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Review

Food irradiation: Applications, public acceptance and global trade

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Food irradiation is the treatment of food products by a definite kind of energy. The process involves exposing the packed or bulked food to the rays of the sun. Food irradiation processing that entails combating post-harvest losses, curtailing food-borne disease and overcoming quarantine barriers has been pursued since the mid-50s. The scientific basis and technological adaptation of the process have been well established more than any other post-harvest food processing techniques. In 1981, the FAO/IAEA/WHO Joint Expert Committees on the wholesomeness of irradiated food (JECFI) concluded, "the irradiation of any food commodity up to an overall average dose of 10 KGy presents no toxicological hazard". The benefits of irradiation technology in addressing post-harvest food problems are, in some cases, unique and can improve the quality of a number of food products by eliminating the risk of pathogenic contaminants. The potential of this technology has been well perceived in recent years in the wake of food-borne disease caused by pathogenic organisms. In fact, many parts of the world are considering food irradiation as a technological saviour in finding a suitable solution for the problems caused by pathogens in food. Irradiation can be regarded as a useful tool to attain food security in the 21st century. Many consumers have misconceptions about the technology and suppose that it makes food radioactive. But, when the method is explained to them they become normally more in favor of it. Over 50 countries have regulatory approvals in place for irradiation of one or more food products. 30 countries are practically applying this technology for a number of food items.

Key words: Food Irradiation, food-borne disease, pathogenic microorganisms, packaging, acceptance.

INTRODUCTION

Iran and some countries that are located in the arid and semi arid zones are characterized by severe weather conditions (Lack of fresh water and wide spread soil erosion). Such climate allows the rapid growth of microorganisms and insects (Hamdan, 1997). As a result, the region faces considerable losses of foods during its storage, transportation and marketing (15% for cereals, 20% for fish and dairy products and up to 40% for fruits and vegetables). The safety and quality of food is also affected due to the presence of pathogenic micro-organisms and parasites (particularly in meat and fish).

Preservation of food and control of microorganisms' infection has been a major preoccupation of man over the centuries. Many processing methods have been developed to prevent food spoilage and raise safety. The traditional methods, such as drying, smoking and salting have been supplemented with pasteurization (by heat), canning, freezing, refrigeration and chemical preservatives (Agrios, 2005). Irradiation is another technology that can be added to this list. Irradiation of food is the process of exposing it to a carefully controlled amount of energy in the form of high-speed particles or rays. Normally, this occurs widely in nature and is included among the energy reaching earth all the time from the sun (Farkas, 2004). The length of time the food is exposed to the ionizing energy, coupled with the strength of the source determines the irradiation dose that is measured in grays (Gy) or kilo grays (1kGy = 1,000 Gy). One gray corresponds to

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the absorption of one joule of energy in a mass of one kilogram (1Gy =1J/kg) (Ahari and Zafarani, 2008). More than 100years of research that have gone into understanding of the harmless and effective use of irradiation as a safety method is more than any other technology used in the food industry today (Scott and Suresh, 2004). The safety of the technology has been repeatedly considered and judged acceptable on available evidence. This has resulted in international bodies including the World Health Organisation (WHO), the Food and Agriculture Organisation (FAO), the International Atomic Energy Agency (IAEA) and Codex Alimentarius commending the process (Landgraf et al., 2006).

The use of chemical fumigants are being phased out, due to their carcinogenic and ozone depleting properties. Thus, alternative methods must be utilized to ensure the quality of food consumed within the region (Ahari and Zafarani, 2008). Irradiation technology can be used as an alternative method for the reduction of food losses which are caused either by insect infestation of grains and pulses, or of animal origin such as poultry and seafood (Marcotte, 2005). Food irradiation has the potential to reduce pathogenic microorganisms and to inactive parasites that may be present in foods (Marcotte, 2005; Patterson, 2005), thus contributing to improvements in food hygiene and enhancing public health. Moreover, irradiation may serve as a quarantine treatment for many fruits, vegetables, nuts, cut flowers and animal origin products, thus facilitating international trade of such foods (Hallman, 2001).

EFFECTS OF IONIZING RADIATION

Ionizing radiation can have an effect (directly and indirectly) on organisms and food products. Since the hydroxyl radical is a powerful oxidizing agent and the hydrated electron is a strong reducing agent, the radiolysis of water can be expected to cause oxidizing and reducing reactions in foods through free radical attack (Miller, 2005).

