FRI Briefings

Food Irradiation

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The continuing saga of foodborne disease outbreaks as reported in scientific publications and the popular press has raised consumer anxiety about foodborne illness and revitalized interest in irradiation as a method for eliminating or reducing foodborne pathogens.In addition to the well-known problems of salmonellae on poultry products, *E. coli* O157:H7 in hamburger, and, most recently, *Listeria* in packaged meats, there have been numerous reports of *Vibrio* spp. in shellfish and of fresh fruits and vegetables contaminated with bacteria, viruses, and parasites such as *Cyclospora*. Irradiation has the potential to enhance food safety for both fresh foods that will be consumed raw and for raw foods that will be further processed. Many of the recent, well-publicized, large recalls of hamburger and other meats have raised consumer awareness of the particular significance of food safety for the young, the old, and those with impaired immune systems. These factors and better education of consumers about what irradiation of food involves and what it does (and does not do) to foods appear to have increased consumer acceptance of irradiation as one means of producing safe foods.

Decades of research in the USA and in other countries have supported the safety and wholesomeness of foods irradiated under Good Manufacturing Practices. A number of well-respected independent organizations, including the World Health Organization (WHO), Codex Alimentarius (*21*), U.S. Food and Drug Administration (*2*,*13*), American Dietetic Association (*6*), Institute of Food Science & Technology (*20*), Institute of Food Technologists (*30*), and the Council for Agricultural Science and Technology (*7*), have concluded that irradiation of food is safe and can be an effective method to help eliminate foodborne contaminants. However, there remain some concerns related to the irradiation of food which may limit its usefulness in certain situations and which cause anxiety among consumers. These points include fate of pathogens that survive radiation; destruction of vitamins; induction of lipid oxides and off-flavors; possible toxicity of radiolytic products in irradiated foods; and effects of irradiation on packaging materials. This paper will briefly describe the irradiation process and its effectiveness, review issues of concern, and provide information on the regulatory status and current use of irradiation for destroying pathogens.

Process of Irradiation

Most food irradiation facilities utilize the radioactive element cobalt-60 as the source of high energy gamma rays. These gamma rays have sufficient energy to dislodge electrons from some food molecules, thereby converting them into ions (electrically charged particles).**Gamma rays do not have enough energy to affect the neutrons in the nuclei of these molecules; therefore, they are not capable of inducing radioactivity in the food.** Some irradiation facilities use cesium-137 as a source of gamma rays while others use machines to produce x-rays or beams of electrons. Again, none of these sources produce beams of high enough energy to induce the formation of radioactive isotopes in foods. All of the energy sources do cause the production of ions and free radicals (reactive compounds with unpaired electrons), including transient high energy oxygen radicals, which kill or damage pathogenic organisms. Since gamma rays from cobalt-60 can penetrate several feet while electrons produced by electron beam facilities penetrate only a few inches, cobalt-60 is usually the preferred source of radiation for food. Irradiation dosage is a function of the energy of the radiation source and the time of exposure. Doses are usually expressed in kiloGrays (kGy); 1 Gray is equivalent to 1 joule of absorbed radiation/kg tissue or 100 rads (*10*). These irradiation doses can be directly related to extent of killing of bacterial pathogens. However, D-10 values (irradiation doses required to cause a 1 log reduction of cells) will differ for different types of foods depending on their density, antioxidant levels, moisture content, and other food components. External factors, such as temperature and the presence or absence of oxygen, also influence the effectiveness of a given radiation dose (*10*,*23*,*30*).

Effectiveness of Irradiation

Sensitivity to irradiation varies among microbial species and is affected by the components of foods and temperature during irradiation and subsequent storage (*12*,*14*,*16*,*28*). Bacteria and parasites are much more sensitive to irradiation when tested in laboratory media than in real foods. Therefore, it is important to test likely contaminants in relevant foods under realistic, expected storage conditions and also under conditions of temperature abuse to determine the effectiveness of different irradiation doses. Under some conditions (high bacterial load, inadequate radiation dose, high concentrations of antioxidants), damaged cells may be able to repair themselves and grow to detectable and dangerous levels (*8*,*25*,*26*,*31*,*32*,*33*). Although it has been suggested that irradiated meats and fish be vacuum packaged or stored under anaerobic conditions to prevent revival of injured cells, there has been concern that *Clostridium botulinum* would thrive under these conditions.

