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Gamma Irradiation for Fresh Produce

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1. Introduction

Food irradiation is a promising food safety technology that has a significant potential to control spoilage and eliminate food-borne pathogens. The Food and Agricultural Organization (FAO) has estimated that approximately 25% of all worldwide food production is lost after harvesting due to insects, microbes, and spoilage. As the market for food becomes increasingly global, food products must meet high standards of quality and quarantine in order to move across international borders. The FAO has recommended that member states need to implement irradiation technology for national phytosanitary programs. There is a trend to use food irradiation mainly due to three main factors: the increase of foodborne diseases; high food losses from contamination and spoilage; and increasing global trade in food products. The ever increasing foodborne illness outbreaks associated with fresh produce continue to prove that traditional measures are not sufficient to eliminate food borne pathogens. More effective countermeasures are clearly needed to better manage the foodborne pathogen risks posed by contaminated produce. Fresh produce industries, government regulatory agencies, and consumers all are advocating for new technologies that will eliminate or significantly reduce foodborne pathogens on fresh produce. With increasing awareness of the foodborne idleness linked to fresh produce, gamma irradiation could be applied to mitigate human pathogens in fresh fruits and vegetables. Food irradiation is a safe and effective tool and could be used with other technology to control pathogenic bacteria in fresh produce. Irradiated foods are generally nutritious, better or the same as food treated by convectional methods such as cooking, drying, and freezing. Food irradiation also has other benefits such as delay in repining and sprouting. Further more food irradiation has a significant potential to enhance produce safety and if combined with other anti-microbial treatments; this technology is promising to solve some of the current produce pathogen problems. Although irradiation is safe and has been approved in 40 countries, food irradiation continues to be a debate and slows extensive acceptance and use in the food industries. Several foodborne pathogens have been linked to fresh produce and gamma irradiation could be applied to eliminate microbes before reaching the consumer. There is an urgent need to educate consumer on the principles and benefits of this promising technology.

2. Fresh produce and foodborne pathogens

Consumption of fresh produce in many countries has increased substantially in recent years, in part due to an increased awareness of the health benefits that fresh produce provides.

However, foodborne illness outbreaks linked to fresh produce are becoming more frequent and widespread (Warriner et al, 2009; Harris et al., 2003; Sivapalasingam et al, 2004). Foodborne illness outbreaks associated to leafy vegetables is an indication that increased consumption of fresh produce could present new challenges with regard to fresh produce safety (FDA, 2008). Recent outbreaks of foodborne illness linked with produce have raised concerns and underline the challenges to the public health as well as to fresh produce industry. The increased concern of fresh produce and its relation to food borne illness has been indicated by several surveillance studies (Ilic, Odomeru, & LeJeune, 2008; little & Gillespie, 2008). Other countries together with the United States of America have targeted foodborne pathogens in fresh produce as emerging issue in food safety and one of the most pressing public health needs. Fresh fruits and vegetables are frequently contaminated since they are grown in open fields with potential exposure to enteric pathogens from animals, soil, irrigation water, and manure. Cross contamination of fresh produce with foodborne pathogens may occur during the production cycle and can originate from soil, insects, equipment, animals or humans (Tracy and Harris, 2003; Liao and Fett, 2001; Ukuku and Sapers, 2001). It is indicated that pathogen contaminated water or surface run-off waters can lead to cross-contamination of fruits and vegetables in the field (Beuchat and Ryu, 1997). Similarly, the application of raw animal manure for fertilizer increases the threat of contamination on fruits and vegetables (Brackett, 1992). Direct or indirect pathogen contamination of fresh produce can occur at many points in the production chain during growth and processing (Fenlon, et al, 1996; Beuchat and Ryu. 1997), thus presenting a food safety challenge to consumers.