Bacteria, yeasts, molds, viruses and other parasites and insects and mites are the interesting bio-organisms for food preservation and safety (Marcotte, 2005). It is accepted that the biological effects caused by ionizing radiation are primarily the result of disruption of the nucleic acid molecules (DNA or RNA) in the nuclei of cells (Scott and Suresh, 2004). The DNA structure is that of very long ladder twisted into a double helix. Since there is only one (or at most a few copies) of the DNA molecule in a cell, and if it becomes damaged by either primary ionizing events or through secondary free radical attack, the induced chemical and biological changes can prevent replication and cell death. DNA is much larger than the other molecular structures in a cell and this is an important reason for the high sensitivity of DNA to the effects of ionizing radiation (Scott and Suresh, 2004; the Institute of Food Science and Technology 2006).

Viruses

Viruses are not true cells, but are parasites that replicate by injecting their genetic material into a host cell. They do not grow in food, but can infect host bacteria (Deeley, 2002). Poliomyelitis viruses and infectious hepatitis can be transmitted via contaminated shellfish and raw milk (DeWit et al., 2003; Frankhauser et al., 2002).

Viruses are generally more radiation resistant than other organisms since the size of the DNA molecule generally increases with the complexity of an organism (Koopmans and Duizer, 2004). However, radiation sensitivity is affected by many other factors. These include temperature, the composition of cellular medium, and the growth cycle of the cell (Stewart, 2004a). Lowering the temperature decreases the metabolism rate (simple H_2O activity) and the formation and mobility of free radicals. For the same reason, drying and freezing also generally decrease radiation sensitivity. Whereas, Viruses can be inactivated by heat, the combination of heating with irradiation can be used successfully (IAEA, 1996; Koopmans and Duizer, 2004).

Bacteria

On the basis of food safety, bacteria are generally divided into 3 groups: (A) useful bacteria, (B) spoilage bacteria that are responsible for undesirable changes in the odor, flavor, texture and appearance of food, and (C) pathogenic (disease causing) bacteria responsible for most of the outbreaks of food-borne illness (Miller, 2005). The endospores of spore-forming bacteria are resistant to most treatments (irradiation is no exception). Doses used to pasteurize foods below 10 KGy may only give a 2-3 $\log_{10}$ reduction in spore numbers. This is not sufficient to produce shelf-stable foods (Patterson, 2005).

Yeasts and molds

Yeasts are generally more radiation resistance than molds and vegetative bacteria. So, they can become important in the spoilage of irradiated meat products (such as sausages) stored at refrigeration (Ahari and Zafarani, 2008; Patterson, 2005; Scott and Suresh, 2004).

Fungi are different in their radiation resistant. *Alternaria* sp. and *Fusarium* sp. are more resistant, the *penicillium* sp. and *Aspergillus* sp., *Fusarium* and *Alternaria* spores are multicellular. If only one cell escapes damage, the spore may still have the ability to germinate. So, these spores are more radiation resistant as higher doses will be needed to destroy all the cells (Patterson, 2005).

Insects

Insects, mites and other such pests are higher level multicellular organisms responsible for considerable loss of fresh produce and grains (Ahari and Safaie, 2008). They can also serve as vectors for carrying pathogenic parasites and bacteria. Excellent control of insects in agricultural products can be achieved by using fumigants (such as ethylene bromide). But, the use of these pesticides has been banned or severely restricted in most countries (IAEA, 1996; World Health Organization, 2005). Therefore, radiation has been suggested as an alternative to them. On the basis of practical experience, the necessary radiation dose is in the range of 100 - 800 Gy (according to different growth stages). A dose level of 250 Gy can be used as a quarantine treatment of fruit flies, while a dose of 500 Gy can control all stages of most pests (IAEA, 1996; Landgraf et al., 2006; Marcotte, 2005).

NUTRITIONAL QUALITY OF IRRADIATED FOODS

Additionally, In order to determine the minimum dose required to control food spoilage agents, it is necessary to estimate the maximum acceptable dose (Miller, 2005), because high doses can have negative sensory effects on foods. The effects of ionizing radiation on the primary components of foods, including carbohydrates, lipids and proteins, as well as some important micronutrients (vitamins) are summarized. For these large molecules any excess energy is most likely to be absorbed in those parts of the molecule having the greatest electron density, or where bonds are weak. Therefore, it is not surprising that the products of radiolysis are nearly likened to the products resulting from cooking, for example (Scott and Suresh, 2004; The Institute of Food Science and Technology, 2006).