Irradiation readily kills most non-spore-forming bacteria and parasites in foods. Published data on D values range from 0.022 kGy for *Vibrio parahaemolyticus* in freshwater fish homogenate at 24°C to 0.78 kGy for *Salmonella stanley* in ground beef at 18–20°C. In general, *Salmonella* and *Listeria* are more resistant to irradiation than *E. coli* and *Staphylococcus*. *Yersinia, Vibrio, Arcobacter, Aeromonas*, and *Campylobacter* are the most sensitive species. Pathogenic protozoa (such as *Toxoplasma* and *Cyclospora*) and parasitic worms (*Trichinella*, tapeworms, liver flukes) are killed by radiation doses of <1 kGy. However, enteric viruses, spores of *Clostridium* spp., *Bacillus* spp., and molds, and microbial toxins from molds, *Staphylococcus aureus*, and *Clostridium botulinum* are extremely resistant to irradiation and cannot be effectively eliminated at approved doses of irradiation considered reasonable for most foods (£10 kGy) (*28*). Irradiation doses approved for foods normally range from <1 up to 10 kGy. Larger doses (up to 30 kGy) have been approved for dried herbs, spices, and dehydrated vegetables, and up to 44 kGy are used to sterilize packaged meats for astronauts (*12*,*13*, *14*, *21*,*27*).

The safety of irradiated raw pork was found to depend on the size of the initial population of a pathogen, such as *Yersinia*. A dose of 1 kGy was sufficient to eliminate relatively low, naturally occurring levels of *Yersinia*. However, with higher initial cell concentrations (10^6 cfu/g), even 6 kGy was insufficient to kill all the *Yersinia* and injured cells recovered and grew during storage at 2–4°C (*31*). Experiments comparing the effects of irradiation on *Yersinia* in raw pork and in processed pork products revealed that bacteria in ham and salami were killed more easily by irradiation than those in raw ground pork (*22*). It is likely that the salt, spices and other additives in preserved meats enhance the killing by irradiation or inhibit recovery of radiation-injured bacteria.

Fresh foods containing the unicellular parasites *Cyclospora* and *Cryptosporidium* have become a food safety concern in the USA in the past several years. In tests to estimate the radiation sensitivity of these parasites, a related species, *Toxoplasma gondii*, with a better characterized life cycle and well-established tests for infectivity, was inoculated onto, or injected into, raspberries and then exposed to irradiation. When unsporulated oocysts (the resting stage) were irradiated at 0.4–0.8 kGy, they were able to sporulate but were not infective to mice. In most cases, already sporulated oocysts on and in raspberries were unable to infect mice after a dose of 0.4 kGy (*11*). These results indicate that low-dose irradiation may be an effective method for decontamination of fresh fruits and vegetables.

So far, experimenters have not observed the development of radiation resistance in microbes that survive irradiation of foods. In fact, a number of experiments demonstrated that these survivors are weakened and more susceptible to high or low temperatures and to increases in salt concentrations (*19*,*25*,*33*). Nevertheless, microbes are extremely adaptable and the possible evolution of greater resistance to radiation and to other environmental stresses in survivors of irradiation should be monitored.

Issues of Concern

Along with damage to molecules in foodborne pathogens, irradiation also causes some chemical changes in the molecules of foods. Cooking and thermal processing of foods also cause chemical changes and in many cases these are similar to reactions occurring with irradiation (*10*,*23*). With both processes, we have concerns about destruction of micronutrients such as vitamins; oxidation of lipids; changes in protein and carbohydrate molecules leading to the formation of heat- or irradiation-related compounds; and effects on packaging materials.

Destruction of Vitamins

One undesirable side effect of irradiation is the destruction of some vitamins in foods (*24*,*30*). Early experiments testing vitamin survival in water or some solution (rather than in foods) suggested that the loss of certain vitamins during irradiation might be significant. However, as with pathogenic bacteria, vitamins are less sensitive to irradiation when present in the complex matrices of foods. Recent experiments with chicken breast meat demonstrated that some reduction in thiamin levels occurred during irradiation but these losses were less if irradiation was done at lower temperatures (*18*). It should be remembered that vitamins are also destroyed during cooking and other thermal preservation processes (*23*). Several researchers have concluded that vitamin losses due to irradiation would not be significant to those consuming a typical American or European diet (*30*). An analysis of the possible effects of irradiation on vitamin levels in the Argentine diet (*29*) came to a similar conclusion. However, normal levels of vitamin D and folacin are low in the Argentine diet and the authors caution that folacin concentrations, in particular, should be monitored.

