamination of spices, seasonings, flour, shell eggs, poultry, shellfish, and more recently, for lettuce and spinach. All fruit and vegetables are approved for irradiation at specified maximum dose levels to delay of maturation (ripening) and disinfestation. In the U.S., gamma irradiation has been widely used for decontamination of spices, seasonings, flour, shell eggs, poultry, shellfish, and more recently, for lettuce and spinach. All fruit and vegetables are approved for irradiation at specified maximum dose levels to delay of maturation (ripening) and disinfestation [21-80].

Several scientists have documented the impacts on the profiles of several foods including chemical and antioxidants as influenced by exposure to gamma and electron beam radiation. Irradiation treatment of Amanita mushrooms resulted in significant changes in sugar, protein, fatty acid, and antioxidant activity. The significant raise in protein quality of irradiated mushrooms was attributed to the growth of nitrogen atoms owing to the elimination of C-N interactions or the unfolding of proteins during the Kjeldahl reaction, which resulted in a higher nutritional level [81-84]. Exposing mushrooms to gamma irradiation dose of 2 kGy resulted in a decrease in sugar content [85]. Gamma irradiation and electron beam irradiation decrease the antioxidant activity in wild *Arenaria montana* L [86]. *Arenaria montana* L contains apigenin derivates which are bioactives that exhibit anti-inflammatory and anti-cancer properties [87].

Electron beam: From within the electron gun, high energy electron beams **(Figure 3)** are emitted and electrons are easier to maneuver with a magnetic field. In this case, the word

Table 1 Benefits of food irradiation.

Benefits to consumer	Environmental benefits
Extension of storage of produce	Less spoilage in transit and so lower costs
Control of spoilages	More efficient food supply
Delay in ripening and senescence	Potential reduction in cold storage needs
Increase trade in food products	Less use of fumigation
Better choice of safe to eat “exotic’ foods and fruits	
Eliminating pathogenic causing foodborne diseases	

Table 2 Sources of ionizing radiation.

Variables	Electron beams	X-rays	Gamma-rays
Power source	Electricity	Electricity	Radioactive isotope (^{60}Co or ^{137}Cs)
Properties	Electrons	Photons ($\lambda = 3 \times 10^{-10}$ m)	Photons ($\lambda = 1 \times 10^{-12}$ m)
Emissions	Unidirectional	Forward peaked	Isotopic (direction cannot be controlled)
Maximum penetration	38 mm from 10 MeV	~400 mm	~300 mm
Adapted from Berejka and Larsen [21].			

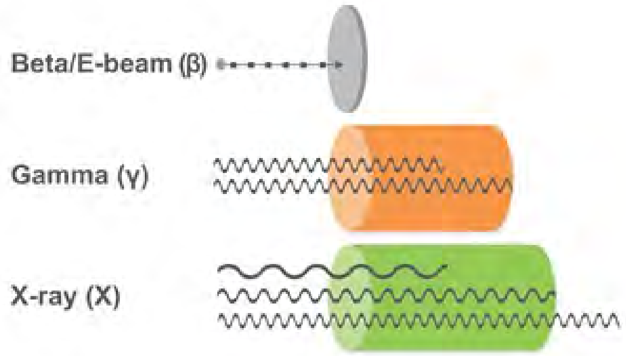

Figure 1 Schematic diagram of penetration levels of eBeam, Gamma, and X-ray.

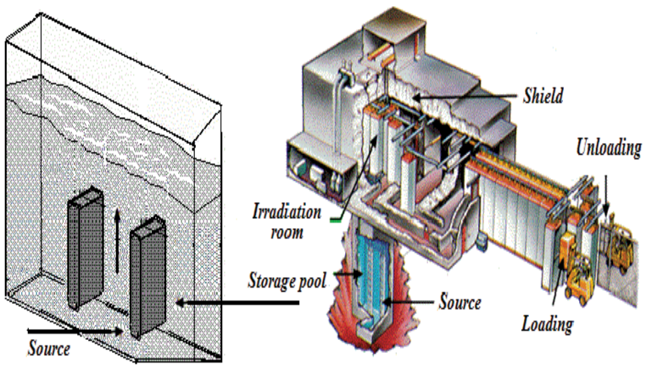

Figure 2 Schematic diagram of a typical commercial gamma irradiator.

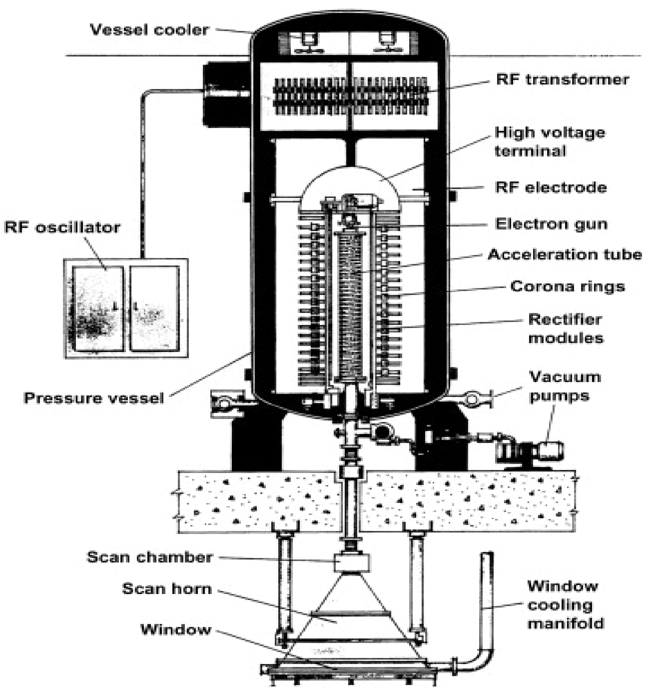

Figure 3 Schematic diagram of a typical electron beam generator.

