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Irradiation in food processing: A Review

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Abstract
Most of the irradiation studies relating to quality issues have been carried out to date with raw meat, because irradiation is not permitted for use with meats containing additives, further processed or precooked RTE meat products. Therefore, future irradiation studies should be focused on further processed and precooked ready-to-eat meat products, especially in relation to investigating methods to prevent negative flavor, odor and taste modifications, as well as investigating approaches to improving microbial safety in these products. Additionally, limited research has been conducted to date on dried and semi-dried meat products. Dried and semi-dried meat products contain much lower levels of water than normal meat products, and thus the irradiation efficiency and the response of meat to irradiation could be different from those of normal products. Therefore, microbial and quality research on dried and semi-dried processed meat products is required.

Keywords: Irradiation, Food, Processing

1. Introduction

The first half of the last century could be called as the age of inventors (Diehl, 2002) [3] because in that period radiation facilities were not of suitable capacities for practical applications. However, from the middle of the XXth century, systematic research efforts, several national research programmes and international cooperations together with technical developments established a solid scientific and technical background for the utilization of this technology. Due to its uniqueness, lack of application history and experience, it was important and necessary to also clarify the wholesomeness (toxicological and microbiological safety and nutritional adequacy) of irradiated food. This required an unprecedentedly careful and wide-ranging effort of such testing, which was beyond even the capability of the most developed countries. Therefore, specific research programmes and international projects supported by specialized agencies of the United Nations such as the Food and Agricultural Organization (FAO), the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) were important partners in assisting progress. The most extensive one of such international cooperations was the International Project in the Field of Food Irradiation (IFIP, Karlsruhe) with the involvement of up to 24 countries between 1970 and 1982. International groups of experts, the Joint FAO/IAEA/ WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI), evaluated periodically (in 1964, 1969, 1976, and 1980) the results of wholesomeness testing. The JECFI reached a “landmark” decision at its 1980-meeting, reporting its main conclusions as “.the irradiation of any food commodity to an overall average dose of 10 kGy presents no toxicological hazard, hence, toxicological testing of food so treated no longer required.”, and “.irradiation of foods up to an overall average dose of 10 kGy introduces no specific nutritional or microbiological problems.” (WHO, 1981). The JECFI recognized that higher doses of radiation were needed for certain applications but did not consider the toxicological evaluation and wholesomeness assessment of them because insufficient data sets for this purpose were available that time.

Considering the potential role of food irradiation in the safety of food supply, the World Health Organization formed a positive attitude towards the utilization of food irradiation. For example, in collaboration with the FAO, the WHO published in 1988 a booklet entitled “Food Irradiation. A technique for preserving and improving the safety of food” (WHO, 1988). In its “WHO Golden Rules for Safe Food Preparation”, the WHO as Rule No. 1 (“Choose foods processed for safety”) states among others that “.always buy pasteurized as opposed to raw milk, and if you have the choice, select fresh or frozen poultry treated with ionizing radiation.”. Noting that unwarranted rejection of the food irradiation process, often based on a lack of understanding, may hamper its use in those countries likely to benefit most, WHO set up again a WHO Consultation on Food Irradiation in 1992, and published its detailed report in 1994, endorsing that “food irradiation is a thoroughly tested technique, that it has not been shown to have any deleterious effects when performed in accordance with good manufacturing practice, and that it can help to ensure a safer and more plentiful food supply by extending shelf-life, eradicating pests and inactivating pathogens" (WHO, 1994). It can be noted from these databases that food irradiation is currently approved for use in over 55 countries, and 68 food irradiation facilities registered worldwide, at least 25 of them being situated in Asia and Australia. In spite of these encouraging data, it is true that, due to opposing attitudes of certain activist groups forming "public opinion", inducing unfunded fears by misinformation, and unwillingness of legislators and industrial stakeholders to act, the implementation of the food irradiation process is seriously hampered, particularly in the European region.

With the possibility that the processing of foods by ionizing radiation may become more extensive than that by thermal processing, it becomes quite evident that a rigorous program must be established relative to safety in operation of radiation sources and in consumption of irradiated foods. The public health aspects involved in the radiation processing of foods, by either electron beams or y-rays may be considered through evaluation of the following factors in the testing of the process and product for safety.

(1) Safety in the operation of the radiation source.

(a) Proper irradiation dose and control of radiation dose by adequate dosimetry.

(b) Adequate precautions as to shielding.

(c) Prevention and elimination of contamination of product by radioactive isotopes during processing.

(2) Safety in the use or consumption of irradiated foods.

(a) Establishment of the lack of induced radioactivity at the current radiation doses used in processing.

(b) Feasibility of working at higher energy levels and the potential hazard, if any, involved through the presence in the food of short half-life isotopes

(c) *Toxicity* or *non-toxicity* of the irradiation end products of the food components, viz. fats, proteins and carbohydrates or even the vitamins.

(i) Toxicity or wholesomeness of the food will be established using several test animals through typical short term subacute toxicity experiments (8 weeks) or long term chronic toxicity experiments (104 weeks).

(ii) Through long term animal feeding experiments the effect of irradiated foods on growth, reproduction, lactation, life span and cellular enzymes can be properly evaluated.