Formation of Lipid Oxides

Another undesirable effect of irradiation is the formation of lipid oxides by the reaction of membrane lipids and other lipids in foods with oxygen radicals, produced by gamma rays (*5,10*). These oxides may impart off-odors and tastes to foods and may contribute to lipid-related diseases. For this reason some foods, such as fatty fish and meat and some dairy products, are not considered good candidates for irradiation (*12*). Formation of these oxides can be decreased by reducing oxygen and temperature levels during irradiation. Other approaches which have met with some success include the addition of carnosine, an antioxidant, to ground turkey (*32*) and the addition of vitamin E, another antioxidant, to feed for turkeys and chickens (*3,4,15*). The increased vitamin E levels in muscles of the poultry decreased formation of lipid oxides during subsequent irradiation of the meat. All of these procedures also affected the destruction of pathogens, usually requiring a greater irradiation dose to be effective.

Radiolytic Products in Foods

Although irradiation does not make food radioactive, it does induce some chemical changes in foods leading to production of small amounts of so-called radiolytic products. These new or increased amounts of certain chemical compounds found in irradiated foods are not unique but are similar to compounds formed in foods during cooking (*9,10*). In fact, much larger amounts of some of these compounds are formed during ordinary cooking. Numerous experiments with laboratory animals and some trials with humans have demonstrated that no adverse health effects occur when irradiated foods containing these compounds are consumed.

Radiolytic compounds formed from carbohydrates and proteins in foods are largely a product of reactions with hydroxyl radicals (powerful oxidizing agents) and hydrated electrons (powerful reducing agents), both of which are generated from water molecules by gamma rays. Free radicals reacting with proteins may cause breaks in the protein chains or changes in the secondary or tertiary structure of proteins. These changes would be lethal to a living organism (foodborne bacteria) but do not affect the nutritional quality of the food. Reaction of hydroxyl radicals with starch produces formic acid, some aldehydes and ketones, and different sugars which contain one less carbon. Radiolytic products formed from fats are not usually a result of reactions with disrupted water molecules. Rather, gamma rays interact directly with lipid molecules to form cation radicals or excited lipid molecules. These products may then generate lipid oxides (which result in off odors and tastes) and small amounts of fatty acids, aldehydes, esters, ketones, and other compounds. Again, it should be mentioned that these chemical changes in foods are small and these compounds are also produced by cooking or thermal processing.

Packaging Materials

Since post-irradiation contamination can be minimized by irradiating foods in their final packaging, the effects of irradiation on packaging materials and the migration of components such as plasticizers into foods must be considered (*10*). Experiments conducted with food-grade PVC (polyvinyl chloride) film exposed to high doses of electron beam irradiation (20–50 kGy) demonstrated that increased amounts of dioctyl adipate, a plasticizer, migrated into olive oil after the higher dose of irradiation (*17*). These radiation doses are in excess of those usually recommended for foods. However, this experiment points out a potential problem for irradiation of foods in plastic containers. Any such plastics must be tested for effects of irradiation on the migration of components of the plastic into the types of foods which would be stored in these containers. Irradiation can also affect the structure and stability of some plastics, thereby rendering them unsuitable for exposure to irradiation.

Although adipate plasticizers are not potent toxins, they have been shown to have some deleterious effects in laboratory animals. Since plastics are so widely used, there is a potential for exposure to these plasticizers from many sources. Whether the accumulated dose from these different exposures can be harmful to humans is as yet uncertain but should be considered.

Regulatory Status of Irradiation

In the USA, irradiation has been approved by the FDA (*13,14,27*) for the purpose of microbial disinfestation of the following:

Product	to a limit of:
dry or dehydrated enzymes	<10 kGy
spices, herbs, dehydrated vegetables	<30 kGy
fresh or frozen uncooked poultry	<3.0 kGy

pork carcasses and meat (*Trichinella*)	<1.0 kGy
packaged meat for NASA flights	<44 kGy
fresh or frozen red meat	<4.5 kGy (fresh) <7 kGy (frozen

Irradiation of red meat was approved by the FDA in December 1997, and the recommended procedures for irradiating meat were published by the USDA in the Federal Register on February 24, 1999 (*14*). Following a 60-day period for comments, the final regulations will be published and then commercial irradiation of meat could commence.

A number of individual European countries have regulations in place permitting (or in some cases prohibiting) irradiation of foods under specified conditions. The European Community is at this time working to establish a common set of guidelines. According to data from the International Atomic Energy Agency (IAEA, *21*), as of 1997, a total of 35 countries worldwide had approved irradiation of certain types of foods under specified conditions.

Summary

Acceptance of irradiation as a tool for food preservation is increasing but it should be emphasized that Good Manufacturing Practices in all aspects of food production are still essential in order to produce safe food. Not all pathogenic spores and viruses will be destroyed by irradiation and if food is not handled properly after irradiation, it can become contaminated. However, irradiation is a safe and effective means of destroying many foodborne pathogens and it should be useful in contributing to a safe food supply.

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