'irradiation' may be misleading, as food is not exposed to electromagnetic or beta rays, but this process has an impact similar to gamma rays. While shielding is still required during the process, it is not necessary as required in the handling of the gamma-ray. However, increase in irradiation doses of 0, 2, 5, 7, and 9 kGy was found to negatively affect color preference, taste, hardness, and gumminess of spicy yak jerky treated with electron beam irradiation. In another study, the effect of electron beam irradiation with doses ranging from 0.5 to 3.0 kGy on shelf-stability and its effectiveness for inactivating *Escherichia coli* K-12, was investigated. Results obtained indicated a successive decimal reduction dose, D_{10} values, of *E. coli* in cultural medium and blueberries (0.43 ± 0.01 kGy and 0.37 ± 0.015 kGy), respectively. More so, irradiation reduced bacteria inoculated on blueberries from 7.7 × 108 CFU/g to 6 CFU/g at 3.13 kGy and decreased the decaying of blueberries stored at 4°C up to 72% and at room temperature up to 70% at this dose.

The e-beam's main drawback is its penetration depth and is limited to approximately one inch which limits its use to a lot of foods, as shown in **Figure 1** [20,21].

X-rays: In comparison to modern approaches, high energy photons that could have a greater range of penetration than gamma-(γ) rays are introduced to food **(Figures 1 and 2).** In contrast to gamma rays, X-rays can be turned 'on' or 'off', however, protection is also required when it is in operation, but not as required during the handling of gamma irradiation. No hazardous substances or byproducts are generated by this method [20]. Another advantage of X-Rays and e-beams is that they are generated from machine sources **(Figures 3 and 4).** X-Ray and e-beam sources are specified by beam-power: the range from 25 to 50 kW is typical for food applications. X-Rays are created by reflecting a high-energy stream of electrons off a target substance — as a rule, one of the overwhelming metals — into food. X-ray irradiation is utilized as an elective to strategies that utilize radioactive materials and created from machine sources worked at or below an energy level of 5 MeV. The choice of a radiation source for a specific application depends on such viable perspectives as thickness and thickness of the fabric, dosage uniformity ratio (DUR), least dosage, handling rate, and financial matters.

Principles of food irradiation

Food irradiation principles identify the mechanisms by which

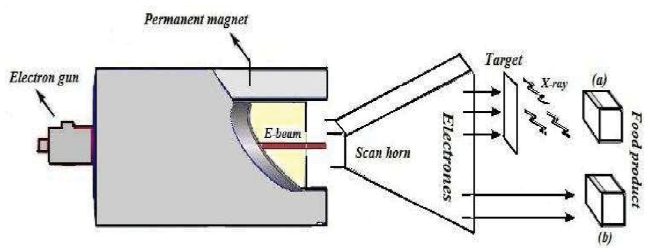

Figure 4 Schematic diagram of a typical X-ray electron generator.

irradiation particles interact with food. This provides intelligent insights within the arrangement of energetic electrons at arbitrary all through the matter, which causes the arrangement of energetic molecular particles. These particles may be subject to electron capture and separation, as well as rapid modification through ion-molecule responses, or they may separate with time depending on the complexity of the molecular particle. Impacts of radiation on matter depend on the sort of radiation and its energy level, as well as the composition, physical state, temperature, and the climatic environment of the retaining material.

Irradiated foods are foods or food products that have gained some form of irradiation treatments depending on the reason for exposure. This preparation is a physical treatment that comprises exposing foods to the direct activity of electronic, electromagnetic beams to guarantee the innocuity of foods and to increase the shelf-life. Practically, the irradiation source and the treated food do not come in contact during the course, and it is not conceivable to induce radioactivity within the food by utilizing gamma beams or electron beams at a limit of 10 MeV [22]. The ionizing emission is part of the electromagnetic continuum of electric waves on two sides, with the heavy energy rays with gamma rays on the other **(Figure 5).** In the middle, there are visible light rays from all sides of infrared and ultraviolet waves. The microwaves that are standard domestic or kitchen appliances are between the radios and the rays. Since they are both members of the electromagnetic spectrum, they may have certain specific issues. Both are waves of a normal wavelength, frequency and some related strength. The higher the wavelength, the littler is the related energy. Radio waves, with considerably long wavelengths of 30 cm to 3 km have very limited energy associated with them.

Microwaves can induce molecular vibration in materials such as food that contain moisture and fat, even if their energy waves are relatively weak, in extremely quick heating. By comparison, X- and gamma rays are extremely short, incredibly high-energy wave-length radiations. They will thump an electron from the neutron, or ionizing molecule when forced to shield toward materials. For this reason, ionizing irradiation is called regularly. The purpose of food irradiation is ionizing irradiation [23].

The irradiation sources that are permitted for use in food processing are gamma rays produced from the radioisotopes cobalt-60 (1.17 and 1.33 MeV) and caesium-137 (0.662 MeV). Gamma-rays and X-rays exchange energy in several ways, each including the release of quick electrons that at that point lose energy in electronic interactions.

Another source is beta rays which are a stream of electrons (most extreme energy 10 MeV). Since the related energy levels of these rays are as well low to be of any practical esteem in terms of irradiation preservation, they got to be accelerated (in cyclotrons, direct accelerators, etc.) to make them obtain the specified energy. Cautious safety measures ought to be taken to guarantee that all electrons have sufficient energy. On the off chance that the obtained energy is as well high, actuated radioactivity in foods may happen upon irradiation [23-45].

Cobalt-60 and Cesium-137 are radioactive, which postures critical challenges in securing, transporting, putting away, and shielding them. Because of the potential for the robbery of the radioactive material, there's a solid thrust by the International Atomic Energy Agency (IAEA), the U.S National Nuclear Security Administration (NNSA), and the U.S Defense Threat Reduction Agency (DTRA) to restrain the commercial utilization of these radioactive materials since elective innovations are accessible.

Even though eBeam and X-ray irradiation advances utilize ionizing radiation, the radiation isn't created by radioactive materials. Or maybe, it is produced by specialized gear called industrial electron accelerators. These accelerators are switch-on/switch-off innovations that can be turned off when not in use. In contrast, radioactive sources, such as cobalt-60 and cesium-137, cannot be put off; hence, they generate gamma radiation continuously because they are undergoing natural radioactive decay. The capacity to switch the radiation source on and off has major suggestions in terms of working costs, specialist security, and the carbon impression of an eBeam or X-ray food handling facility.