(d) *Nutritional adequacy* of radiation processed foods must be assessed and comparisons made with raw food sand foods processed by conventional heat processing methods. Ionizing radiation can produce changes in the molecular structure of the macronutrients (fats, carbohydrates and proteins) and the micronutrients (especially those labile to radiation). Therefore, feeding experiments and biological procedures must be so designed to ascertain any deviations from the normal with respect to nutrient content.

(e) Alteration in *antigenicity* of proteins should also be explored with the probability that extensive molecular changes or rearrangements occur in food proteins undergoing radiation treatment. Using "primed" animals (guinea pigs), the extent of reduced allergenicity in irradiated proteins can be accurately measured.

(f) Since irradiated end products must be proven as toxic or non-toxic in animal and human feeding experiments, in similar manner animal feeding experiments must be set up to establish whether or not irradiated foods possess any induced *carcinogens.* Exhaustive investigations must, therefore, be undertaken to ascertain the carcinogenic properties, if any, of irradiated foods. Extracts from foods which contain compounds of known carcinogenic potential can be tested on mice and rats. The techniques used may include feeding, subcutaneous administration and skin painting.

(g) The effectiveness of ionizing radiation in processing foods from the standpoint of bacteriological safety must be firmly established. Not only must careful consideration be given to the absence of spoilage micro-organisms, but conclusive evidence must be obtained as to absence of pathogenic micro-organisms.

(h) Parasitological infestation of foods must also be considered, and the adaptation of radiation treatment of foods must be fully explored in the elimination of such public health hazards. (i) Since radiation sterilization and/or preservation of foods are an entirely new concept in food preservation, a testing program on wholesomeness must be comprehensive. Since man's experience for many years has been with heat treated, frozen and dehydrated foods, it is inevitable that comparisons in biological properties of irradiated foods with these types of foods will be made.

1.1. Irradiation

The term "irradiation" is used to describe the application of "ionizing" energy to a product to achieve a desired end result. Electron beam irradiation is a non-thermal intervention that does not alter the physical properties and characteristics of most foods when the proper dose is applied. Electron beam (eBeam) irradiation is also known as "electronic pasteurization" or "cold pasteurization." Results of electron beam irradiation mirror the food safety intervention results that are achieved by milk pasteurization, water chlorination, and the protection of the public's health through immunization against life-threatening or deadly diseases.

Irradiation is the only intervention available that will consistently reduce foodborne pathogens and adulterants to undetectable levels when the irradiation dose is properly and uniformly applied based on the food processor's or food manufacturer's established dose to achieve undetectable levels of foodborne pathogens and adulterants.

Irradiation is also the only intervention that will reduce foodborne pathogens and adulterants that are internalized in a food, such as raw beef, as well as those causing surface contamination, while leaving the food in the raw state. Cooking of a food such as ground beef is the only other intervention that provides safety that is comparable to electron beam irradiation. Electron beam irradiation leaves no chemical residues or compounds. Electron beam irradiation applied at any dose level does not make a food radioactive.

Irradiation has been scientifically researched with findings documented for over 100 years and has been found to be a safe, proven and well-established technological intervention used in the treatment of food to reduce harmful and deadly foodborne pathogens and adulterants, which can cause long-term illness, disabilities or premature death. Electron beam irradiation protects the public's health from foodborne illness outbreaks. While the term and use of "irradiation" may be considered controversial by certain individuals and consumer groups, research conducted by government agencies, universities, and the private sector support the use of irradiation to make food safe and protect the public's health. Government agencies, public health officials and doctors, universities, food manufacturers, retailers, trade associations, and health organizations worldwide generally concur that food irradiation is a safe and viable intervention, which should be used to protect the public's health from foodborne illness. The research and documentation on irradiated foods has proven conclusively that irradiated foods are safe, wholesome, and nutritious for consumption.

In the USA, the Government Accountability Office (GAO) in the report titled "GAO/ RCED-00-217 Benefits and Risks of Food Irradiation" dated 24 August 2000 (GAO, 2000) and delivered to the Subcommittee on Oversight and Investigations, Committee on Oversight, House of Representatives stated: "However, many food safety experts believe that irradiation can be an effective tool in helping to control foodborne pathogens and should be incorporated as part of a comprehensive program to enhance food safety." (GAO, 2000) The report also stated: "A major benefit of food irradiation is its effectiveness as a tool in reducing foodborne pathogens, according to numerous studies conducted worldwide for over 50 years. Irradiation, within approved dosages, has been shown to destroy at least 99.9% of common foodborne pathogens, such as *Salmonella (various species), Campylobacter jejuni, Escherichia coli (E. coli) O157:H7, and Listeria monocytogenes*, which are associated with meat and poultry." (GAO, 2000).

The GAO in the report titled "GAO-10-309R Federal Oversight of Food Irradiation" dated 16 February 2010 (GAO, 2010) and delivered to Congressional Committees stated: "The pathogens that account for much of the most severe foodborne illness can be greatly reduced by subjecting food to ionizing radiation, also known as food irradiation. For example, irradiation can eliminate as much as 99.999% of *E. coliO157:H7*, *Listeria*, and *Campylobacter*. On the basis of extensive scientific studies and the opinions of experts, we reported in 2000 that the benefits of food irradiation outweigh the risks. Moreover, many experts believe that irradiation can be effectively incorporated into an establishment's food safety program to further ensure the safety of the food against pathogens." (GAO, 2010). GAO concluded, "Pathogens such as *Salmonella and E. coli O157:H7* continue to cause severe foodborne illness outbreaks, with the populations most susceptible to these illnesses growing in number. Subjecting food to ionizing radiation has been shown to not only be safe but to reduce pathogens in food by as much as 99.999 percent" (GAO, 2010).