Pathogenic microorganisms, such as *Cyclospora cayetanensis*, *Escherichia coli* O157:H7, Hepatitis A, *Listeria monocytogenes*, Norovirus, *Salmonella* spp., and *Shigella* spp. are the major foodborne microbial pathogens associated with fresh produce. *Salmonella*, *Escherichia coli* O157:H7, and *Listeria monocytogenes* have been associated with fresh produce over the past two decades. *E. coli* O157:H7 illnesses have also been linked to the consumption of fresh fruits and vegetables (Tauxe, et al 2000). *E. coli* O157:H7 is capable of causing hemorrhagic colitis and hemolytic uremic syndrome (HUS) and thus has gained attention from public health agencies and institutions. Proximity of domestic or wild animals to irrigation water systems may result *E. coli* O157:H7 (Wachtel, et al 2002) and other pathogenic bacteria being washed from manure to production fields. *E. coli* O157:H7 contaminated manure may get into the water system, and once present, can be applied to growing crops (Institute of Food Technologists, 2002). Foodborne pathogens in the fresh produce indicate a weakness in the fresh produce industry has was demonstrated by recent multi-state (Unites States) outbreaks in produce, including *E. coli* OH7:H7 outbreak from spinach that lead to 183 cases of illness, 29 cases of Hemolytic Uremic Syndrome (HUS), 95 hospitalizations, and one death (<http://www.cdc.gov/foodborne/ecolispinach>) ; *Salmonella* Typhimurium outbreak from tomatoes that involved 183 cases of illnesses <http://www.fda.gov/bbs/topics/NEWS/2006/NEW01504.html>); and in December 2006, Taco Bell restaurants in the Northeast were also associated with *E. coli* O157:H7 and iceberg lettuce was considered to be the single most likely source of the outbreak, 8 cases of Hemolytic Uremic Syndrome (HUS), and 53 hospitalizations were reported to Center of Disease Control (<http://www.cfsan.fda.gov/~news/whatsnew.html>. *Salmonella enteritidis*, *S. infantis*, and *S. typhimurium* have also been reported to be capable of growth in chopped cherry tomatoes (Asplund, K., and E. Nurmi.1991). *Listeria monocytogenes* is a common contaminant and has

also been associated with several produce recalls (Faber and Peterkin, 1991; Leverentz, 2004), including red bell peppers, romaine lettuce, sprouts, and apple slices. Presence of this pathogen has also been reported in potatoes, radishes, cabbage, cucumbers, and mushrooms obtained from the market (Heisick, et al 1989).

Many outbreaks have been traced to produce, and this will continue to occur until fresh produce growers, processing plants, retail stores, and consumers increase their knowledge and awareness of the risks and consequences of foodborne pathogens. Given that fresh produce is ready to eat, and is not subjected to further microbial killing steps, there is a call for produce industry to use effective methods to eliminate or reduce the risk of foodborne pathogens. Gamma irradiation could be applied as a control measure to help minimize food safety risks associated with foodborne pathogens.

3. Gamma irradiation

Gamma rays use irradiation given off by Cobalt-60, a radioisotope of cobalt (Steele and Engel, 1992). It is reported that all radiation facilities in the world use Cobalt-60 rather than Cesium-137 (WHO, 1987). Cobalt-60 is derived from cobalt-59 which is placed in a nuclear reactor and bombarded with neutrons until an extra neutron is absorbed forming the unstable radioisotope cobalt-60. Over 80% of the cobalt-60 available on the world market is being produced in Canada (Diehl, 1995). For use as a radiation source the activated cobalt pellets are encapsulated in a stainless steel linear in form of pin or pencil to minimize absorption of the cobalt and to minimize heat build up. The stainless rods are placed on racks which are stored in approximately 25 feet of water and raised into concrete irradiation chamber to dose the food (Jones, 1992). As the food goes through the chamber, the stainless steel linears are raised above the water so that it is exposed to gamma rays. The irradiation dose applied to food is measured in terms of kiloGy (kGy) and is usually measured in a unit called the Gray, abbreviated Gy. The newer unit, 1 Gy = 100 rads; 1 kGy = 1,000 Grays). The practical working range of food irradiation is generally from 50 Gy to as high as 10,000 Gy, depending upon the food in question and the effect desired (Satin, 1993). There are three general application and dose categories that are referred to when foods are treated with ionizing radiation (Urbain, 1986): (1) Low dose (radurization) up to approximately 1 kGy for sprout inhibition, delay of ripening, and insect disinfection, (2) Medium dose (radicidation)-1 to 10 kGy for reduction of non-spore forming pathogens, delay of ripening, and reduction of spoilage microorganisms, and (3) High dose (radappertization)-10 to 50 kGy for reduction of microorganisms to the point of sterility. In the United States, the amount of irradiation dose applied to food is controlled by plant quality personnel and United States Department of Agriculture (USDA) and inspectors (Giddings and Marcotte, 1991).