Dosimetry

The amount of irradiation energy received by a food or food

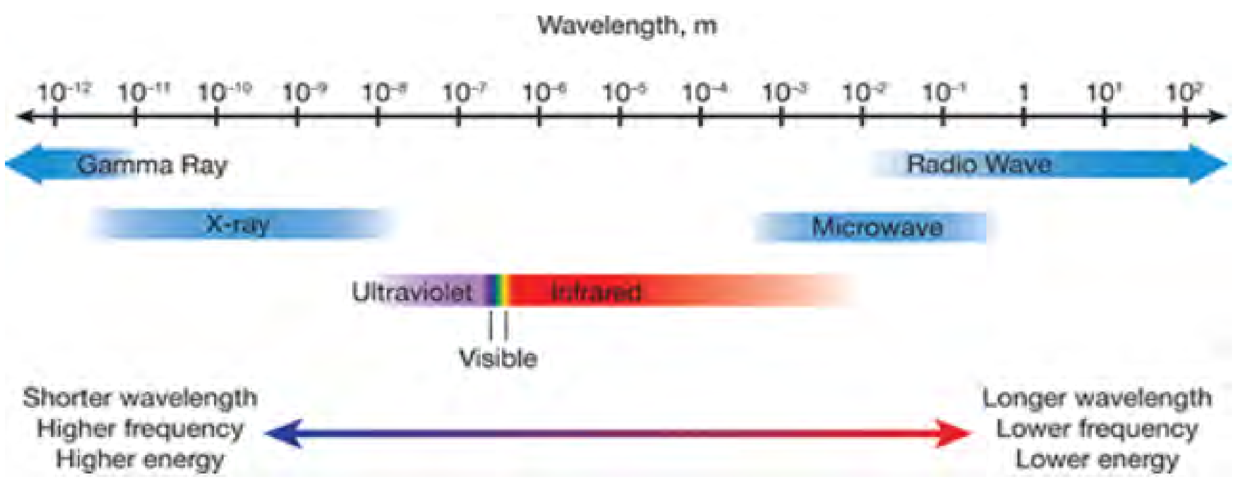

Figure 5 Schematic representation of the electromagnetic spectrum.

product is classified as the dosage. Dosage in this context is measured in Gray (Gy), which is the universally accepted unit. One unit of Gray is equivalent to one joule of energy absorbed per kilogram (J/Kg) of an irradiated food. It is also equivalent to 100 rad (an old unit of measurement). The process of measuring the irradiation dosage received by a food product is known as dosimetry. The fundamental purposes of measuring the dose of irradiation received by a food can be summarized as found below;

- To create the right measurements for the food product under research
- To get information for commissioning the food product through the administrative organization and
- To establish the quality control method within the food production plant.

Identification and detection of irradiated foods

It's in the interests of government officials, food producers, and customers to be able to accurately discern between irradiated and non-irradiated products or ingredients. In order to satisfy the labelling criteria (see below) to distinguish irradiated products, identification methods may also be used. Labelling increases customer protection by affirming the freedom to select the item. In addition, the scientific foundation for the safety assessment of irradiated foods is the knowledge of radiation-induced chemical changes of food [46].

Several detection methods have been subjected to inter-laboratory collaborative studies including electron spin resonance (ESR), luminescence methods, physical methods, chemical methods, and biological methods [47,48]. ESR measures the concentration of free radicals in the irradiated matter. The luminescence strategies degree the nearness of energized atoms such as light emanation upon heating material (thermoluminescence, TL). The physical strategies are based on changes in physical properties of matter e.g. thickness [49]. The chemical strategies are based on the estimation of radiolytic items, e.g., utilizing gas chromatography (GC) to degree unstable radiolytic items such as alkanes, alkenes, and 2-alkylcyclobutanones in fat-containing food, or to degree non-volatile compounds such as 6-ketocholesterol and o-tyrosine. The biological strategies are based on estimations of changes in reasonable microorganisms or changes in plant germination as a result of irradiation. The most practical methods are ESR (for foods containing bones, shells, or other particles), TL (for foods containing mineral dust particles), and GC (for fat-containing food [50]). Continuing efforts to develop detection methods are focusing on the DNA comet assay [50-54], and the changes in protein molecular mass distribution measured by discontinuous SDS-polyacrylamide electrophoresis (SDS-PAGE) and quantified by laser scanning densitometry [55].

Labelling of irradiated foods

It is required that when a food has been irradiated or contains irradiated ingredients or components, it must be labelled with a statement that the food, ingredient, or components have been treated with ionizing radiation. Like other forms of food handling, irradiation can influence the characteristics of food. Customer choice commands that irradiated food be satisfactorily labelled and under the common labelling prerequisites, it is essential that the food processor illuminates the shopper that food has been irradiated. Labelling of irradiated foods, be that as it may, is experiencing reevaluation within the US. In case entire foods have been irradiated, FDA requires that the label bear the 'radura' image **(Figure 6)** and the express "treated with radiation" or "treated by irradiation". However, if irradiated ingredients are included in foods that have not been irradiated, no extraordinary labelling is required on retail packages. Extraordinary labelling is required for foods not however within the retail market which will experience further handling to guarantee that foods are not irradiated at numerous times. In this direction, the FDA prompts that other honest articulations, such as the reason for irradiating the food, perhaps included [56].

Radiation as a preservation technique

Radiation is one of the latest methods of food preservation. The radiation technique makes the food safer to eat by destroying bacteria which is very much similar to the process of pasteurization. In impact, radiation disturbs the organic forms that lead to rot and the capacity to grow. Being a cold process, radiation can be utilized to pasteurize and sterilize foods without causing changes within the freshness and texture of food, not at all like heat. Furthermore, unlike chemical fumigants, radiation does not impart any hurtful poisonous buildups in food and is more successful and can be utilized to treat packaged commodities as well. Countries guard against the import of exotic insect pests by requiring a postharvest disinfestation treatment of commodities that can carry pests. Overall, radiation innovation for food preservation will be moving quickly to the status of a 'wonder technology' to fulfil the clean and phytosanitary prerequisites of importing nations.

Applications of food irradiation

The types of irradiation process can be categorized by the intention of processing and the dose used as described in the following sections **(Table 3). Table 4** summarizes food products, dose, purpose and the dates of approval.