Irradiation is typically used as the final intervention step applied in a company's multi-hurdle Hazard Analysis Critical Control Point (HACCP) and Hazard Analysis and Risk-based Preventative Controls (HARPC) system in accordance with regulatory approvals and under regulatory inspection. Food products approved for treatment include fresh or frozen ground beef, red meat, poultry, fresh iceberg lettuce, fresh spinach, dried spices, shell eggs, molluscan and crustacean shellfish, animal feed, animal feed ingredients, pet food, and pet treats. These food products are irradiated to reduce harmful foodborne pathogens and adulterants in the post-packaged products to undetectable levels, to protect public health. Irradiation of tropical fruits is also approved as a phytosanitary treatment to eliminate harmful pest infestations that are detrimental to crops and the environment.

1.2. Food Irradiation around the World

At this writing, there are more than 180 commercial irradiators built and operated around the world, with a high percentage being Co-60 irradiators. Most of these irradiators, however, are for irradiating disposal medical supplies and cosmetic products. Only a few are dedicated to food irradiation. The first dedicated food irradiator in the United States was built in 1991 in Mulberry, Florida. The initial name of the company was Vindicator, later changed to Food Technology Service. Since 2000, there have been several linear accelerators installed in Minnesota and Iowa for irradiating meat and poultry, and one in Hawaii, called Hawaii Pride, for disinfesting tropical fruits (Moy and Wong, 2002). With the new regulations by USDA-APHIS allowing foreign countries to export fruits and vegetables to the United States, it is expected that countries such as Chile, Brazil, Mexico, the Philippines, Malaysia, and Thailand, etc. will increase their capability in food irradiation (Anonymous, 2001b).

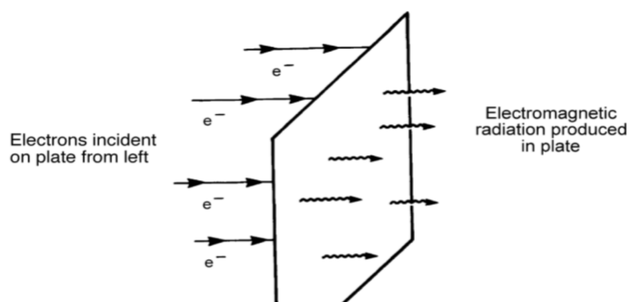
Ranges of Food Irradiation Doses

- Low dose irradiation (<1 kGy): Sprout inhibitions; delay in ripening; insect disinfestations; parasite inactivation.
- Medium dose irradiation (1 – 10 kGy): Microbial inactivation; non spore forming pathogens i.e. disease causing microorganisms.
- High dose irradiation (>10 kGy): Microbial inactivation to the point of sterility.

2. Sources of Irradiation Energy

The radionuclides approved for food irradiation include 137Cs and 60Co. radioactive cobalt (60Co) decays to non-radioactive nickel by emitting a particles and c-rays. The c-rays kill rapidly growing cells (microbes) but do not leave the product radioactive (Lagunas-Solar, 1995). Because it is highly penetrating, it can be used to treat packaged food. Non-radioactive 137Cs occurs in various minerals. It can be produced when uranium and plutonium absorb neutrons and undergo fission in a nuclear reactor, then decay to non-radioactive barium by emitting b particles and c-rays. High energy particles can also be produced by ‘‘accelerating"electrons using electricity. These high energy, accelerated electrons are propelled out of an electron gun in a stream (e-beam). No radioactive source is required to produce accelerated electrons. They can penetrate 5–10 cm into food. X-rays can be produced by accelerating electrons into a thin metal plate (Satin, 2002)

Conversion of Electrons Into X-Rays



3. Consumers and Irradiated Foods

It is necessary to label food products which have been irradiated with the Radura symbol and "Statement of Irradiation" to inform the consumer that the food products they are purchasing have had this additional food safety intervention of irradiation applied. The Radura is the international symbol that identifies a food has been irradiated. The food processor or manufacturer must share with the consumer why it is important to irradiate food products, including what the benefits are, particularly the increase in the safety and nutritional quality of an irradiated food product. Consumers expect that the foods they are purchasing are free of foodborne pathogens and adulterants and are safe for consumption. University and private surveys estimate that approximately 70–80% of consumers, when informed of what irradiation is and that irradiated food is safe and nutritious, will purchase irradiated foods.

However, consumers have been slow to purchase irradiated foods due to three main factors. The three primary factors working in concert are misinformation, retail price and limited availability of irradiated food products. The consumer must not be provided with misinformation of what irradiation is, how irradiation works or what irradiation does. The truthful and accurate information about the safety and nutritional value of irradiated foods must be provided to the consumer by the food processor and retailer. The manufacturer and retailer must not discourage purchase by inflating the price of irradiated food. The price must accurately reflect the value of the additional food safety intervention applied. Inflating the price of irradiated food further deters the consumer from purchasing these products.

