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Food Irradiation as a Model Preservation Technique for the Food Industry: The Pros

9.1 Introduction

There's an old Chinese proverb that says "May you live interesting times". With respect to food irradiation (Borsa 2000), today's proponents and other observers of this technology have good reason to feel that indeed these are interesting times in this unfolding story. Studied intensively for more than half a century, and approved in some 50 countries around the globe for a wide variety of food products (ICGFI 2005), irradiation has been widely used for spices and other food ingredients for many years, but perishables (meat and produce) it is just now emerging into a significant commercial reality. In United States from basically a standing start at the beginning of this recent period, but powered by a high level of entrepreneurial energy and zeal, commercialization of irradiation technology in the food industry accelerated rapidly to reach heights far beyond anything previously achieved. Almost overnight, irradiated products appeared in literally thousands of retail and foodservice outlets (Sure Beam; 2001). Investors took notice (Titan Corp; 2001) and millions of dollars were raised for ventures targeting the opportunity presented by the very real needs recognised in food safety (Osterholm and Norgan; 2004) and quarantine security (IAEA 2004). The fact that those needs are evident all over the world added to the investment appeal. In these positive circumstances, interest in food irradiation rapidly escalated, giving rise to an exciting play in the investment world. Unfortunately, in 2004 a major business miscalculation intervened and this nascent industry suffered a significant setback just as it appeared to be getting over the hurdles associated with its launch. Not surprisingly, and to the great satisfaction of the sceptics and antitechnology activists, unreasonable expectations had exceeded the actual pace of adoption, especially by the major food processors, and the simple but inexorable math of the business world led

Sure Beam ™, the most prominent player in the field, to declare bankruptcy (Egerstrom 2004). This failure caused considerable consternation and uncertainty in the fledgling industry, raising concerns as to whether it would survive the setback. Now, more than 5 years later and with the dust largely settled, it appears that emerging from this uncertainty is a restructured food irradiation industry that is gradually regaining momentum. The fundamental benefits offered by the technology remain the same (Olson 2004) and the new path forward, although lacking the brash boldness and dash of the Sure Beam ™ approach, offers prospects for a more sustainable long – term future.

9.2 Description

Three types of ionizing radiation are used in commercial radiation to process products such as foods and medical and pharmaceutical devices (International Atomic Energy Agency [IAEA], 1982): radiation from high-energy gamma rays, x-rays and accelerated electrons. In accordance with the CODEX General Standard for Irradiation Foods (Codex Alimentarius Commission, 2003), only these ionizing rays are authorised to be used in food irradiation applications. These types of radiation are called “ionizing” because their energy is high enough to dislodge electrons from atoms and molecules and to convert them to electrically charged particles called “ions.” Ionizing radiation may originate from different sources:

- Gamma rays which are produced by radioactive substances (called radioisotopes). The approved sources of gamma rays for food irradiation are the radionuclides cobalt- 60 (60Co; the most common) and cesium - 137 (137Cs). They contain energy levels of 1.17 and 1.33 MeV (60Co) and 0.662 MeV (137Cs).

- Electron beams, which are produced in accelerators, such as in a linear accelerator (linac) or a Van de Graaff generator at nearly the speed of light. Maximum quantum energy is not to exceed 10MeV.

- X-rays or decelerating rays, which can be likewise produced in accelerators. Maximum quantum energy of the electrons is not to exceed 5MeV.

Gamma rays and X-rays form part of the electromagnetic spectrum, like radio waves, microwaves, ultraviolet, and visible light rays. Gamma rays and X-rays are in the short wavelength, high –energy region of the spectrum. Both gamma and X-rays can penetrate foods to a depth of several decade centimetres. Energies from the previously mentioned radiation sources are too low to induce radioactivity in any material, including food. There is wide expertise in the design, building, and operation of both radionuclide and electrical machine irradiation facilities (Leemhorst and Miller, 1990). Radionuclide facilities are currently used for the treatment of food and for non-food applications, such as sterilization of medical supplies and for pharmaceutical, cosmetics, and veterinary products. Electron accelerators are used in the manufacture of certain packaging materials (e.g., cling film) and in the treatment of plastic wire insulation to improve its properties. Commercial irradiation facilities for food are available in approximately 50 countries. Food irradiation plants may be operated in batch or continuous mode. Batch facilities are considered to be more flexible and able to accommodate a wide range of doses (World Health Organisation, 1988). Continuous facilities are better able to accommodate large volumes of food products, especially when treating a single food, at a specific dose. Mobile irradiations have been used in research for the treatment of seasonal food, such as fruits and vegetables, and for fish irradiation on board ships. A comparison of radionuclide irradiators and electron accelerators is shown in Table 9.1. A food irradiation facility is composed of the following elements:

- A source of radiation (i.e., radionuclide or electron beam).
- Biological shielding to protect personnel operating the facility from radiation exposure.
- A carrier or conveyor system to take food product into the vicinity of the source for processing.
- An air evacuation system.

Table 9.1 *Comparison of Radionuclide Irradiators and Electron Accelerators; From Fink and Rehmann (1994).*

Radionuclide Irradiators	**Electron Accelerators**
Good penetration power of gamma rays; can be used to treat food in large packaging units	Relatively limited penetration power (5 8 cm).
Low dose rate	High, variable dose rate; allows high throughput (e.g., grain).
High reliability	More sensitive to breakdown; need for specialized personnel for regular maintenance.
Need to replenish radionuclide source	High requirements for power and cooling Machine can be switched off.
	Small units of equipment could be integrated into a production line.

- A safety interlock/control console system, which ensures that conveyor movement occurs when the source is exposed or the machine is switched on (no conveyor movement when the source is in a ‘‘safe’’ position or the machine is turned off) (Farkas, 1988).

The food irradiation facilities do not become radioactive and do not create radioactive waste. 60Co is manufactured in a commercial nuclear reactor by exposing nonradioactive cobalt to intense radiation in the reactor core. The cobalt sources used in irradiation facilities decay by 50% in 5 years and therefore require periodic replacement. The source are removed from the irradiation when the radioactivity falls to a low level, usually between 6 and 12% of the initial level (this takes 16-21 years for 60Co). The small radioactive cobalt “pencils” are shipped back to the original nuclear reactor. The shipment occurs in special hardened steel canisters that have been designed and tested to survive crashes without breaking. Cobalt is a solid metal and even if something should break, it will not spread through the environment. 60Co may also be disposed of as a radioactive waste. Given its relatively short half – life (5 years) and its stable metallic from, the material is not considered to be a problematic waste. Electron beam and X-ray facilities do not use or create radioactive substances (IAEA, 1992).

9.2.1 Application

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

Low-dose (<1 kGy)

(a) Sprouting Inhabitation

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 Safaie2008; Ahari and Zafarani; 2008; Bibi et., 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 residue 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 for 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 the 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 disinfestations, 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 150-700 Gy. A dose level of 250 Gy can be effective on quarantine treatment of fruits flies, whereas a dose of 500 Gy can control all stages of most pests (Farkas, 2004; Miller, 2005).

Meduim – Dose (1-10 kGy)

(c) Food Borne Pathogens

Beef, Pork, Poultry, Seafood, eggs and dairy products are all recognised as major source 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 Organisation, 2005; Ziebkewicz et al., 2004).

(d) Shelf Extension

The same dose levels appropriate for food borne pathogens can also significantly extend the shelf life of the products just discussed by reducing populations of spoilage bacteria, moulds, 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 moulds 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 2-3 kGy inhibits cap opening and stem elongation and can be increased at least by two fold (by storage at 10 ℃). Treatment of strawberries (which are spoiled by Botrytis sp.) with a dose of 2-3 kGy, followed by storage at 10 ℃ 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 start (Hammad et al., 2006; Lagoda, 2008; Marcotte, 2005).

(e) Spice Irradiation

The fresh plants from which spices are derived are almost always contaminated by microorganisms from soil, with blown dust and by bird droppings. During the drying process, these microorganisms can grow to population densities exceeding 106 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 satirizing 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 practices in many countries for several years. Doses of 5-10 kGy usually give quite satisfactory results (elimination of bacteria, mould 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 sea foods 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 flavours resulting from lipid oxidation, oxygen must be excluded by vacuum packaging and the irradiation must be performed at low temperatures (-20 ℃ to -40 ℃). 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).