Figure 6 The Radura, international symbol of irradiation.

Sterilization: Although it is technically conceivable to disinfect meats and other items utilizing irradiation, the dosage required (e.g. 48 kGy for a 12D lessening of *C. botulinum* [57] would make items organoleptically unsatisfactory, there's in this way, small commercial intrigue in disinfection, with the special case of herbs and spices which are as often as possible sullied by heat-resistant, spore-forming microbes. These items can be disinfected employing a dosage of 7 ± 10 kGy **(Table 3),** which diminishes the microbial stack to a worthy level without critical loss of volatile oils, the most quality characteristic. The most advantage of irradiating spices is the substitution of chemical sterilization utilizing ethylene oxide, which has been prohibited by the EU since 1991 as a result of concerns over buildups within the item and security of specialists dealing with the gas. The other fundamental application is the sanitization of clinic meals **(Table 3).**

Reduction of pathogens: Food poisoning bacteria can be destroyed by doses of 2.5 ± 10 kGy [58]. This is often progressively one of the foremost vital applications of food irradiation as the incidence of food poisoning is consistently expanding in many countries [59]. Irradiation of ruddy meat has been legitimated within the USA since 1999 and has been utilized commercially since 2002, basically for ground/minced meat for burger patties [60]. Fresh poultry carcasses irradiated with a measurement of 2.5 kGy are for all intents and purposes free of *Salmonella* and the shelf-life is multiplied when the item is held below 5°C. Higher dosages can be connected to frozen poultry or shellfish (at -18°C) to annihilate *Campylobacter spp*., *Escherichia coli* O157:H7 or *Vibrio spp*. (e.g. *V. cholerae, V. parahaemolyticus, V. vulnificus*) without causing the unsatisfactory organoleptic changes that would happen in items irradiated at encompassing temperatures. Crawford and Ruff [61] have checked on these applications. Thayer and Rajkowski [62] have surveyed the rate of food poisoning from a wide extend of fresh fruit and vegetables and items such as fruit juices, and depict thinks about that have been made to control pathogens utilizing irradiation. They concluded that irradiation

Table 3 Applications of food irradiation and doses.

Application	Dose range (kGy)	Examples of foods	References
Low dose (up to 1 kGy)			
Inhibition of sprouting	0.05-0.15	Potatoes, garlic, onions, root ginger, yam	[24], [25]
Disinfestation (e.g. arthropods)	0.15-0.5	Fruits, grains, flours, cocoa beans, dry foods (e.g. fruits, meats, fish)	[26-29]
Delay ripening	0.2-1.0	Fresh fruits and vegetables	[30-33]
Medium dose (1-10 kGy)			
Extension of shelf-life	1-3	Strawberries, fresh fish and meat at 0-4°C, mushrooms	[34-38]
Control of moulds	2.5	Extended storage of fresh fruit	[39], [40]
Sterilization of foods	7-10	Herbs, spices, meat, poultry, sea foods	[41], [42]
High dose (>10 kGy)			
Decontamination of food additives	10-50	Enzyme preparations, natural gums	[43]
Sterilization of packaging materials	10-25	Wine corks	[44], [45]
Sterilized hospital diets	30-50	Ready meals	[18]

Table 4 Foods, dosage, purpose and date approved, for irradiation by the FDA [70].

Product	Dose (kGy)	Purpose	Date Approved
Wheat, wheat flour	0.2-0.5	Insect disinfestation	1963
White potatoes	0.05-0.15	Sprout inhibition	1964
Pork	0.3-1.0	Control *Trichinella spiralis*	7/22/85
Enzymes (dehydrated)	10 max	Microbial control	4/18/86
Fruit	1 max	Disinfestation, delay ripening	4/18/86
Vegetables, fresh	1 max	Disinfestation	4/18/86
Herbs	30 max	Microbial control	4/18/86
Spices	30 max	Microbial control	4/18/86
Vegetable seasonings	30 max	Microbial control	4/18/86
Poultry, fresh or frozen	3 max	Microbial control	5/2/90
Meat, packaged and frozen[a]	44 or greater	Sterilization	3/8/95
Animal feed and pet food	2-25	*Salmonella* control	9/28/95
Meat, uncooked and chilled	4.5 max	Microbial control	12/2/97
Meat, uncooked and frozen	7.0 max	Microbial control	12/2/97

[a] for meats used in the National Aeronautics and Space Administration space program.

can progress the security of fresh fruits which may be far better; a much better; a higher; a stronger; and improved elective to chemical surface treatments **(Table 4)**.

Prolonging shelf-life: Therapies for radiation will enhance consumer health by the elimination of foodborne and shelf-life contaminants, thereby rising food waste. As a phytosanitary procedure, fruits and vegetables can be irradiated at up to 1 kGy and can hinder development and maturation [63]. Generally, low dosages **(Table 3)** are required to annihilate yeasts, parasites, and non-spore-forming microscopic organisms. This process is utilized to extend shelf-life by an overall decrease in vegetative cells. Microbes that survive irradiation are more vulnerable to heat treatment and the combination of irradiation with heating is in this manner useful in causing a more noteworthy lessening in microbial numbers than would be accomplished by either treatment alone [64]. Venugopal et al [65], surveyed the utilization of radurisation for amplifying the shelf-life of fresh fish and shellfish. A few sorts of fruits and vegetables, such as strawberries and tomatoes, can be irradiated to expand their shelf-life by two or three times when left at 10°C. Measurements of 2 ± 3 kGy caused a two-fold increment in shelf-life of mushrooms and restraint of cap opening. A combination of irradiation and modified atmosphere packaging has appeared to have a synergistic impact, and as a result, lower radiation measurements can be utilized to attain the same impact.

Control of ripening: Fruit and vegetable items ought to be ripe before irradiation since irradiation restrains hormone generation and hinders cell division and development, in this manner restraining maturing. Enzymic deterioration of foods isn't completely anticipated by irradiation and an isolated heat treatment is required for drawn-out capacity.