The availability of irradiated foods, such as irradiated ground beef, has also been limited. While food processors and retailers agree that products such as irradiated ground beef should be available for purchase by the consumer on the grounds of both safety and quality, they are reluctant to do so because they perceive that customers are unwilling to purchase irradiated foods. This has become a self-fulfilling prophecy. Those companies that have sold irradiated food products have not lost sales. In the author's opinion, food manufacturers and retailers should be more responsive. They should give consumers the choice of purchasing a product of proven safety and quality at a reasonable price, as well as play their part in educating consumers, together with the government agencies responsible for food safety, about the benefits of food irradiation in improving the safety and quality of the food available to consumers.

3.1. Application Potential of Food Irradiation

Irradiation of the main commodities such as tuber and bulb crops, stored grains, dried ingredients, meats, poultry and fish, or fruits has an enormous literature evolved during the past 60 years, (e.g. Molins, 2001; Wilkinson & Gould, 1996). The chief potential values to consumers and food safety are in the area of preventing of food poisoning through elimination of non spore forming pathogens, particularly from some meats and seafood and they are well established. Recent research and development directed more on irradiation of minimally processed fresh produce and cook-chill foods, where our own laboratory is also involved (Farkas, 2001a). The potential application of ionising radiation in food processing is based mainly on the fact that ionizing radiations damage very effectively the DNA so that living cells become inactivated, therefore microorganisms, insect gametes, and plant meristems are prevented from reproducing, resulting in various preservative effects as a function of the absorbed radiation dose. At the same time, radiation-induced other chemical changes in food are minimal (Thayer, 1990).

According to the Codex General Standard for Irradiated Foods (CAC, 2003), ionising radiations foreseen for food processing are limited to high energy photons (gamma rays of radionuclides 60Co and, to a much smaller extent, 137Cs, or, X-rays from machine sources with energies up to 5 MeV, or accelerated electrons with energies up to 10 MeV. In the USA, the Food and Drug Administration amended recently the food additive regulations by establishing a new maximum permitted energy level of X-rays for treating food of 7.5 MeV provided that the X-rays are generated from machine sources that use tantalum or gold as the target material (FDA, 2004).

High energy electron beams are produced by electron accelerating machines. X-ray production starts with high energy electrons: X-ray machines convert electron energy to electromagnetic X-rays called Bremsstrahlung. These types of radiation are chosen because

(a) They produce the desired food preservative effects.

(b) They do not induce radioactivity in foods or packaging materials.

(c) They are available in quantities and at costs that allow commercial use of the irradiation process (Farkas,2004).

Radiation treatment causes practically no temperature rise in the product. Irradiation can be applied through packaging materials including those, which cannot withstand heat. This means also that radiation treatment can be performed also after packaging thus avoiding re-contamination or re-infestation of the product.

Accelerated electrons have low penetrability thus the practically usable penetration depth-limit for 10 MeV electrons in high moisture food (water-equivalent material) is 3.9 cm. Gamma rays and X-rays have high penetrating characteristics, thus they can be used to treat food even in pallet-size containers. Except for different penetration, effects of electromagnetic ionizing radiations and electrons are equivalent in food irradiation.

The mechanism of microbial inactivation by ionizing radiation is mainly due to the damage of nucleic acids, direct damage or indirect damage, affected by oxidative radicals originating from the radiolysis of water.

Differences in radiation sensitivities among the microorganisms are related to differences in their chemical and physical structure, and in their ability to recover from radiation injury. The amount of radiation energy required to control microorganisms in food, therefore, varies according to the resistance of the particular species and according to the number of organisms present. Besides such inherent abilities, several factors such as composition of the medium, the moisture content, the temperature during irradiation, presence or absence of oxygen, the fresh or frozen state influence radiation resistance, particularly in case of vegetative cells

Similar to heat resistance, the radiation response in microbial populations can be expressed by the decimal reduction dose (D10-value). The radiation sensitivity of many moulds is of the same order of magnitude as that of vegetative bacteria. However, fungi with melanised hyphae have a radiation resistance comparable to that of bacterial spores (Saleh, Mayo, & Ahearn, 1988). Yeasts are as resistant as the more resistant bacteria. Viruses are highly radiation resistant (WHO, 1999).

Some products may require irradiation under special conditions such as at low temperature, or, in an oxygen-free atmosphere, or with combination treatments such as heat and irradiation (Farkas, 1990; Grant & Patterson, 1995) [19].

The actual dose employed is a balance between what is needed and what can be tolerated by the product without unwanted changes, (e.g. off-flavours, in case of protein foods, and/or texture changes in fresh fruits and vegetables).

3.2. Irradiation and Hurdle Technology of Irradiated Fruits

Moreno *et al*. (2007) reported that no significant weight losses were induced to packaged fresh blueberries (Vaccinium corymbosumL.) by electron beam irradiation (1.1, 1.6, 3.2 kGy). Moisture content and water activity of the fruits ranged between 79.6 and 81.8 g/100 g and 0.87 to 0.92, respectively.