9.3 General Analysis

9.3.1 Global Perspective

Over 90, 000 tonnes of dried herbs, spices, and vegetables seasonings were irradiation in some 20 countries in 2000, with around half of this quantity being irradiated in the USA. Food irradiation is classified as a food additive in USA legislation. Since 2002, beef has also been irradiated in the USA and sold to a growing market. One major E-Beam facility in the USA overestimated the expected uptake of irradiated beef for the school Lunch Programme and went out of business in 2004. However, a Texas – based investment firm purchased the assets in June 2005 and in late December, the plant began processing about 40 000 pounds per day of animal feed for mills in the US Midwest. Fermented pork sausages (Nam) usually consumed raw in Thailand have been irradiated since 1986 (Food Standard Agency 2004). A survey of the extent to which foods are irradiated in the EU, carried out by the commission of the European Communities. (EC. 2004) found: Belgium irradiated 6.613 tonnes (frozen 'frog' legs, frozen seafood and spices/seasonings were the principal products) Germany irradiated 795.3 tonnes (dried aromatic herbs and spices and herbal tea-for expert to Poland comprises the majority of products) France irradiated 5,129 tonnes (mechanically recovered chicken meat, spices and frozen frogs' legs were the principal products) The Netherlands irradiated 7,114.4 tonnes (dehydrated vegetables, spices and herbs, frozen poultry and foods intended for export to third countries comprises the majority No food was irradiated in the UK.

In the UK very few, if any, irradiated food products are on retail sale. A survey was carried out in 1996 and repeated in 2002 to investigate whether irradiated food is on sale in UK but not labelled as such (Food Standards Agency, 2002). In this country, 543 samples without declared irradiated ingredients covering three food categories (203 herbs and spices, 138 dietary supplements and 202 prawns and shrimps) were analysed. These three food categories were selected because a number of reports had claimed that these products were likely to have been irradiated and unlabelled. One of the herbs and spices (ground nutmeg), five prawns and shrimps and forty – four dietary supplements (42%) were found to be irradiated ingredients without appropriate labelling. The analytical methods used PSL (photo stimulated luminascene) as a screening procedure while TL (thermolumunescence) was used to confirm those samples which gave 'positive' or 'intermediate' (suspected irradiation) when analysed by PSL. Comments were elicited from all the retailers or suppliers of the offending products. These varied from a declaration that the company does not knowingly sell irradiated food to queries over the accuracy of the analytical results or that an excipient ingredient (talc) may have been responsible for the false positive. The food (Control of irradiation) Regulations came into force in 1991 and was amended in 2001. On 15 June 2004, the UK Food Standards Agency (FSA) issued an alert (Food Alert for Information (FAFI) on noodle based snacks due to undeclared presence of irradiated ingredients contained in the vegetable seasoning mix of the dried spicy soup.

9.3.2 Consumer Attitude to Food Irradiation

The introduction of irradiated foods has many analogies with the introduction of pasteurisation of milk over a century ago-one of the most significant advances ever made in food safety. The principal allegations advanced against the introduction of thermal pasteurisation of milk and food irradiation (cold pasteurisation) are very similar (Satin, 1996). Opponents of both thermal pasteurisation of milk and cold pasteurisation of foods by irradiation have claimed:

- Nutritional value will be diminished.
- The price will be increased.
- Possibly unsafe.
- Will be used to mask filthy products.
- Legalises the right to sell stale food.
- Is unnecessary.

- Is meddling with nature.
- Will take the ‘life’ out of the product.

Many surveys have been carried out (mostly in the USA to assess consumer attitude to food irradiation e.g. Bruhn and Schutz 1989; Resurrection et al 1995; Fox 2002; Nayga et al. 2005). Results have consistently shown that many consumers have misconceptions about the technology and believe that it makes food radioactive. When consumers are given information about the process and a chance to try irradiated products for themselves they are much more likely to accept technology. Market trials have also met with success. One of the most successful market trials of irradiated foods was carried out in 1991 in a small food store in Chicago, USA. Clearly labelled irradiated strawberries, oranges, and grapefruits outsold their non-irradiated counterparts by a ratio of 9.1. In the following season, irradiated unirradiated product. This positive experience encouraged approximately 60 stores in India, Illinois, and Ohio to sell a variety of irradiated foods (Pszczola, 1992).