Disinfestation: Grains and tropical fruits and vegetables may be swarmed with creepy crawlies, hatchlings, and organisms, which bring down their export potential and requires an isolated period for disinfestation. Numerous nations have prohibited the fumigants ethylene dibromide, ethylene dichloride, and ethylene oxide. Methyl bromide, which depletes the ozone layer, was prohibited in most industrialized nations in 2005 and will be staged out in developing nations by 2015 [66]. Irradiation maintains a strategic distance from the utilization of fumigants and pesticides or surface treatments that leave chemical buildups on foods. Irradiation measurements of 0.25 ± 1.0 kGy can control parasitic protozoa and helminths in fresh fish and avoid the advancement of insects in dried fish [65] (e.g. *Toxoplasma gondii* is inactivated at measurements of 0.25 kGy and *Trichinella spiralis* at 0.3 kGy [67]. Low measurements, below 1 kGy, are successful for disinfestation conjointly amplifies the shelf-life by postponing ageing and anticipating growing. The utilization of irradiation to treat dried fruits and nuts is portrayed by Johnson and Marcotte [68].

Inhibition of sprouting: The innovation is successful in repressing sprouting of potatoes and in Japan, for illustration, measurements of approximately 150 Gy have been utilized since 1973 on potatoes intended for advance handling [69]. Comparative measurements are compelling in avoiding sprouting of onions and garlic.

Safety of irradiated foods and food products

Radiological safety: According to the USDA, the clear-cut differences between pasteurization and irradiation relies on the source of their energies, where the former relies on heat, the latter relies on ionizing energy. The FDA in 1963, found food irradiation to be safe, however, it is not a substitute for good sanitation and process controls in meat and poultry plants, but an added layer of safety. Since radiation only passes through irradiated foods, leaving no radioactive residues, food irradiation does not make foods radioactive. However, this is not the case when certain food constituents are exposed to higher energy levels [70,71] where ionization has been found to be capable of making them radioactive. In some studies, induced radioactivity was detected in ashes of beef or beef when exposed to an X-ray irradiation energy of 7.5 MeV, however, the induced radioactivity was found to be significantly lower than the natural radioactivity in food. Irradiated foods are wholesome and nutritious, however, nutrient losses as with other forms of food preservation occur during the irradiation of foods but in an insignificant manner (less than those found in pasteurization, cooking, and freezing). Satisfactorily, public health agencies globally have over the last 50 years evaluated the safety of foods and found them to be safe.

Microbiological safety: Depending on the dose of radiation energy applied, foods may be pasteurized to reduce or eliminate pathogens, or they may be sterilized to eliminate all microorganisms, except for some viruses [72]. Irradiation creates damage in the genetic material of the cell by causing a lesion in the DNA **(Figure 7)** or breaking both strands of DNA. DNA harm prevents duplication and arbitrarily restrains cell capacities, coming about within the passing of the cell [73]. Cases of microorganisms that can be disposed of from food utilizing irradiation incorporate *E. coli* 0157:H7, *Campylobacter* and *Salmonella*. Higher measurements of radiation energy can improve sterilize foods to guarantee the greatest shelf life and food security. This can be especially valuable for certain bunch, such as campers, climbers, and crisis aid operations. Such foods have moreover been used by space explorers and armed forces in numerous nations. In expansion, sterile foods are as well utilized in hospitals and other restorative facilities for immune-compromised and immune-suppressed patients who must have bacteria-free food [17].

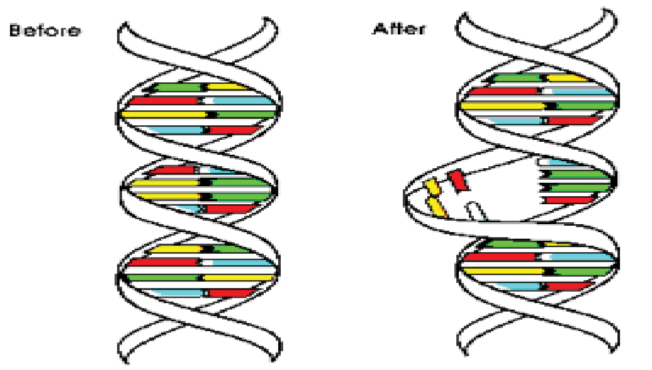

Figure 7 Schematic diagram of a DNA cell before (left) and after (right) exposure to irradiation.

Food irradiation and packaging

Preferences for convenient packaging, pre-cutting and pre-packaging have resulted in an array of challenges in maintaining high food safety standards [74] and quality. The use of food irradiation can reduce pathogenic bacteria's growth and increase material shelf life and reduce the germination of certain items. The US accepted healthy food meat, fish, chickens, mash, herbs, fresh fruits and greens are used in the irradiation process; Allowed radiation doses do not normally exceed 10 kGy [63].

Foods, though irradiated may be re-contaminated unless fittingly packaged. Subsequently, in case the irradiation process is aiming to control microbiological deterioration or insect infestation, prepackaging gets to be an indispensable portion of the method. Since packaging materials are too exposed to radiation amid the treatment, the packaging material aside having a few specialized capacities like the anticipation of moisture take-up and loss, etc. must moreover, fulfil extra prerequisites such as resistance to radiation. It ought to not moreover transmit poisonous substances into food nor give any off smell to the items. Of a few packaging materials right now accessible such as cellulose, glass, metals, and organic polymers, plastics offer interesting points of interest over the utilization of ordinary inflexible holders from the point of view of adaptability, low costs, lightweight, and low weight to volume proportion. Multi-laminate packaging structures of polymers like nylon, EVOH, PVC, cellophane, PET, and Polyester are utilized as unmistakable obstruction material within the packaging of irradiated food.

Packaging materials utilized for irradiated foods are broadly classified into two (2) categories depending on the sort of food radiation treatments, which are;

- Processes requiring less than (<) 10 kGy, such as the expansion of shelf life of food.
- Processes requiring measurements from 10-60 kGy, for putting away such things as meat and poultry for long periods without refrigeration.