These results indicated that exposure of blueberries to irradiation up to 3.2 kGy did not affect the juiciness of the fruits. Irradiating the blueberries up to 3.2 kGy did not affect their pH and the fruits had acceptable acidity levels that remained unchanged throughout storage time (at 5◦C and 70.4% RH for 14 days). Only irradiation at doses higher than 1.6 kGy induced undesirable texture changes (i.e. softening) in the fruits. Blueberries exposed up to 1.6 kGy dose were found acceptable by the panelists in terms of overall quality, color, texture, and aroma.

According to El-Samahy *et al*. (2000) irradiation treatments (0.5, 0.75, 1.0, and 1.5 kGy) in conjunction with hot water dipping (55◦C/5 min) caused significant decrease in firmness values of mango fruits (Mangiferaindica L.), variety "Zebda," either at zero time or during the storage (12 ± 1◦C and 80–85% relative humidity). This decline in firmness was shown to be proportional to the radiation dose. The results clearly indicated that samples irradiated up 1.0 kGy were acceptable organoleptically until 50 days of storage at 12◦C. After 60 days, mangoes were over-ripe with a buttery texture. Phenolic compounds and total content of carotenoids in mango significantly increased when there was subjected to irradiation.

3.3. Irradiated Vegetables

Fan and Sokorai (2005) assessed the radiation sensitivity of fresh-cut vegetables using electrolyte leakage measurement. Fresh-cut vegetables were gamma irradiated at doses up to 3 kGy at 0.5 kGy intervals. Electrolyte leakage increased linearly with higher radiation dose for all vegetables. Red cabbage, broccoli, and endive had the highest radiation resistance while celery, carrot, and green onion were the most sensitive to radiation.

The radiation sensitivity was not necessarily correlated with endogenous antioxidant capacity or phenolics content of the vegetables, which displayed large variation among the test samples.

Song *et al*. (2006) investigated carrot and kale juice during a three-day storage period (10◦C). They reported that the total phenolic contents of both vegetable juices were significantly higher in the irradiated (3 kGy) samples than in the non irradiated control. The antioxidant capacity of the irradiated carrot juice was higher than that of the non-irradiated control. On the other hand, over the storage period, the antioxidant capacity decreased in spite of increase in the phenolic content of the kale juice.

Wang and Du (2005) found that the vitamin C content, and the rehydration ratio of dried potato was greatly affected by the irradiation dose (2, 4, 5, 6, 8, or 10 kGy). They claimed that the greater the dose, the lower the vitamin C content and the rehydration ratio.

The effects of cooking followed by irradiation (10 kGy) on vitamins B1 and C, and the anti nutritional factors, phytic acid and nitrates, in a ready-to-eat meal of sorghum porridge and spinach-based relish were investigated by (Duodu *et al*., 1999). Cooking reduced vitamin B1 and C contents of the spinach relish, and irradiation caused further losses. Cooking did not alter vitamin B1 content (0.28mg gr^{-1}) of the sorghum porridge but irradiation decreased it drastically (0.04 mg gr^{-1}). Cooking did not decrease phytic acid in the sorghum porridge whereas irradiation caused a significant decrease.

3.4. Irradiation Effects on Meat Odor and Flavor

''Flavor" results from the combined effects of basic tastes (sweet, sour, bitter, salt, and umami) derived from water-soluble compounds and odor derived from volatile substances present in the food product from the outset or derived via various reactions (Brewer, 2006). The chemical composition of fresh meat provides the precursor compounds for development of aromas and flavors, desirable or undesirable. A wide array of flavor- and odor-active volatiles occur in meat (acids, alcohols, aldehydes, aromatic compounds, esters, ethers, furans, hydrocarbons, ketones, lactones, pyrazines, pyridines, pyrroles, sulfides, thiazoles, thiophenes, pyrroles, and oxazoles; Shahidi, 1994). Heterocyclic compounds containing nitrogen, sulfur and/or oxygen, such as pyrazines, thiazoles, and oxazoles appear to be major contributors to meatodor (Lorenz *et al*., 1983). The compounds which elicit various tastes and odors have widely different thresholds for perception and a particular compound may taste/smell different at different concentrations. For example, compounds with a 2-methyl-3-(methylthio) furanyl group have a characteristic meaty aroma at low levels; if the concentrations are >1 lg, they produce a sulfurous off-odor (Mottram, 1998).

The odor of irradiated meat has been described as rotten egg, sweet, bloody, cooked meat, barbecued corn, burnt, sulfur, metallic, alcohol, acetic acid, liver-like serumy, and bloody (Groninger, Tappel, & Knapp, 1956; Hampson, Fox, Lakritz, & Thayer, 1996;Jo, Lee, & Ahn, 1999; Lee, Sebranek, Olson, & Dickson, 1996b; Lee, Sebranek, & Parrish, 1996a; Luchsinger *et al*., 1997c; Merritt, Angelini, Wierbicki, & Shultz, 1975). More than 7% of the volatiles found in irradiated foods are hydrocarbons commonly found thermally processed and unprocessed foods (Nawar, Zhu, &Yoo, 1990). Most chemical changes in irradiated meat are associated with free radical reactions (Ahn & Lee, 2004).