Carbohydrates

Carbohydrates are a main basis of energy for the body. When subjected to radiation, the complex carbohydrates breakdown into simpler sugars, while the monosaccharides breakdown into sugars acids and ketones. These are the same compounds that result from normal hydrolysis (Marcotte, 2005). Consequently, low and medium radiation doses have little effect on the nutritional value of carbohydrates. High radiation doses, however, can deteriorate fibrous plant cell wall material leading to a deterioration of texture and loss of quality (Marcotte, 2005; Miller, 2005; Suresh et al., 2005).

Proteins

Proteins are large compounds that have long chains of amino acids attached by peptide bonds (the carboxyl group of one amino acid is related to the amino group of another). Protein molecules range from the long (insoluble fibers that make up connective tissue), soluble enzymes that can pass throughout cell membranes and catalyze metabolic reactions necessary for life. The role of a protein molecule is largely established by its three-dimensional structure (Ziebkewicz et al., 2004).

Whereas amino acids by themselves are relatively susceptible to free radical attack following irradiation, they are much less sensitive when buried in the rigid structure of a protein molecule. As a result, low and medium doses cause only a small breakdown of food proteins into lower molecular weight protein parts and amino acids. Indeed, trial evidence suggests that such treatments cause less protein degradation than steam heat sterilization. At high doses, irradiation can result in protein denaturation, with resulting loss of food quality (Miller, 2005; Stewart, 2004a; Suresh et al., 2005).

Lipids

Lipids are fats and oils composed of the same elements (carbon, hydrogen and oxygen) as carbohydrates. At low and medium doses, the effect of irradiation on the nutritional content of lipids is minimal. Additionally, it is also significant to note that such doses will not cause the formation of aromatic or heterocyclic rings, or the condensation of aromatic rings, all of which are measured to be carcinogenic, and are known to be visible at high cooking temperatures (Patterson, 2005; Scott and Suresh, 2004). However, the irradiation of lipids at high doses, and especially in the presence of oxygen, can lead to the formation of liquid hydro peroxides. Whereas not necessarily dangerous, these substances often have undesirable odors and flavors. The unsaturated fatty acids are more prone to develop rancidity. Lipid oxidation can be considerably reduced by freezing, and/or by oxygen removal prior to irradiation (Marcotte, 2005; Stewart, 2004a).

Vitamins

Vitamins are small molecules not found in great quantity in foods, nevertheless are essential for proper functioning of the body. Being smaller molecules, the primary effects of radiation on vitamins at low and medium doses are not considerable (Miller, 2005). However, the antioxidant vitamins can combine with free radicals generated through irradiation and lose some of their influence. Niacin (B3) and pyridoxine (B6) (of the water soluble vitamins) are reasonably resistant to radiation effects, while ascorbic acid (C) and particularly thiamin (B1) are least resistant. Of the fat-soluble vitamins, only vitamins E and A evidence any radiation sensitivity. The radiation-sensitive vitamins can be rather protected by the exclusion of oxygen and by irradiating at reduced temperatures (Stewart, 2004a, 2004 b; The Institute of Food Science and Technology, 2006).

In summary, the macronutrients (carbohydrates, proteins and lipids) are not noticeably affected by low and medium range doses with regard to their nutrient content and digestibility. Indeed, heating, drying and cooking may cause upper nutritional losses. In addition, after irradiation, carcinogenic aromatic and heterocyclic ring compounds that are produced during cooking at high temperatures are not observed. However, the structural properties of the fibrous carbohydrates in medium-high and high radiation doses can be degraded and lipids can become rancid, leading to a loss of food quality. Thiamine (of the micronutrients) is of concern because of its relatively high sensitivity to the effects of radiation, so the foods that contain it (pork, for example) are excellent candidates for irradiation to develop food safety.

APPLICATIONS OF FOOD IRRADIATION

Applications of food irradiation are usually organized into three categories according to the range of delivered dose.