In one study, the sensory characteristics and consumer acceptance of E-Beam irradiated (at 1, 2, and 3 kGy) RTE meats (frankfurters and diced chicken) were evaluated by a consumer panel of 50. After 18 days of refrigerated storage for the chicken and 32 days for the frankfurters the acceptability of the irradiated products was significantly higher than for the non-irradiated (Johnson et al, 2004). The same authors compared attitudes towards irradiated foods over ten years 1993 to 2003. Consumer awareness was no higher in the 2003 study than in 1993 but more consumers were willing to buy more irradiated foods in the 2003 than in 1993 (69% and 29% respectively). Consumers in both studies showed more concern over pesticides and animal residue, growth hormones, food additives, bacteria and naturally occurring toxins than irradiation. The slight concern expresses regarding irradiation has decreased significantly among this group. Approximately 76% prefer to buy irradiated pork and 68% prefer to buy irradiated poultry to decrease the possibility of illness from *Trichinella and Aalmonellae* respectively (Johnson et al, 2004).

In another study, 113 consumers who were over 18 and consumed ground beef at least once a month were selected for a trial in Mesa, Arizona to examine the effects of products exposure and consumer education about irradiation. Products exposure was found to exert no effect while educating consumers had most significant impact on their views of food irradiation. Sensory evaluation showed that consumers could not differentiate between irradiation and non-irradiated ground beef either at the beginning of the study or after months frozen storage. Groups that receive irradiation education were more accepting of the technology and more consumers in these groups changed their perceptions of irradiation in a positive way (Hamilton et al, 2004).

A similar study (Nayga ety al. 2005) carried out in 2002 in four Texan towns (Austin, Houston, San Antonio, and Waco) involved face to face interview with 484 customers intercepted at random at supermarkets entrances. Each respondent was initially asked to say to which of four consumer segments they belonged "strong buyer", "interested", "doubter" or "rejecter" of irradiated foods. They were then presented with two informative statements, the first pertaining to the nature and benefits of food irradiation. The second statement described the two different processes of irradiation (gamma rays and E – Beam) and also involved watching a short video illustrating the E-Beam process. The results are presented in the accompanying table. Males were more inclined to change their view than females and switch towards the segment more likely to purchase irradiated foods.

***Table 9.2** Effects of Consumer Education on Consumer Attitudes.*

	Strong buyer	Interested	Doubter	Rejecter
initially	8.4%	73.8%	13.9%	3.8%
after first statement	28.3%	66.6%	3.4%	1.7%
after second	42.2%	54.0%	3.2%	0.6%

These results strongly support the thesis that supplying digestible information can be highly effective in shifting consumer attitudes in favour of purchasing irradiated foods. The participants were also asked about their perception of the Radura symbol: 67.1% considered it an assurance of quality. 5.5% considered it a warning signal and avoided the product. 17.1% indicated it did not affect buying decisions. 10.3% did not recognise the symbol.

Consumer acceptance of irradiated foods in the USA is being reinforced by three key – drives; these being (i) growing public awareness of the risks from bacteria in meat products, (ii) growing levels of educational media coverage on food irradiation and (iii) fear of bioterrorism on centralised food production. (Delay, 2002). In the EU Member States the use of irradiation inorganic food expressly prohibited (EU Regulation 2093/91). This sector is enjoying the fastest growth of any sector of the foods industry in the UK and many other European countries and thus represents an expanding market sector not open to irradiated foods.

9.4 Actualisation

9.4.1 The Case of Carcinogens and Their Relation to Irradiation

Reduction of Volatile N-Nitrosamine and Nitrite Content with Irradiation

Human exposure to carcinogen N-nitrosamines occurs through endogenous and exogenous sources such as foods and beverages (Chung, 1996, 2000). The major

N-nitrosamines found in food systems are notrosodimethlamine (NDMA) and nitrosopyrrolidine (NPYR) (Lijinsky, 1999). Low levels of biogenic amines in food are not considered a serious risk. However, if the amount consumed is high enough, or normal pathways of amine catabolism are inhibited, various physiological effects may occur, such as hypotension or hypertension, nausea, headache, rash, dizziness, cardiac palpitation and emesis, and even death (Rawless et al., 1996). The formation of N-notrosamines in foods occurs due to an addition of nitrite, smoking, drying with combustion gas, salting, pickling, fungal contamination, or food contact materials (Thicker, 2000). Nitrite is an essential addictive for developing typical cured meat colour, flavour, and texture.