Organism	Approximate lethal dose (kGy)
Insects	0.22 to 0.93
Viruses	10 teo 40
Yeasts (fermentative)	4 to 9
Yeasts (film)	3.7 to 18
Molds (with spores	1.3 to 11
Bacteria (cells of pathogens)	
Mycobacterium tuberculosis	1.4
Staphylococcus aureus	1.4 to 7.0
Cornybacterium diphtheriae	4.2
Salmonella spp.	3.7 to 4.8
Bacteria (cells of saprophytes)	
Gram-negative	
Escherichia coli	1.0 to 2.3
Pseudomonas aeruginosa	1.6 to 2.3
Pseudomonas fluorescens	1.2 to 2.3

Enterobacter aerogenes	1.4 to 1.8
Gram-positive	
Lactobacillus spp.	0.23 to 0.38
Streptococcus faecalis	1.7 to 8.8
Leuconostoc dextranicum	0.9
Sarcina lutea	3.7
Bacterial spores	
Bacillus subtillus	12 to 18
Bacillus coagulans	10
Clostridium botulinum (A)	19 to 37
Clostridium botulinum (E)	15 to 18
Clostridium perfringens	3.1
Putrefactive anaerobe 3679	23 to 50
Bacillus stearothermophilus	10 to 17

* Adapted from Frazier, W.C., and Westhoff, D.C. 1988. Chapter 10. Preservation by radiation. In Food Microbiology (Fourth edition). McGraw-Hill. New York, NY.

S.no	Commodity	Summary	Reference
1	Apple juice	Irradiation of apple juice increased the antioxidant power and reduced brownness, rendering the juice lighter in color	(Fan and Thayer, 2002).
2	Orange juice	No changes in the appearance or aroma were evident in reconstituted orange juice irradiated to 2.5 kGy	(Niemira *et al*., 2001).
3	Orange juice	Aroma-related acyclic monoterpenes in orange juice were found to be sensitive to irradiation	(Fan and Gates, 2001).
4	tamarind juice	The color, taste and antioxidant capacity of tamarind juice was stable or slightly improved in irradiation treatments of up to 3 kGy Overall acceptability of treated tamarind juice was also stable up to 3 kGy, but declined with a 5-kGy dose	(Lee *et al*., 2009).
5	Kale and carrot	Total ascorbic acid content (ascorbic1dehydroascorbic) was stable in kale and carrot juice treated with 3 kGy. A taste panel determined the sensory acceptability of juices so treated were not different from controls immediately after treatment; during storage, the irradiated juices retained acceptable quality, while the non-irradiated controls deteriorated.	(Song *et al*., 2005).
6	meat	Maintenance of ideal meat color during irradiation can be enhanced by various combinations of pre-slaughter feeding of antioxidants to livestock, optimizing the condition of the meat prior to irradiation, addition of antioxidants, gas atmosphere (MAP), packaging, and temperature control.	Susan Brewer 2004
7	Mushroom	The irradiation of mushrooms can be a safe and cost effective method to enhance shelf-life as well as to ensure hygienic and sensory quality.	Kashif Akram and Joong-Ho Kwon 2010
8	mushroom	In order to make the dried mushroom insect free, a low dose of 0.5 kGy can retard the growth of moth's adults within 5 days after treatment	[Boshra, 2007].
9	Mushroom	In order to avoid the spoilage of mushrooms during storage, and to ensure consumer safety regarding their consumption, irradiation of mushrooms may be a best possible option	[Malec-Czechowska *et al*., 2003].
10	Wheat	Low dose of radiation causes DNA damage, resulting in the retardation of cell growth and multiplication, while higher doses may be required in order to produce immediate sterilization by causing insect death	[Molins, 2001].
11	Celery	Irradiated diced celery at 0.5 and 1.0 kGy and found greater than a 5-log reduction of both *E. coli* and *L. monocytogenes*. In the same study, irradiation was more effective than conventional treatments (acidification, blanching and chlorination) at suppressing bacterial re-growth during 22 days of posttreatment storage.	Prakash *et al*. (2000)
12	Sprouts	Irradiated several kinds of salad sprouts inoculated with *E. coli O157:H7* and *Salmonella* and determined the radiation doses required to achieve a 1-log (90 percent) reduction of pathogen loads. The doses were 0.34, 0.27 and 0.26 kGy for *E. coli* on radish, alfalfa and broccoli sprouts, respectively, and from 0.46 to 0.54 kGy for *Salmonella* on radish sprouts.	Rajkowski and Thayer (2000)
13	Packaging material	A combination of low-dose irradiation (0.5 or 1.0 kGy), a warm-water dip, and modified atmosphere packaging (MAP) reduced bacterial loads in lettuce more effectively than irradiation alone, without significant loss of sensory quality.	(Fan *et al*. 2003b).
14	MAP	Irradiation at 0.3 and 0.6 kGy combined with MAP reduced *L. monocytogenes* on endive by 2.5 to 3 logs	(Niemira *et al*. 2005);
15	Green onions	Kim *et al*. (2005) irradiated fresh-cut green onions and found that doses of 1.0 to 1.5 kGy reduced total aerobic count by about 3 logs, but with this particular food, a warm water dip had no additional anti-bacterial benefits	Kim *et al*. (2005)
16	Lettuces	(Fan *et al*. 2003b) reported that irradiation doses greater than 1 kGy caused softening (loss of crispness), browning and decreased vitamin C content in lettuce, while earlier work had shown that irradiation at 2 kGy wilted lettuce. But they also found that when lettuce irradiated at 0.5 and 1.0 kGy was dipped in water heated to 47 ºC (117oF), the combination of treatments reduced bacterial loads by about 3logs without significant effects on sensory quality or vitamin C content.	(Fan *et al*. 2003b)