4. Benefits of gamma irradiation

4.1 Penetrating sterilization

There has been mounting interest all over the world to utilize gamma irradiation to improve the shelf life of perishable foods as well as to ensure the microbiological safety of the products (Kamat A et al, 2003). According to Chervin and Boisseau, 1994 and Buchanan et al., 1998, ionizing irradiation is a fitting method to control the microorganisms on fruits, fresh fruit juices, fresh-cut vegetables, salads, sprouts, seeds and other, minimally processed

foods. The efficacy of irradiation is not only limited to the surface, but it can penetrate the product and eliminate microorganisms that are present in crevices and creases of vegetables such as lettuce (Prakash et al., 2000). According to Takeuchi and Frank 2000, Solomon et al. 2002, bacteria gets inside tissues of leafy vegetables through natural openings or through breakage caused by insect and mechanical in harvesting. Internalization of bacterial pathogens into the edible portions of plants is of particular concern as these microorganisms are unlikely to be detached by washing or surface sanitization methods (USFDA, 1999; Jablasone et al., 2005). Chlorinated water is widely used for disinfection of foods; but it does not completely inactivate bacteria in fresh produce (Seo and Frank, 1998) due to its limited penetrating power into plant tissues. Ionizing radiation is an effective non-thermal means of eliminating pathogenic bacteria in surface, subsurface, and interior regions of fresh produce. Unlike chlorine treatment, low dose irradiation may be effective method of reducing pathogen such as internalized *E. coli* O157:H7 in and on the surface of fruits and vegetables. Irradiation technology, due to its ability to penetrate through the food, can be used to effectively control foodborne pathogens in fresh produce. The International Commission on Microbiological Specifications for Foods (ICMSF) in 1980 established that cobalt-60 rays penetrate approximately 20 cm of food (Frazier and Westhoff, 1988). Food irradiation using cobalt-60 is the mostly used method by most processors, because the deeper penetration enables administering treatment to entire industrial pallets, reducing the need for material handling Maurer K.F, 1958). Low dose (0.15-0.5 kGy) irradiation has been reported to be workable dosage range for fresh cut lettuce (Hagenmaier and Baker, 1997). Irradiation thus is potentially more effective than washing or other surface treatments against spoilage organisms and pathogens (Niemira and Fan 2006).

4.2 Gamma irradiation and survival of foodborne pathogens

In recent years, leafy vegetables and salads are gaining great importance in the human diet, in part due to due to the health concerns. The intake of fruit and vegetable juices are suggested for diverse health effects (Williams, 1995) and are considered a part of a healthy diet and assist in the protection against various diseases. However, fresh produce may harbor potential of foodborne pathogens (Beuchat, 1996; Sumner and Peters, 1997). The food safety regulations on fresh produce set by the Food and Drug Administration are expected for the producers and handlers to reduce the risk of future outbreaks caused by fruits and vegetables (Warner, 1997). Studies have also shown that irradiation as a means of controlling human pathogens such as *E. coli* O157:H7 (Thayer and Boyd., 1993) and *Salmonella* (Thayer et al., 1991). Fortunately, the majority of food poisoning pathogens are sensitive to radiation and water is the principal target of ionizing radiation. Water radiolysis generates free radicals, which in turn damage microorganisms deoxyribonucleic acid DNA (Scott J. S, and P. Pillai, 2004). This "ionizing" effect splits water molecules into hydrogen (H⁺), hydroxyl (OH⁻) and oxygen (O⁻²) radicals and deactivate bacterial DNA, proteins, and cell membranes (Niemira and Sommers 2006). The gamma rays hit the double helix of the DNA and cause it to split which results in breaks. The severity and the number of the breaks determine the bacterial cells ability to repair and recover (Jay, 1992). The killing effect of irradiation on microbes is measured in D values. One D value is the amount of irradiation needed to kill 90% of that organism for example, it takes 0.3 kiloGrays to kill 90% of *E. coli* O157: H,7 so the D value of *E. coli* is 0.3 kGy (CAST, 1996). The D-values are different for each organism and change by temperature and the type of food. Irradiation is a treatment