Table 9.3 *Effect of Irradiation on Protease Inhibitors in Various Products.*

Food Type	Gamma Irradiation Dose (kGy)	Irradiation Effect	Reference
Soybean seeds	0, 1, 5, 10, 20, 40, 60, 80, and 100	Inhibition of 25.4% trypsin inhibitor activities and 16.7% chymotrypsin inhibitor activities were found when the soybean seeds were irradiated at 100 kGy.	Hafez et al., 1985
Safflower oilcake	0.07 0.1	The trypsin inhibitor was inactivated at 0.42 kGy, whereas the chymotrypsin inhibitor remained active, even at the much higher dose of 0.1 kGy. The *in vitro* digestibility values also showed a significant improvement after irradiation.	Joseph and Dikshit, 1993
Karanja oil seed residue	1, 5, 10, and 50	Trypsin and chymotrypsin inhibitor activities retained in the cake on exposure to 50 kGy dose were 22 and 16%, respectively.	Rattansi and Dikshit, 1997
Broad bean	0, 2.5, 5, 7.5, and 10	Irradiation treatment reduced the trypsin inhibitor of irradiated seeds. In subsequent dose of irradiation, the decrease in trypsin inhibitor was proportional to the irradiation dose.	Al Kaisey et al., 2003
Soybean grains	2, 4, and 8	Radiation with dose of 2 kGy promoted reduction of 11.19% on average in trypsin inhibitory activity, and a dose of 4 kGy reduced 28.59% and that of 8 kGy reduced 37.60%.	de Toledo et al., 2007

Several methods have been developed to inhibit nitrosamine formation with the use of green tea (Yang and Wang, 1993), ascorbic acid (Vermeer et., 1999), and phenol compounds (Bartsch et al., 1988). Fiddler et al. (1981) found that irradiation sterilization (30 kGy) reduced residual nitrite in bacon prior to frying, thereby reducing volatile nitrosamines after frying, and destroyed performed volatile nitrosamines in the bacon before irradiation. Hu and Song (1988) reported that g-irradiation could reduce nitrite from 41.2 to 21.0 ppm in eel at 5 kGy of irradiation. Jo et al. (2003a) studied the packaging and irradiation effect on pork sausage. Emulsion –type cooked pork sausage was made with (156ppm) or without $NaN0_2$ and packed at 4 ℃ in aerobic, vacuum, and CO2 (100%) conditions. The samples were irradiated at 0 and 5 kGy. Residual nitrite content was the lowest in the sausage with CO_2 packaging, but no irradiation effect was found at 5 kGy. The 5 kGy irradiation eliminated the nitrodopyrrolidine (NPYR) in the sausage with vacuum or CO_2 packaging at 0 weeks. At 4 weeks, the NPYR content in the sausage regardless of packaging. Moreover, irradiation at 5 kGy significantly reduced the NDMA content regardless of packaging method. The characteristics of nitrite radiolysis with g0rays were investigated by Ahn et al. (2003a). Sodium nitrite in deionized distilled water was irradiated at 0, 5, 10, 20, 25, 30 and 40 kGy. The sodium nitrite was reduced approximately 50% by 10 kGy irradiation, and complete degradation was shown over 40 kGy. When nitrite was nitrosated at different pH ranges (2, 3, 4, and 6) after irradiation, the irradiated nitrite could not form the carcinogenic N-nitrosodimethylamine. The authors concluded that g-irradiation could be effectively used for reducing nitrite, and radiolytically destroyed nitrite could not form carcinogenic N-nitrosamine, even in a model human stomach condition. Ahn et al. (2002a) studied the reduction of carcinogenic N-nitrosamines and residual nitrite in model system sausage with irradiation. Sausages were packed under air and under vacuum and irradiated at 0, 5, 10, 20, and 30 kGy. The residual nitrite levels were significantly reduced with g-irradiation, and in vacuum packaging the reduction was done dependent. Vacuum packaging proved to be more effective than aerobic packaging for lowering the nitrite levels. In aerobic packaged sausage, NPYR levels were not affected by irradiation. However, after weeks of 20 and 30 kGy of irradiation, NPYR levels were reduced 47.7 -51.0% in VP compared to non-irradiated sausage. NDMA levels in non-irradiated aerobic and VP samples were significantly higher than those in 20-kGy irradiated samples. A significant difference was found between non-irradiated samples and samples irradiated with a 10-kGy or higher dose in aerobic packaging.