Low-Dose (<1KGy)

a. Sprouting inhibition

In order to provide consumers a year-round supply of various sprouting foods, such as potatoes, yams, garlic and onions, storage durations of up to several months are often necessary (Ahari and Safaie, 2008; Ahari and Zafarani, 2008; Bibi et al., 2006). Sprouting can be inhibited by refrigeration and the application of various chemicals such as hydrazide (preharvest) and isopropyl chlorocarbamate (postharvest). But, refrigeration is expensive and particularly so in the tropical and subtropical zones of the world. Whereas, the chemical treatments are relatively cheap and efficient, they do leave residues and many countries have banned their usage for health reasons. In such instances, irradiation can be recommended as a reasonable alternative. Sprouting prevention and reduced rotting and weight loss have been observed in potatoes, garlic, onions and yams in the range of 50 -150 Gy (IAEA, 1996; Lagoda, 2008; Marcotte, 2005).

b. Insect disinfestations

The best control of insects in grain and grain products can be achieved by using fumigants such as ethylene dibromide or ethylene oxide (IAEA, 1996; Landgraf et al., 2006). Until 1984, fruits and vegetables from infested areas were fumigated with chemicals to meet he quarantine regulations. However, the use of these chemicals has been banned or strictly restricted in most countries for health and environmental reasons. Whereas heat and cold treatments are capable of insect disinfesttations, they can also acutely degrade the taste and appearance of the produce (Marcotte, 2005; Stewart, 2004b). Radiation processing has therefore been suggested as an alternative to fumigation. Disinfestations is intended at preventing losses caused by insects in stored grains, pulses, flour, cereals, coffee beans, dried fruits, nuts and dried fish (Farkas, 2004; Landgraf et al., 2006). Practical experience shows that the required radiation dose is in the range of 150 - 700 Gy. A dose level of 250 Gy can be effective on quarantine treatment of fruit flies, whereas a dose of 500 Gy can control all stages of most pests (Farkas, 2004; Miller, 2005).

Medium-Dose (1 - 10 KGy)

a. Food borne pathogens

Beef, Pork, poultry, seafood, eggs and dairy products are all recognized as major sources of food borne illness. The most serious contaminants are *E.coli*, *listeria* and tapeworm for beef. For poultry and eggs, the predominant pathogens are salmonella and campylobacter. Excellent control of all these organisms can be achieved with doses in the range of 1 - 3 KGy (Patterson, 2005; World Health Organization, 2005; Ziebkewicz et al., 2004).

b. Shelf-life extension

The same dose levels appropriate for control of food borne pathogens can also significantly extend the shelf life of the products just discussed by reducing populations of spoilage bacteria, molds and yeasts. For example, a dose of 2.5 KGy can extend the shelf life of chicken and pork by as much as a few weeks, while the shelf life of low-fat fish can be extended from typically 3 - 4 days without irradiation to several weeks with 5 KGy (Patterson, 2005). In addition, the shelf life of various cheeses can be extended significantly by eliminating molds at doses of less than 0.5 KGy. Finally, shelf life extension for strawberries, carrots, mushrooms, papayas and packaged leafy vegetables also appears to be promising at dose levels of a few KGy or less (Bibi et al., 2006; Hammad et al., 2006). Irradiation of mushrooms at 2 - 3KGy inhibits cap opening and stem elongation and can be increased at least by two-fold (by storage at 10°C). Treatment of strawberries (which are spoiled by *Botrytis* sp.) with a dose of 2 - 3 KGy, followed by storage at 10°C can result in a shelf life of up to 14 days (Ahari and Safaie, 2008).

Ripening in bananas, mangoes and papayas can be delayed by irradiation at 0.25 - 1 KGy. It is important to irradiate them, before ripening starts (Hammad et al., 2006; Lagoda, 2008; Marcotte, 2005).

c. Spice irradiation

The fresh plants from which spices are derived are almost always contaminated by microorganisms from the soil, windblown dust and by bird droppings. During the drying process, these microorganisms can grow to population densities exceeding 10^6 organisms per gram of material (Marcotte, 2005). When used as seasonings in the manufacture of processed foods for which the manufacturing process does not include a sterilizing step, these organisms can cause rapid food spoilage and can lead to food borne illness. Since moist heat treatment is not generally suitable for such dry products, spice producers in the past routinely used fumigants for disinfestations. Producers are now increasingly turning to ionizing radiation. In fact, the commercial irradiation of spices has been approved and practiced in many countries for several years. Doses of 5 -10 KGy usually give quite satisfactory results (elimination of bacteria, mold spores and insects) without negative impact on chemical or sensory properties (Farkas, 2004; IAEA, 1996; Koopmans and Duizer, 2004).