that is highly effective against microbial pathogens found in fresh produce. Anu Kamat et al. (2003) reported that a low-dose irradiation (1 kGy) was efficient enough for decontamination and elimination of potential pathogens. Irradiation has been successful in eliminating or greatly reducing the heavy load of spoilage microorganisms in vegetables, herbs, and spices (Satin, 1993). Kim et al. (2005) found that doses of 1.0 to 1.5 kGy reduced total aerobic count on fresh-cut green onions by about 3 logs. According to Lambert and Maxcy, (1984) *Camylobacter jejuni*, *Aeromonas hydrophila* (Palumbo et al., 1986), and *Yersinia enterocolitica* (El Zawahry and Rowley, 1979) have been found to have a low tolerance for irradiation.

The potential of gamma irradiation to inactivate foodborne pathogens on fresh produce has been investigated by various scientists. A dose of 5 kGy is reported to reduce a population of *Salmonella serotypes*, *Staphylococcus aureus*, *Shigella*, *E. coli*, and *Vibrio* species by at least 6 log cycles (Diehl, 1995). This also applies to *E. coli* O157:H7 which is reported to be readily inactivated by irradiation (Clavero et al., 1994). Hagenmaier and Baker (1997) have also indicated that normal microflora on lettuce was reduced with a irradiation dose of 0.19 kGy. Irradiation at 0.3 and 0.6 kGy combined with Modified Atmosphere Packaging system MAP is reported to reduce *L. monocytogenes* on endive by 2.5 to 3 logs (Niemira et al. 2005). A 5 log reduction in *E. coli* O157:H7 and lack of adverse effects on sensory attributes was reported (Foley et al, 2002) when lettuce was subjected to 0.55 kGy. Farkas, et al, 1997 also observed a 4-log reduction of *L. monocytogenes* on the surface of sliced bell peppers irradiated at 1.0 kGy. Gamma irradiation is highly effective in inactivating micro-organisms in fresh produce and offers a safe alternative as a food decontamination method.

5. Effects of gamma irradiation on quality of fresh produce

Safety of irradiated foods involves four aspects: radiological safety, toxicological safety, microbiological safety, and nutritional adequacy. The Bureau of Foods Irradiated Food Committee (BFIFC) of Food and Drug Administration FDA established that more than 90% of all radiolytic compounds in irradiated foods were similar to those found in heating, drying, and freezing of food (Diehl, 1995 and FDA, 1988). Basing its recommendations on radiation chemistry, FDA has concluded that foods irradiated at dose levels up to 1 kGy and foods comprising no more than 0.01 % of daily diet irradiated at 50 kGy or less can be considered safe for human consumption without any toxicological testing (Diehl, 1995). Free radicals are formed when food is irradiated, but they are also formed by exposure to sunlight, frying, baking, grinding, and drying. In wet foods, free radicals disappear within a fraction of a second; in dry foods, the free radicals are much more stable and do not disappear as quickly (ACSH, 1988).

5.1 Nutrition quality of irradiated fresh produce

Irradiated foods are wholesome, nutritious, and nutrient losses are not significantly different from other alternative treatments. The extent of nutritional losses as a result of irradiation is comparable to or less than that of most other processing methods (Josephson and Peterson, 1983; Nawar, 1986). Generally, there is no effect of γ -radiation (up to 10kGy) on the nutrients of irradiated foods. In a previous study, papayas, rambutans, and Kau oranges were acceptable after subjecting to a quarantine level of 0.75kGy (Follet and Sanxter,