In conclusion, for reduction of NDMA and NPYR in sausage, 20 kGy of irradiation or higher was needed. Gamma irradiation was applied for the breakdown of the volatile N-nitrosamines, NDMA, and NPYR. NDMA and NPYR were dissolved in distilled water, dichloromethane, or ethanol and irradiated at 2.5, 5, 7.5, 10, 15, 20, and 25 kGy. The NDMA in dichloromethane was broken to the level of 448 ppb (mg/1) at 2.5 kGy, and NPYR was completely broken at the same dose. The NDMA required a dose of 10 kGy or higher of g-irradiation to achieve 99% breakdown. NDMA and NPYR dissolve in ethanol were comparatively stable to g-irradiation. At the dose of 20 kGy, NDMA and NPYR showed 95 and 100% breakdown, respectively. NDMA and NPYR dissolved in distilled water were easily broken down with g- irradiation, and all of the volatile N-nitrosamines were undetectable at 5 kGy or higher. NDMA and NPYR displayed 65-84% breakdown at 2.5 kGy, and NPYR was the most sensitive to g-irradiation. The results indicated that volatile N-nitrosamines in distilled water were easily decomposed with g-irradiation at doses of 5 kGy or higher (Ahn et al., 2002b). Ahn et al. (2003b) studied salted and fermented anchovy sauce spiked with or without NDMA and NPYR. Samples were irradiated at 0, 5, 10, 15, and 20 kGy. NDMA and NPYR reduction with irradiation was not observed in non-spiked samples at 0 weeks, whereas a significant reduction was observed after 4 weeks of storage at 15 ℃. NDMA and NPYR levels decreased with irradiation at 5 kGy or higher after storage at 15 ℃. After storage, the degraded nitrosamines with irradiation were not recombined. The impact of different doses of irradiation on NDMA content of pepperoni sausage, packages under air, and fermented anchovy sauce at Week 0 is shown in Figure 9.1. Byun et al (2004a) studied volatile NDMA and NPYR in irradiated pepperoni and salami sausages. These fermented sausages were packed under vacuum air, 100% CO_2, 100% N_2or

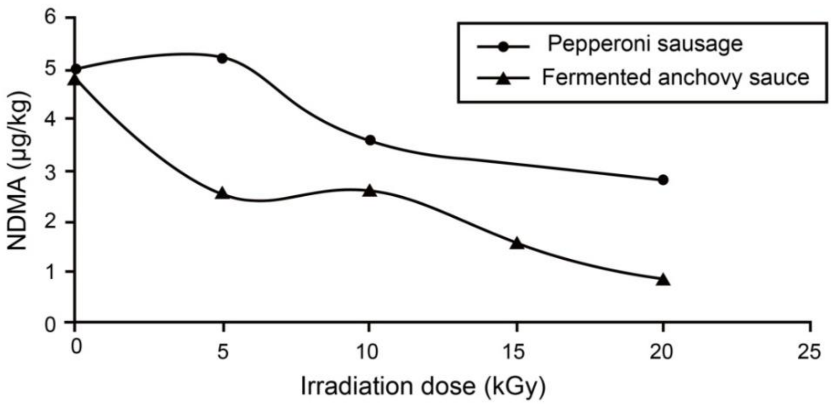

Figure 9.1 *Effect of different doses of irradiation on N-nitrosodimethylamine (NDMA) content of pepperoni sausage, packaged under air (Byun et al., 2004a), and fermented anchovy sauce at Week 0 (Ahn et al., 2003b).*