High-Dose (>10 KGy)

Some foods such as fresh fruits and vegetables deteriorate when subjected to high radiation doses. However, other foods, including meat, poultry and certain seafoods do maintain good quality, provided that certain precautions are taken. As a result, it is possible to effectively sterilize these foods with doses in the range of 25 - 45 KGy (Stewart, 2004a, 2004b; The Institute of Food Science and Technology, 2006). To prevent off-flavors resulting from lipid oxidation, oxygen must be excluded by vacuum packaging and the irradiation must be performed at low temperatures (-20°C to -40°C). Foods which are preheated to inactivate enzymes can be commercially sterilized such as it occurs in canning. These products can be stored at room temperature almost indefinitely. While these additional procedures and high doses significantly increase costs, these products are nonetheless important for hospitalized patients with suppressed immune system and NASA astronauts (Patterson, 2005; Scott and Suresh, 2004).

PACKAGING FOR IRRADIATED FOODS

Since food is often pre-packaged before radiation, it is possible that irradiation might either influence barrier properties or that radiolysis products formed in the packaging might be absorbed into the product (Deeley, 2002; Hammad et al., 2006). This subject is covered in “High-dose irradiation: Wholesomeness of food irradiated with doses above 10 KGy” (World Health Organization, 2005). FDA in the USA requires that packaging be evaluated and accepted before irradiation. Ionizing radiation rarely creates new compounds and usually only serves to increase the size of peak (indicating the increase in quantity of products already present). Any novel compounds are generally of low molecular weight. These possibly already exist in the unirradiated polymer but are desorbed from the polymer over time. Any product unique to irradiation will only occur at very low levels. A standard level of 0.5 ppb for non-carcinogenic compounds has been set; below which level the compounds are considered too insignificant to warrant rigid concern. The original packaging materials (polyolefin’s, polystyrene, cellophane, vinylidene chloride copolymers, etc) were approved back in 1964. In 2001, the FDA determined gamma rays, X-ray and E-beam to be equivalent in conditions of types and levels of radiolysis products generated in the packaging materials used in pre-packaged foods before irradiation. Unique chemical markers present in irradiated packaging have not been recognized. Labeling is required, either “irradiated” or “treated with ionizing radiation” coupled with the symbol illustrated (Deeley, 2002; Johnson and Estes, 2004) (Figure 1).

IRRADIATION FACILITIES

The kind of radiation used in processing materials is restricted to radiations from high energy gamma rays and electron accelerator.

Gamma irradiators

Gamma-ray forms part of the electromagnetic spectrum and occurs in the short-wavelength, high energy region of the spectrum and has the greatest penetrating power. Gamma rays come from spontaneous breakdown of radionuclides. Certain radiation sources can be used in food irradiation. These are: the radionuclide’s cobalt-60 (with a half-life of 5.3 years) or cesium-137 (with a half-life of 30 years). ^{60}Co are used almost absolutely for the irradiation of food by gamma rays (Figure 2.). The radiation source used in the gamma facilities consists of sealed elements of ^{60}Co or ^{137}Cs which are typically linear rods or pencils arranged in one or more planar or cylindrical arrays (Suresh et al., 2005).

In the case of a gamma irradiator, the radionuclide source continuously emits radiation and when not being used to treat food, must be stored in a water pool to absorb the radiation energy and protect workers from exposure (if they must enter the irradiation room).

Electron accelerator (electron and X-ray modes)

Electrons can be produced from machines capable of

Figure 1. International logo known as the radiation symbol for irradiated food.

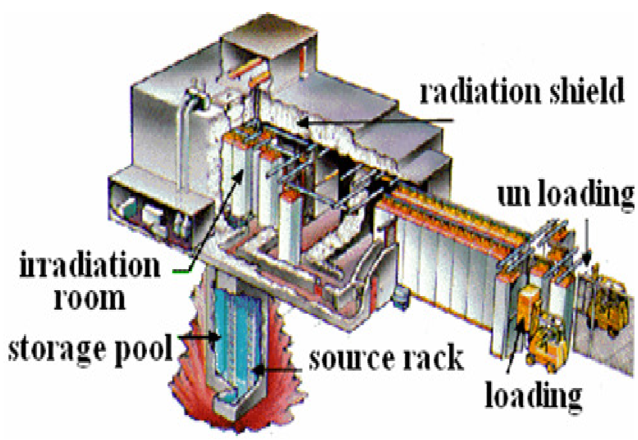

Figure 2. Gamma irradiator for food products.