2002). According to Scott J. S, and P. Pillai, 2004, vitamins have been shown to keep considerable levels of activity post irradiation. In general, proteins, lipids, and carbohydrates quality is not get affected as a result of irradiation (Thayer, 1990; Thayer et al., 1987; WHO, 1999). The nature and extent of the effects of ionizing radiation on nutrients depends on the composition of food, radiation dose, and modifying factors such as temperature and presence or absence of oxygen. It has been documented that minerals are also stable to irradiation ((Diehl, 1995). According to a report by Fan and Sokorai, 2002, irradiation can reduce vitamin C in some vegetables, but the decrease is usually inconsequential and does not exceed the decline seen during storage. Research on vitamin B₆ has shown less destruction of this vitamin in products sterilized by ionizing energy than by heat (CAST, 1986). Follet and Sanxter (2002) studied the tropical fruits and found papayas, rambutans, and Kau oranges were acceptable when treated with a quarantine level of 0.75kGy (minimum dose required is 0.25 kGy). Irradiation is also reported to increase phenol compounds of certain vegetables consequently increasing their antioxidant ability (Fan, 2005).

Fresh produce may loss firmness after irradiation (Gunes et al., 2000; Palekar et al., 2004). However, the softening of fresh produce can be lessened by combining different treatments. According to Gunes et al., 2000; Prakash et al., 2007, dipping diced tomatoes and fresh-cut apples in a calcium solution prior to irradiation prevents the softening of the tissue.

5.2 Sensory quality of fresh produce

Generally, fresh produce indicate little change in appearance, flavor, color, and texture, after low doses (1 kGy or less). It has been reported that irradiation does not increase the temperature significantly and therefore, there is retention of color, flavor and textural properties (Willis, 1982). In a previous study, celery irradiated at 1kGy, was suggested to be better-quality in sensory qualities as compared to celery subjected to blanching, chlorination, and acidification (Prakash, 2000). Follet and Sanxter (2002) found that Chompoo and Biew Kiew fruit to be more satisfactory when treated with 0.40 kGy than with the currently used hot-water immersion.

6. Challenges of food irradiation

6.1 Consumer acceptance

Currently, there is not yet a large market demand for irradiated foods in the US and the rest of the world. In spite of additional of safety benefits offered by irradiation, marketing of irradiated foods has not been successful; in part due to consumers' believe that irradiated foods form harmful compounds in food (Oliveira & Sabato, 2002). The terms "radiation" and "radioactivity" have negative connotations to many consumers. Occasionally, consumers believe that food become radioactive after irradiation. Food does not become radioactive as the energy passes through; it only destroys bacteria and does not leave behind any residual radioactivity. There are anti-food radiation activists campaing against the public acceptance of irradiated food. It is crucial to educate the consumers and highlight the benefits of irradiation, particularly since the public has indicated to be more receptive to the negative argument (Fox, 2002; Hayes et al., 2002). It is indicated that given the preference and the

access to irradiated products, consumers are willing to purchase them in noticeably great numbers (Bruhn, 1995).

6.2 Gamma Irradiation and cost of food

The principal economic challenge of food irradiation is the projecting of market demand for irradiated fresh produce. A strong market demand, will attract investors absorb the large up-front costs needed to support food irradiation. Definitely, economic considerations are some of the factors that slow the widespread use of food irradiation. As any other food process, food irradiation adds a few cents per pound to the cost of production (<http://www.fipa.us/q%26a.pdf> Food Irradiation Processing Alliance).

Contributing to the limited marketing of irradiated food in USA, is the insufficient food irradiation facilities. As of August 2000, there were only two facilities in the United States used primarily for gamma irradiation of food. (GAO-10-309R. 2010. Federal Oversight of Food Irradiation (<http://www.gao.gov/new.items/d10309r.pdf>). It is costly to build an irradiation facility. A commercial food irradiation plant is in the range of \$3 million to \$5 million, depending on its size and processing capacity. Consumer reception of novel food technologies depends on risks and benefits associated to the new technology and reachable alternatives. Some consumer are attracted to purchase irradiated produce by the discernment that irradiated it is safer. Irradiated produce tend to have longer shelf life hence less storage losses. The cost of irradiated food could be offset by benefits such as keeping a product fresher longer and enhancing its safety (<http://ag.arizona.edu/pubs/health/az1060.pdf>).