25% CO_2/75% N_2 and they were irradiated at 0, 5, 10 and 20 kGy and then stored for 4 weeks at 4 ℃. Irradiation significantly reduced the NDMA in the salami sausage at 0 weeks, whereas the NPYR was not detected in the sausage irradiated over 5 or 10 kGy. Regarding the pepperoni sausage, the VP showed lower nitrosamine content than that of the air packed. After storage for 4 weeks, the irradiated salami showed low NDMA and NPYR contents compared to non-irradiated ones. Results indicated that high dose of irradiation (>10 kGy) was required to reduce the carcinogenic N-nitrosamines in the fermented sausages. The effect of different doses of irradiation on NPYR content of pepperoni sausage, packaged under air, and fermented anchovy sauce is displayed in Figure 9.2. Ahn et al. (2004c) investigated the combined effects of irradiation and modified atmospheric packaging (MAP) on residual nitrite and NDMA in sausage during storage. Sausages were packed under air, vacuum, CO_2, N_2 OR CO_2/N_2 packaging and irradiated at 5 kGy. Residual nitrite was reduced by irradiation, and the contents were lower under vacuum or MAP than aerobic ones. Furthermore, NDMA was significantly reduced with a 5-kGy dose. Ahn et al. (2004b) investigated the irradiation effects on cooked pork sausage during storage at 4 ℃. Sausage with aerobic or vacuum packaging was irradiated at 0, 5, 10, or 20 kGy. It was found that irradiation treatment reduced the nitrite contents of sausage, and especially under vacuum, nitrite content decreased with g-ray dose in adose – dependent manner. Irradiation at 20 kGy reduced the residual nitrite contents to 31 and 17% under aerobic and vacuum packaging, respectively. After 4 weeks of storage, a decrease in residual nitrite content was reported in all samples, and the irradiation effect was still found. Residual nitrite contents of sausage irradiated at 5 kGy or higher were lower than those of non- irradiated control for both packaging conditions. NDMA contents in sausage with VP were decreased by irradiation at 10 and 20 kGy, whereas no different was found.

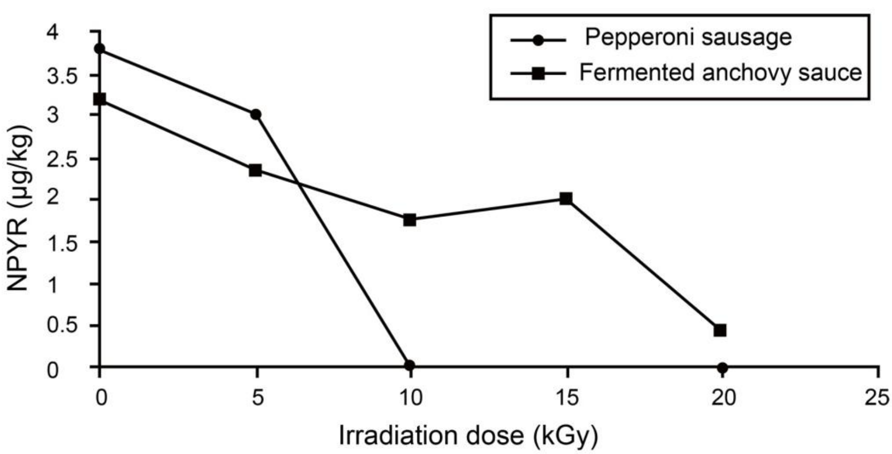

Figure 9.2 *Effect of different doses of irradiation on N-nitrosopyrrolidine (NPYR) content of pepperoni sausage, packaged under air (Byun et al. 2004a), and fermented anchovy sauce at Week 0 (Ahn et al., 2003b).*

In aerobic packaging at 0 weeks. Irradiation reduced NPYR contents in sausage with aerobic packaging, and NPYR was not detected by irradiation at 5 kGy or higher. After 4 weeks of storage, irradiation decreased NPYR contents in sausage with VP, whereas the packaging effect was not found during storage.