Limitations and acceptability of food irradiation and irradiated foods

The accomplishment of the expertise potential for food radiation is as acknowledged by the action of the buyers' acquisition and appreciation of the product. Innovation in the nuclear industry remains largely restricted to Belgium and France, where food irradiation is not a problem because of the high importance of the nuclear industry [75]. By 1998, the Pacific countries, such as Bangladesh and Thailand, have also taken advantage of the advantages of radiated food according to studies focused on the convention conducted by Bangkok on the identification and development of irradiated foods in Asia. Thailand facilitated a flourishing market for irradiated food products. The People's Republic of China affirmed the irradiation of food (by classes) in terms of nature of the food, such as fruits and vegetables, meat and poultry, spices, cooked meat, dried fruits, and nuts and dehydrated vegetables. Other nations, such as Sri Lanka, Pakistan, the Philippines, and South Korea took steps toward setting up irradiation facilities for two years.

Acceptability in a few nations has been nearly outlandish judging by people's conviction or obliviousness of the nuclear industry coupled with articulations by media reports and weight bunches all of which had an excessive impact on public supposition. Food irradiation notwithstanding of faultfinders is among the foremost fastidiously explored food conservation methods over the past five decades and is still on-going [75,76]. Although general awareness of the breakthrough is expressed and the belief that irradiation renders food toxic is ignored, there are certain critical questions regarding the misconceptions about the need for irradiation, the exceptional lack about nutrients and the availability of hazardous chemicals. The public highlights the flaw of irradiating products with heavy microbial spoilage. Food processors are an urgent mandate to take large industrial measures; however, they must be mindful of the popular anxiety and determination that can begin to mitigate public concern which understandably, is not supposed to disappear immediately.

Future trends

The key to the slow implementation of the multiple potential uses of food irradiation technology is to better appreciate its potential role in the management of foodborne diseases, spoilage and readiness to pay for food safety processing [77]. Additional developments in regulation on food irradiation, particularly in the European Union, will enable all parties involved to consider the process more generally. Consumer acceptance is a problem of education and good communication which reduces the unjust picture of the nuclear technology of food irradiation, [78]. Demystification of food irradiation is necessary for the challenge represented by consumer acceptance and regulatory approval [79]. Marketing surveys have shown that an increasing number of customers are prepared to purchase irradiated products, given that they are sufficiently educated about the procedure and its effect on food [80].

The process images may also be transformed into one kind of electrical technology by further developments in designing and adjusting the uses of machine radiation sources (E-beam equipment and X-raying machinery) [81-83]. Commercial application is very important in the United States and in some countries where health authorities actively promote the use of this technology in the last few years advanced. However, progress is still slow in the European Union [16].

In the end, radiation processors are also needed to acknowledge the difficulties that food trade experiences when inserting an additional and unknown technical step on the supply chain for highly destructive commodities from farm to fork [84-87]. The irradiation step should be made as straightforward and smooth as possible.

Discussion

Food irradiation has found successful applications in increasing the microbiological safety of foods and shelf life extension, hence, reducing food losses. Advancement and presentation of satisfactory discovery methods should moreover offer assistance to console the public that the method is secure and not being abused. However, the high cost of irradiation units and, in particular, the negative perception of the consumer for its safety, is not as widespread as other conventional technology. Irradiation can be used mainly to avoid the growth of toxigenic fungi and increased development of mycotoxins by mixing effective production and storage activities. Also important is that irradiation should not be used to solve the problem in products already infected by mould or contaminated with mycotoxins.

Conclusion

In conclusion, the high cost of irradiation units and, in particular, the negative perception of the consumer for its safety, are not as widespread as other conventional technology. Irradiation can be used mainly to avoid the growth of toxigenic fungi and increased development of mycotoxins by mixing effective production and storage activities. Notably, irradiation should not be used to solve the problem in products already infected by mold or contaminated with mycotoxins although cobalt-60 radioisotope (gamma radiation) is the most common commercially used source of food treatment. Technologies to substitute high-risk radioactive sources used in commercial, medical and scientific uses, like cobalt 60, are also available. Devices which use electricity to produce X-rays or electron beam radiations are the most advanced and commercially available alternative technologies. To assure consumers of their safety and health, extensive studies on the long-term effects of food irradiation on health should be carried out.

Conflict of Interest

Authors have no conflicts of interests to declare.

References

1 Loaharanu P (1994) Food irradiation in developing countries: a practical alternative. IAEA Bull 1: 30-35.

2 Satin M (1996) The prevention of food losses after harvesting. Food Irradiation: A Guide Book (2nd edn) 81–94.

3 Agrios GN (2005) Plant pathology (5th Edition) Academic Press, San Diego, USA.

4 Klein JD, Lurie S (1990) Prestorage heat-treatment as a means of improving post-storage quality of apples. J Am Soc Hortic Sci 115: 265-269.

5 Carlson B (1996) Aseptic processing and packaging of food. CRC Press, New York, USA, p. 130.

6 Kasmire RF, Thompson JF (1992) Cooling horticultural commodities III. Selecting a cooling method. In Postharvest Technology of Horticultural Crops (A.A. Kader, Ed.), University of California Publication 3311, Davis, C.A., USA. p. 63.

7 McCarthy MA, Mathews RH (1994) Nutritional quality of fruits and vegetables subject to minimal processes. In: Minimal Processed Refrigerated Fruits and Vegetables. (Wiley, R.C., Ed). Chapman and Hall, USA, p. 313–326.

8 Abu-Bakar A, Abdullah MY, Azam K (1994) The effects of caramel on the quality of smoked fish. ASEAN Food J. 9: 116–119.

9 Bennik MHJ, Peppelenbos HW, Nguyen-the C, Carlin F, Smid EJ (1996) Microbiology of minimally processed, modified atmosphere packaged chicory endive. Postharvest Biol Tec 9: 209-221.

10 Beudry R, Watkins C (2001) Use of 1-MCP on apples, Perish. Handling Quart 108:12.

11 Barros-Velazquez J (2011) Innovations in food technology special issue. Food Bioproc Tech 4: 831–832.

12 Knorr D, Froehling A, Jaeger H, Reineke K, Schlueter O, et al. (2011) Emerging technologies in food processing. Ann Rev Food Sci Technol 2: 203–235.

13 Lung HM, Cheng YC, Chang YH, Huang HW, Yang BB, et al. (2015) Microbial decontamination of food by electron beam irradiation. Trends Food Sci Technol 44: 66–78.