6.3 Regulatory approval and labeling

Labeling of irradiated food has been considered indispensable in order to inform the consumers. Labeling laws of irradiated foods differ from country to country. In the U.S., as in many other countries, irradiated food are labeled as "Treated with irradiation" or "Treated by radiation" and require the use of the radura symbol at the point of sale in (Xuetong et al, 2007). Fresh produce should have the radura symbol displayed at the point of sell. For fruits and vegetables, radura symbol can be on each piece, on the shipping container, or on a sign near the merchandise. Analytical methods are used by government and regulatory agencies to determine irradiated foods in the market place (CODEX STAN 231, 2003). Using these methods, existing labeling principles are imposed and consumers' confidence is strengthened

6.4 Consumer education

Consumers' knowledge about food irradiation is insufficient and therefore, education is desired to improve the acceptance of irradiated food by the public. Consumers are confused over what food irradiation and studies time and again display that when provided with science-based information, a high percentage of consumers favor irradiated foods. Food irradiation, pasteurization, canning, freezing, and drying are means of treating food in order to make it safer to eat and longer lasting (Satin, 1993). Despite its advantages, consumer knowledge about it is very limited. Many consumers' fears or misunderstanding of food irradiation are from reports of nuclear incidents at Hiroshima (Japan), Chernobyl (USSR),

and the Three Mile Island (United States) and from nuclear waste disposal. For many, food irradiation is a process that creates the same fear as the word, radiation. Some consumers mistake the association of food irradiation with nuclear radiation, and food irradiation opponents use this as their most effective tool of negative influence. During food irradiation, food is not in contact with radioactive source and therefore, food can not be radioactive (FIFA, 2006).

Conley (1992) advocates that in the US, the Food Safety and Inspection Service FSIS and the National Agricultural Library in cooperation with other food-related agencies such as the FDA should provide education materials to consumers regarding food irradiation. Consumers favor food irradiation after they are given science-based information including product benefits, safety and wholesomeness of irradiated products (Bruhn, 1998; Bruhn, C.M., and Schutz, H.G. 1989). Previous studies indicate that educational activities and science-based information increase consumer acceptance of irradiated foods (Resurreccion et al., 1995; Bruhn, 1998; Fox & Olson, 1998). Nayga et al. (2004) reported that consumers are “willing to pay” premiums for irradiated food depending on the awareness and background information of food irradiation.

7. Conclusion

Food irradiation involves many intricate issues, but if consumers are educated on the benefits, it can be an effective process of reducing microorganisms which cause food spoilage and human illness. It is time to educate the consumers and increase their knowledge and awareness of gamma irradiation as a technology intended to increase the quality and the safety of food, especially fresh produce. Consumer acceptance of food irradiation will definitely influence the intensity to which irradiation gets accepted as an alternative food processing technology.

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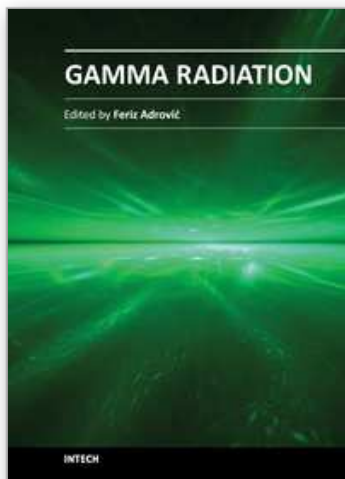
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This book brings new research insights on the properties and behavior of gamma radiation, studies from a wide range of options of gamma radiation applications in Nuclear Physics, industrial processes, Environmental Science, Radiation Biology, Radiation Chemistry, Agriculture and Forestry, sterilization, food industry, as well as the review of both advantages and problems that are present in these applications. The book is primarily intended for scientific workers who have contacts with gamma radiation, such as staff working in nuclear power plants, manufacturing industries and civil engineers, medical equipment manufacturers, oncologists, radiation therapists, dental professionals, universities and the military, as well as those who intend to enter the world of applications and problems of gamma radiation. Because of the global importance of gamma radiation, the content of this book will be interesting for the wider audience as well.

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