Sensory Quality of Irradiated Food

The irradiation process is not suitable for all products. Foods with high fat contents, such as fatty fish and some dairy products, develop off-odours and tastes due to the acceleration of rancidity, even at relatively low doses. Loss of firmness can occur with some fruits and vegetables. Foods with high protein content, such as meat and poultry, can suffer from changes in flavour and odour after irradiation at ambient temperatures but these changes can be reduced by irradiating at chill temperatures and minimised by irradiating at frozen temperatures. For fresh ground beef with a high fat content and for fatty pork products, the maximum dose should not exceed 2.5 kGy to prevent rancidity. Liquid and dry eggs can tolerate doses in excess of 3 kGy, but for shell eggs a 2 kGy dose can cause deterioration of the yolk sac membrane. Milk develops an off-flavour at relatively low doses but various cheese show good tolerance at doses up to 3 kGy (Diehl, J.F., 1983). All these changes are minimised by irradiating at chill or frozen temperatures, and, in addition, many changes can be minimised by careful choice of suitable packaging systems coupled with controlled gas atmospheres.

4. Wholesomeness and Legislation of Irradiated Food

Wholesomeness (toxicological innocuity, nutritional adequacy and microbiological safety) of irradiated food has been carefully evaluated by an unprecedented width of research and testing over more than 50 years. All scientifically acceptable evidence resulted from those studies supports the safety of irradiated food for consumption (Diehl, 1995; WHO, 1994, 1999). The FAO/IAEA/ WHO Expert Committee on Food Irradiation concluded already in its report of 1981: ".the irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard, hence, toxicological testing of food so treated no longer required." And further: ".irradiation of foods up to an overall average dose of 10 kGy introduces no special nutritional or microbiological problems." (WHO, 1981) In the first rule of the WHO's 'Golden Rules for Safe Food Preparation' advises: ".if you have the choice, select fresh or frozen poultry treated with ionising radiation" (WHO, without date). Currently, some 50 countries granted national clearances of irradiation of at least one or more food items or food classes. The itemised database of the International Consultative Group on Food Irradiation (ICGFI) on those clearances can be visited on the web site: http://www.iaea.org/cgi-bin/rifm-ste.1. Over 30 of these countries are actually applying radiation processing of such commodities for (semi) commercial purposes.

The Revised Codex General Standard for Irradiated Foods and the revision of the Codex Recommended International Code of Practice for Radiation Processing of Food have been adopted by the Codex Alimentarius Commission at its 26 session in 2003 (C.A.C., 2003). Post-irradiation detection methods have been developed and standardised for a wide range of foods, which may be subject to irradiation treatment (CEN, Europoean Committee for Standardisation)

Unlike the supporting attitude of the relevant specialized agencies of the UN (the World Health Organization, the Food and Agriculture Organization, and the International Atomic Energy Agency), the European Parliament and the Council of the European Union has a much more restrictive legislative approach. They issued in 1999 a 'framework'

Directive 1999/2/EC on approximation of the laws of the member states concerning food and food ingredients to be treated by ionising radiation, and a Directive 1999/3/EC on the establishment of a community list of foods and food ingredients treated with ionising radiation (E.P., 1999). The present category of foodstuffs authorised by the latter Directive for irradiation treatment is 'dried aromatic herbs, spices and vegetable seasonings', and the permitted maximum overall average absorbed dose is 10 kGy. By the published Directive 1999/2/EC, the European Commission was charged to develop a final positive list of permitted items until the end of 2000, but the contents of this list are not yet published. Instead, National regulations, e.g. in Belgium, France, Italy, The Netherlands, Spain and the United Kingdom, which were established before the EC Directive entered into force were allowed to continue (Anon, 2003). Certain anti-irradiation groups have been effecting for slow take-off of food irradiation at working with the news media.

5. The Prospect of Food Irradiation

In the more than four decades of research and development in food irradiation, people in the 21st century will witness more applications of radiation as an emerging food preservation technology. Government authorities, the food industry, and researchers need to work together to provide more consumer education about the purposes, benefits, and safety of food irradiation. The general public will slowly accept this technology as a sound, sensible technology.

The pace of the meat and poultry industry in adopting this technology will be slow, partly because of the high investment in an irradiation facility and partly because the industry tends to be conservative and at the same time seeks other less expensive ways of maintaining plant sanitation and minimizing contamination of products. On the other hand, growers and packers of tropical fruits, vegetables, and fresh herbs will be eager to explore new markets overseas since it has been proven that radiation is a very efficacious quarantine treatment of these products.

6. Future Trends

Most of the irradiation studies relating to quality issues have been carried out to date with raw meat, because irradiation is not permitted for use with meats containing additives, further processed or precooked RTE meat products. Therefore, future irradiation studies should be focused on further processed and precooked ready-to-eat meat products, especially in relation to investigating methods to prevent negative flavor, odor and taste modifications, as well as investigating approaches to improving microbial safety in these products. Additionally, limited research has been conducted to date on dried and semi-dried meat products. Dried and semi-dried meat products contain much lower levels of water than normal meat products, and thus the irradiation efficiency and the response of meat to irradiation could be different from those of normal products. Therefore, microbial and quality research on dried and semi-dried processed meat products is required.