14 High-dose Irradiation (1999) Wholesomeness of food irradiated with doses above 10 kGy. Report of a Joint FAO/IAEA/WHO Study Group (1999) World Health Organ Tech Rep Ser p. 1-197.

15 Molins RA (2001) Food Irradiation: Principles and Applications

16 Diehl JF (2002) Food irradiation—Past, present, and future. Radiat Phys Chem 63: 211–215.

17 www-pub.iaea.org/MTCD/Publications/PDF/Pub1365_web.pdf

18 Ihsanullah I, Rashid A (2017) Current activities in food irradiation as a sanitary and phytosanitary treatment in the Asian and the Pacific Region and a comparison with advanced countries. Food Cont 72: 345–359.

19 Ehmann WD, Vance DE (1991) Radiochemistry and Nuclear Methods of Analysis.

20 http://leda.law.harvard.edu/leda/data/403/Prejanpap.html.

21 Berejka AJ, Larsen S (2014) Enhanced wood durability from radiation-cured penetrants. Rad Tech Report 2: 15–21.

22 Farkas J (2004) Charged particle and photon interactions with matter. J Am Chem Soc 10: 785-812.

23 Lacroix M, Marcotte M, Ramaswamy H (2002) Irradiation in combination with other processes for the preservation of fruits, vegetables, nuts, and spices.

24 Kader AA (1986) Potential applications of ionizing radiation in post-harvest handling of fresh fruits and vegetables. Food Technol 40: 117–121.

25 Prakash A (2016) Particular applications of food irradiation fresh produce. Rad Physc Chem 129: 50–52.

26 Al-Kahtani HA, Abu-Tarboush HM, Al-Dryhim YN, Ahmed MA, Bajaber AS, et al. (1998) Irradiation of dates: Insect disinfestation, microbial and chemical assessments, and use of thermoluminescence technique. Rad Physc Chem 53: 181–187.

27 Cornwell PB (2013) The entomology of radiation disinfestation of grain: A collection of original research papers. Elsevier.

28 McDonald H, McCulloch M, Caporaso F, Winborne I, Oubichon M, et al. (2012) Commercial-scale irradiation for insect disinfestation preserves peach quality. Rad Physc Chem 81: 697–704.

29 Pillai SD, Shayanfar S (2017) Electron beam technology and other irradiation technology applications in the food industry. Top Curr Chem 375: 249-268.

30 Hossain F, Parvez Ak, Munshi MK, Khalil I, Huque R (2014) Post-harvest treatments of radiation and chemical on organoleptic and biochemical properties of mango (*Mangifera indica*) in relation to delay. J Environ Agric Sci 14: 555–564.

31 Sea S, Rakovski C, Prakash A (2015) Ripening quality of 'Bartlett' pears (*Pyrus communis* L.) subjected to phytosanitary x-ray irradiation treatment followed by a simulated retail display. Hort Science 50: 279–287.

32 Surendranathan K, Nair P (2013) Carbohydrate metabolism in ripening banana and its alteration on gamma irradiation in relation to delay in ripening. J Indian Inst Sci 62: 63-80.

33 Yadav M, Patel N (2014) Optimization of irradiation and storage temperature for delaying ripening process and maintaining quality of Alphonso mango fruit (*Mangifera indica* L). Afr J Agric Res 9: 562–571.

34 Fadhel YB, Leroy V, Dussault D, St-Yves F, Lauzon M, et al. (2016) Combined effects of marinating and γ-irradiation in ensuring safety, protection of nutritional value, and increase in shelf-life of ready-to-cook meat for immunocompromised patients. Meat Sci 118: 43–51.

35 Kumar M, Ahuja S, Dahuja A, Kumar R, Singh B (2014) Gamma radiation protects fruit quality in tomato by inhibiting the production of reactive oxygen species (ROS) and ethylene. J Radioanal Nucl 301: 871–880.

36 Lefebvre N, Thibault C, Charbonneau R, Piette JP (1994) Improvement of shelf life and wholesomeness of ground beef by irradiation—2. Chemical analysis and sensory evaluation. Meat Sci 36: 371–380.

37 Prakash A, Inthajak P, Huibregtse H, Caporaso F, Foley D (2006) Effects of low-dose gamma irradiation and conventional treatments on shelf life and quality characteristics of diced celery. J Food Sci 65: 1070–1075.

38 Yang Z, Wang H, Wang W, Qi W, Yue L, et al. (2014) Effect of 10 MeV E-beam irradiations combined with vacuum-packaging on the shelf life of Atlantic salmon fillets during storage at 4°C. J Food Chem 145: 535–541.

39 Mitchell GE, Isaacs AR, Williams DJ, McLauchlan RL, Nottingham SM, et al. (1991) Low dose irradiation influence on yield and quality of fruit juice. J Food Sci 56: 1628–1631.

40 Mongpraneet S, Abe T, Tsurusaki T (2002) Accelerated drying of welsh onion by far-infrared radiation under vacuum conditions. J Food Eng 55: 147–156.

41 Antonelli A, Fabbri C, Boselli E (1998) Modifications of dried basil (Ocinum basilicum) leaf oil by gamma and microwave irradiation. Food Chem 63: 485-489.

42 Kim HY, Ahn JJ, Shahbaz HM, Park KH, Kwon JH (2014) Physical, Chemical and Microbiological Based Identification of Electron Beam- and γ-Irradiated Frozen Crushed Garlic. J Agr Food Chem 62: 7920–7926.

43 Celiz MD, Morehouse KM, deJager LS, Begley TH (2019) Concentration changes of polymer additives and radiolysis products in polyethylene resins irradiated at doses applicable to fresh produce. Rad Physc Chem 101: 69-76.

44 Davis CR, Fleet GH, Lee TH (1982) Inactivation of wine cork microflora by a commercial sulphur dioxide treatment. Am J Enol Vitic 33: 124–127.

45 Corsi AJ, Robles FC, Corduay CG, Neal JA (2015) The effectiveness of electron beam irradiation to reduce or eliminate mould in cork stoppers. Int J Food Sci Technol 51: 389–395.

46 Diehl JF (1995b) Nutritional adequacy of irradiated foods. In: Diehl, J.F. (Ed.), Safety of Irradiated Foods, second ed.