9.5 Discussion

More than 100 years of research that have gone into 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 accepted 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 thiamine) 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 Organisation, 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 their 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 90 000 tons (being irradiated in 2000). Irradiation of hamburgers in the USA rose from 6.800 tons in 2001 to over 22,000 tons in 2003 (Koopmans and Duizer, 2004; Miller, 2005). About 9 million tonnes bees and papaya were irradiated (in Hawaii) in 2003.1,754 tons 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 favourable outcome.

9.6 General Recommendations

The steps required to exploit the benefits of irradiation involve standardization, communication, and education. WHO, in collaboration with FAO and IAEA should:

- Coordinate the preparation of documentation and the drafting of appropriate technical language for adoption of standards by the Codex Alimentarius Commission.

- Prepare appropriate brochures and documents that integrate food irradiation into existing guidelines and rules governing the safe production, distribution and handling of food (in order to minimise the spread of biological contamination and incidence of food borne illness).

- WHO should take lead in advising international spread of pathogens in food irradiation, for preventing the international spread of pathogens in food and animal feed, for controlling food borne illness and for enhancing their availability of safe and nutritious foods.
- Organise and participate in appropriate training courses and workshops that educate food regulators and food workers about the role food irradiation could, and should, play as a control measure in the framework of application of the HACCP (Hazard Analysis and Critical Control Point) system.

9.7 Conclusion

Those in favour of food irradiation have a number of pros to support their stand. After more than 40 years of studies of the effects of irradiation on approved foods reflect that disease causing microorganisms are either eliminated or reduced. This includes E. Coli, salmonella, and a number of more dangerous food borne illnesses. These illnesses are not only health threatening, but also economic losses created are in the billions.

Irradiation on foods greatly decreases the loss of harvest due to bacteria, insects and spoilage and it reduces use of chemical pesticides, some that are very environmental harmful. Irradiation does not affect the environment as the radioactive materials are fully enclosed and then returned for recycling or disposal. There is also a good safety record for irradiation facilities. Also, food does not become radioactive like some fear.

Irradiation delays ripening and sprouting so food can be longer and nutrient losses from irradiation, which do occur to some extent, have been found to be no worse than loses from cooking and the levels recommended for irradiation does not result in significant loss of vitamin or create any deficiency. Those who are not in favour of irradiation state that since the amount of irradiation allowed does not eliminate all pathogens that the remaining are then radiation resistant and may create strains of hard to delete pathogens.

Also those against irradiation feel that there is not enough known about potential health problems associated with food that has been irradiated. Some people also fear possible devastating accidents at the irradiation facilities and if more foods are approved for irradiation more facilities will have to be built, increasing the risk of accidents. The prices for irradiated foods are slightly higher than other foods.

Food irradiation is done on a constant basis, food growers and sellers say that food irradiation is safe and is means of extending the shelf life of fresh foods. The benefits are high according to food sellers; irradiation kills disease-causing organisms. It also increases the safety of foods for people with low immunity system. It promotes longer life of vegetables in stores; it also prevents the vegetables from sprouting. It is also beneficial for grains; it kills or sterilizes insects that can be found in grains. It also allows fruits to be picked early and delay the ripening of the fruit until it gets to the supermarkets.

Irradiation is the process of exposing fresh foods to low amounts of x-rays to sterilize and prolong its life. Food suppliers say that it is safe and does not make foods radioactive. But the general public has problems with this observation; the general public believes that any radiation exposure holds a threat of health hazard. They also believe that consuming these x-rayed foods on daily basis will pose a threat of developing mutant organisms within the body.

There are government regulations in place that insure the use of certain irradiation processes. The process of x-ray irradiation is allowed, because x-rays travel through an object without leaving radioactive material behind. Food may be irradiated by exposure to cobalt and certain caesium isotopes these methods are considered cold sterilization. There is an exception to meats, x-ray is still allowed, but it takes higher doses of radiation to kill the parasites, salmonella bacteria, and other organisms. There is a warning, meats that are irradiated by irradiation are darker, fish and seafood become mushy, and irradiation of grains destroy the fats found in grains and make them taste sour.

In conclusion, the pros of use of irradiation outweigh the cons and humanity should now move to embrace the use of this novel preservation technique to enable enhanced global food security and safety.

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