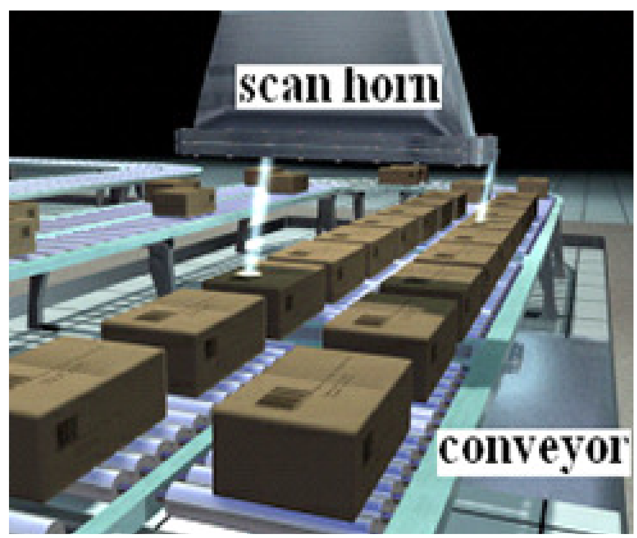

Figure 3. Electron beam irradiator for food processing.

accelerating electrons to near the speed of light by means of a linear accelerator. Since electrons cannot penetrate very far into food (compared with Gamma or X-rays), they can be used only for treatment of thin packages of food (Figure 3.). Thus, to treat the surface or a thin layer of a food, beta particles are usually chosen (that is electrons). These are easy to produce electronically, but they do not have deep penetrating power.

To treat a bulky product such as an entire sack of spices, one would choose gamma rays (X-rays, only more powerful). Machine producing high-energy electrons operates on electricity and can be switched-off (Suresh et al., 2005).

X-ray is similar to gamma radiation from radioactive isotopic sources. Although their effects on materials are generally similar, these kinds of radiation differ in their energy spectra, angular distributions and absorbed dose rates. The origin of gamma and X-rays is the main difference between them (Johnson and Estes, 2004;

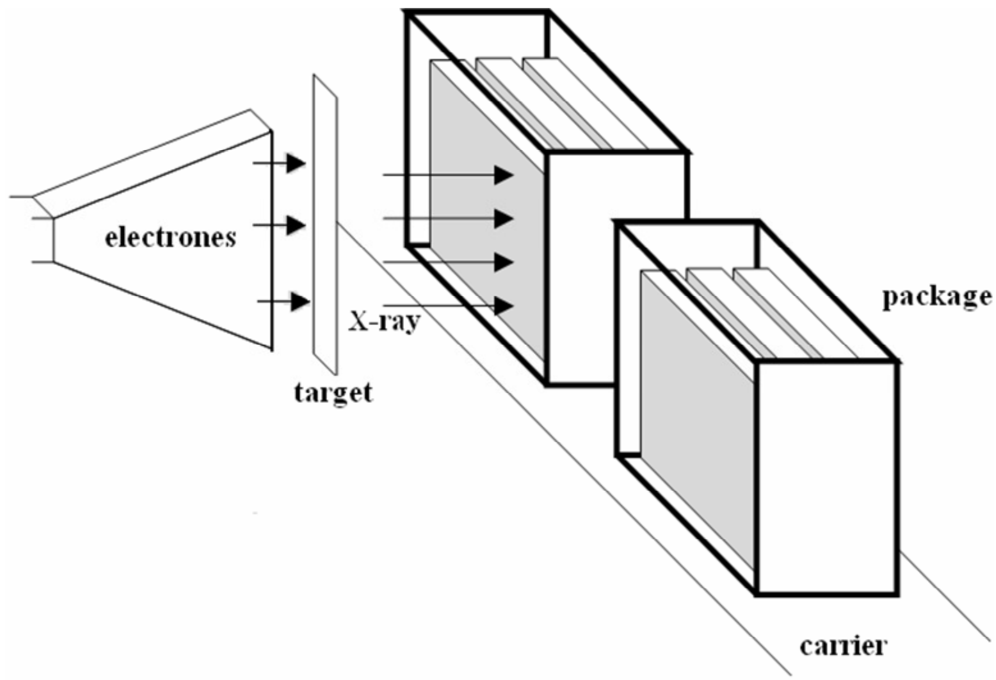

Figure 4. Schematic diagram of a typical x-ray irradiator.