Currently, no information on the mechanisms and causes of odor/taste/ flavor changes in irradiated processed meat products is available. Herbs and spices are used in most of the processed meat products and they play important roles in producing flavor and improving the stability of meat products. Some of the volatiles from spices and herbs can interact with sulfur compounds produced by irradiation, and modify the overall flavor and taste of the products (Yang *et al.*, 2011). Certain herbs and spices produce large amounts of sulfur compounds and some of them are reported to increase radiation sensitivity of pathogens. Therefore, proper use of these herbs and spices can be an excellent tool to mask or minimize irradiation flavor/taste as well as improve microbial safety of irradiated processed meat. Little research on the effect of spices and herbs on microcidal efficiency of irradiation as well as masking flavor/taste of processed meat products, however, have been done and future research should be focused in this area.

7. Research Gap

- ✓ Free radical formation
- ✓ Concentrate on cost effective
- ✓ Petition in 1999 to the FDA for approval of irradiation of many types of ready-to-eat food submitted by a coalition of food irradiation.
- ✓ Most of the irradiation studies relating to quality issues have been carried out to date with raw meat, because irradiation is not permitted for use with meats containing additives, further processed or precooked RTE meat products.
- ✓ Some of the volatiles from spices and herbs can interact with sulfur compounds produced by irradiation, and modify the overall flavor and taste of the products (Yang *et al.*, 2011). Certain herbs and spices produce large amounts of sulfur compounds and some of them are reported to increase radiation sensitivity of pathogens.
- ✓ Therefore, proper use of these herbs and spices can be an excellent tool to mask or minimize irradiation flavor/taste as well as improve microbial safety of irradiated processed meat. Little research on the effect of spices and herbs on microcidal efficiency of irradiation as well as masking flavor/taste of processed meat products, however, has been done and future research should be focused in this area.

8. Conclusion

Consumers are gaining knowledge about the benefits of food irradiation and its potential to reduce the risk of food borne disease, but the process is not a replacement for proper food handling practices. Irradiation, like other prevention methods, is but one method used to prevent food borne illness.

9. References

1. Jozsef F, Csillla Mohacsi F. History and future of food irradiation. Trends in Food Science & Technology. 2011; 22:121-126
2. James H Moy. Food Irradiation—An Emerging Technology. University of Hawaii, Honolulu, Hawaii, U.S.A, 2005.
3. Diehl JF. Food irradiation: past, present and future. Radiation Physics and Chemistry. 2002; 63:211-215
4. Boisseau P. Food Preservation by Irradiation: A brief introduction. Solid State Phenomena. 1992; 30-31:433-45
5. Doellstaedt R, Huebner G. Food irradiation: activities and potentialities. Radiat. Phys. Chem. 1985; 26(5):607-612
6. Brewer S. Irradiation effects on meat color- a review. Meat Science. 2004; 68:1-17
7. Miebach EM. Food irradiation – A means of controlling pathogenic microorganism in food. IPE, Federal research center for nutrition, D-76131, Karlsruhe, Germany, 1993.
8. Farkas J. Irradiation for better foods. Food science and technology. 2006; 17:148-152
9. Dieter AE, Ehlermann. The RADURA-terminology and food irradiation Food Control. 2009; 20:526-528
10. Sommers CH. Microbial decontamination of food by irradiation. USDA-ARS, USA, 2012.
11. Sádecká J. Irradiation of spices – a review. Czech J. Food Sci. 2007; 25:231-242.
12. McLaughlin WL, Boyd AW, Chadwick KH, McDonald JC, Miller A. Dosimetry for Radiation Processing; Taylor and Francis, Ltd: London, 1989.
13. AMA. Irradiation of Food. Council on Scientific Affairs Report 4. American Medical Association, Chicago, IL, 1993.
14. Grant IR, Patterson MF. Sensitivity of foodborne pathogens to irradiation in the components of a chilled ready meal. Food Microbiol. 1992; 9:95-103
15. Udilova N, Jurek D, Marian B, Gille L, schulte-hermann R, nohl H. Induction of lipid peroxidation in biomembranes by dietary oil components. Food Chem Toxicol. 2003; 41:1481-1489.
16. Uloth J, Casiano C, De Leon M. Palmitic and stearic fatty acids induce caspase- dependent and independent cell death in nerve growth factor differentiated PC12 cells. J Neurochem. 2003; 84(4):655-668.
17. Usda fsis. FSIS issues alert on the importance of cooking and handling ground beef. Food Safety and Inspection Service, United States Department of Agriculture, Washington, DC. Available online at: http://www.fsis.usda.gov/OA/news/2004/ alert012904, 2004.
18. Sommers C, Neimira B, Tunick M, Boyd G. Effect of temperature on the radiation resistance of virulent Yersinia enterocolitica. Meat Sci. 2002; 61:323-328.
19. Patterson M. Sensitivity of Campylobacter spp. to irradiation in poultry meat. Lett Appl Microbiol. 1995; 20:338-340.
20. Mclaughlin W, Boyd A, Chadwick K, Mcdonald J. Miller A. Dosimetry for Radiation Processing. Taylor and Francis, New York, 1989.