47 Haire DL, Chen G, Janzen EG, Fraser L, Lynch JA (1997) Identification of irradiated foodstuffs: a review of the recent literature. Food Res Int 30*:* 249-264.

48 Delinceae H, Bognaar A (1993) Effect of ionizing radiation on the nutritional value of legumes. Rad Physc Chem 2: 367-371.

49 Chabane S, Pouliquen SI, Raffi J (2001) Detection of Irradiated Spices by Different Physical Techniques. Can J Physiol Pharmacol 79: 103-108.

50 Cerda H, Delincee H, Haine H, Rupp H (1997) The DNA 'Comet Assay' as a rapid screening technique to control irradiated food. Mutation Res 375: 167-181.

51 Marchoni E, Horavatovich P, Ndiaye B, Miesch M, Hasselmann C (2002) Overview of Irradiation of Food and Packaging. Rad Phys Chem 63: 447-450.

52 Marin-Huachaca NS, Lamy-Freund MT, Mancini-Filho J, Delincee H, Villavicencio ACH (2002) Safety of Irradiated Foods Rad Phys Chem 63: 419-422.

53 Barros AC, Freund MTL, Villavicencio ACH, Delincee H, Arthur V (2002) Overview of Irradiation of Food and Packaging. Rad Phys Chem 63: 423-426.

54 Delincee H (1998) Detection of irradiated food: DNA fragmentation in grapefruits. Rad Phys Chem 52: 135-139.

55 Niaiforovia A, Radoaiia, Milosavljevia BH (2001) Food Irradiation: A Guidebook.

56 Morehouse KM (2002) Food irradiation -US regulatory considerations. Radiat Phys Chem 63: 281-284.

57 Lewis MJ (1990) Physical Properties of Foods and Food Processing Systems; A Woodhead Publishing Series in Food Science Technology and Nutrition.

58 Guise B (1986) Irradiation waits in the wings. Food Eur 6: 7-9.

59 Loaharanu P (1995) Food irradiation: current status and future prospects. 90-109.

60 Ehlermann DAE (2002) The Nutrition Handbook for Food Processors.

61 Crawford L (2001) Change and opportunities for food irradiation in the 21st century. 9-16.

62 Rajkowski KT, Fan XT (2004) Ionizing radiation of seeds and sprouts: A review. Am Chem Soc 875: 107–116.

63 Ionizing radiation for the treatment of food (2018) Code of Federal Regulations, Part 179, Title 21, Section 26.

64 Gould GW (1986) Food irradiation-microbiological aspects. J Food Sci Technol 19: 175-180.

65 Venugopal V, Doke SN Thomas P (1999) Radiation processing to improve the quality of fishery products. Crit Rev Food Sci Nutr 39: 391-440.

66 Anon (2004) Methyl bromide approved for temporary uses.

67 Olson DG (1998) Irradiation of food. Food Technol 52: 56-62.

68 Johnson J, Marcotte M (1999) Irradiation control of insect pests of dried fruits and walnuts. Food Technol 53: 46-53.

69 Stevenson MH (1990) The practicalities of food irradiation.

70 IFT (1998) Radiation preservation of foods; A scientific status

summary by the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition. J Food Tech 52: 55-62.

71 High-dose irradiation: wholesomeness of food irradiated with doses above 10 kGy. Report of a Joint FAO/IAEA/WHO Expert Committee (1999) World Health Organ Tech Rep Ser 890: 1–197.

72 IFT (1983) Radiation preservation of foods. A Scientific Status Summary by the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition. Food Technol 37: 55–61.

73 Lacroix M, Follett P (2015) Combination irradiation treatments for food safety and phytosanitary uses. Stewart Postharvest Rev 11: 1-10.

74 www.npr.org/sections/thesalt/2016/07/12/485098252/as-bagged-salad-kitsboom-americans-eat-more-greens.

75 Kilcast D (1994) Effect of irradiation on vitamins. Food Chem 49: 157–164.

76 Farkas J (1998) Irradiation as a method for decontaminating food: A review. Int J Food Microbiol 44: 189 -204.

77 Farkas J, Mohacsi-Farkas C (2011) History and future of food irradiation. Trends Food Sci Technol 22: 121-126.

78 Teisi M, Fein S, Levy A (2009) Information effects on consumer attitudes toward three food technologies: organic production, biotechnology and irradiation. Food Qual Prefer 20: 586-596.

79 Crawford LM, Ruff EH (1996) A review of the safety of cold pasteurization through irradiation. Food Control 7: 87-97.

80 http://www.foodirradiation.org/Global%20Status%20of%20Food%20irradiation.pdf

81 Arthur TM, Wheeler TL, Shackelford SD, Bosilevac JM, Nou XW, et al. (2005) Effects of low dose, low penetration electron beam irradiation of beef carcass surface cuts on *Escherichia coli* O157:H7 and meat quality. J Food Produc 68: 666-672.

82 Cleland M (2006) Advanced in gamma ray, electron beam, and X-ray technologies for food irradiation.

83 Pillai SD, Shayanfar S (2017) Electron beam technology and other irradiation technology applications in the food industry. Topics Curr Chem 375: 6-20.

84 Roberts P (2016) Food irradiation: Standards, regulations and world-wide trade. Rad Phys Chem 129: 30-34.

85 Fernandes A, Barreira JCM, Antonio AL, Oliveira MBPP, Martins A, et al. (2016) Extended use of gamma irradiation in wild mushrooms conservation: Validation of 2 kGy dose to preserve their chemical characteristics. LWT –Food Sci Technol 67: 99–105.

86 Pereira E, Barros L, Barreira JCM, Carvalho AM, Antonio AL, et al. (2016) Electron beam and gamma irradiation as feasible conservation technologies for wild *Arenaria montana* L: Effects on chemical and antioxidant parameters. Innov Food Sci Emerg Technol 36: 269–276.

87 Oliveira FS, Ribeiro A, Barros L, Calhelha RC, Barreira JCM, et al. (2017) Evaluation of *Arenaria montana* L hydro-ethanolic extract as a chemo-preventive food ingredient: A case study focusing a dairy product (yogurt). J Funct Foods 38: 214–220.