Suresh et al., 2005).

X-rays with varying energies are generated by machine, having a maximum energy of five million electron volts (Mev) (amount of energy gained by an electron when it is accelerated by a potential of one volt in a vacuum). It is produced when a beam of accelerated electrons bombards a metallic target (Figure 4).

ACCEPTANCE AND TRADE

In spite of the fact that irradiated foods and the process of food irradiation have been carefully tested and the greater quality of treated products recognized, the quantity of irradiated foods in the global food trade is not significant. Some countries have regulatory approvals in place for irradiation processing of one or more food products, but not all these countries are virtually applying the technology for a restricted number of food items. The lack of acceptance of food irradiation has been mostly because of misconceptions and irrational fear of nuclear connected technologies. Also, people are confused and fail to differentiate irradiated food from radioactive foods. At no time throughout the irradiation process does the food come into contact with the radiation source and, by using gamma rays or electron beams up to 10 MeV, it is not probable to induce radioactivity in the food (Johnson and Estes, 2004; Marcotte, 2005).

When customers are given information about the process and a chance to try irradiated goods for themselves they are much more likely to recognize the technology. Market trials have also met with success. Radioactive foods are those which have become by chance infected by radioactive substances from weapons testing or nuclear reactor accidents. Many surveys have been carried out (mostly in the USA) to tax consumer's attitudes to food irradiation (Johnson and Estes, 2004; Marcotte, 2005).

As a general rule, consumers are conservative and unless properly explained to, they are reluctant to accept products processed by new technologies and especially when it comes to irradiated foods. Many consumers are initially hostile to irradiation but when the process is explained to them they become generally more in favor. There is a role for respected professional bodies to inform consumers of the advantages and limitations of the technology so that they can make informed decisions on buying and eating irradiated foods (Landgraf et al., 2006; Marcotte, 2005).

PERSPECTIVES

More than 100 years of research that have gone into the accepting of the safe and successful use of irradiation as a food safety method is more than any other technology used in the food industry today, even canning (Scott and Suresh, 2004). The safety and efficacy of the technology has been continually considered and judged acceptable on available confirmation. This has resulted in international bodies including the World Health Organisation (WHO), the Food and Agriculture Organisation (FAO) the International Atomic Energy Agency (IAEA) and Codex Alimentarius commending the process. Irradiation is very successful against living organisms which contain DNA and/or RNA but do not cause any significant loss of macronutrients. Proteins, fats and carbohydrates undergo little modification in nutritional value through irradiation even with doses over 10 kGy, though there may be sensory changes. In the same way, the essential amino acids, essential fatty acids, minerals and trace elements are also unchanged. There can be a decrease in certain vitamins (mostly thiamin) but these are of the same order of magnitude as it occurs in other manufacturing processes such as drying or canning (thermal sterilization) (IAEA, 1996; Landgraf et al., 2006; World Health Organization, 2005). Consequently, with modest radiation doses (1 - 5 KGy), it is probable to successfully destroy the organisms responsible for food borne disease and spoilage with no effect on the nutritional and sensory qualities of foods (Lagoda 2008, Miller 2005).

A maximum overall average dose of 10 kGy was measured adequate for the majority of food applications. To date, over 50 countries have given agreement for the irradiation of over 60 foods and food products on either a conditional or unconditional basis and these figures are growing annually. Spices, dried herbs and vegetable seasonings are most common food products to be treated with over 90000 tons (being irradiated in 2000). Irradiation of hamburgers in the USA rose from 6,800 tons in 2002 to over 22,000 tons in 2003 (Koopmans and Duizer, 2004; Miller, 2005). About 9 million tones of ground beef and papaya were irradiated (in Hawaii) in 2003. 1,754 tones of herbs and spices were irradiated (in South Africa) during 2004 (The Institute of Food Science and Technology 2006).

There is growing public consciousness on food safety and quality combined with current incidences of food-borne pathogens (Patterson, 2005; The Institute of Food Science and Technology, 2006). The rate of irradiation ability is becoming plainer as food security and consumers' safety questions are discussed. Advertising trials of irradiated food have been conducted over the past several years in countries such as France, Hungary, USA, Holland, Belgium, Argentina, Chile, China, Poland, Thailand, Indonesia, Bangladesh, India, Pakistan and the Philippines, all with favorable outcome.

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