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⟨Review⟩

Food Irradiarion: An Alternative Technology for an Emerging Need

Jae-Seung Yang
Korea Atomic Energy Research Institute
150 Dukjin-dong, Yusong-gu, Taejon 305-353, Korea

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Abstract

Development and implementation of food irradiation was driven by needs pertaining to food safety improvement, food spoilage reduction, and quarantine/trade. The need for food safety is caused by the increasing morbidity and mortality caused by food-borne diseases worldwide, and it affects national economy and world-trade. Radiation technology can serve to ameliorate the vulnerability of our food supply system.

1. Introduction

Throughout the ages, people have sought to better manage their food supplies through various means of preservation in order to control spoilage, food-borne diseases and insect infestation. Over the centuries, food preservation techniques have evolved as our knowledge of science has grown. Current methods include freezing, drying, canning, pickling, pasteurization, fermentation, cool or controlled atmospheric storage, chemical fumigation and the addition of preservatives. Our food supply system has changed dramatically, and continues to change, because of the continued process of urbanization and life-style changes. Urbanization requires changes in the way food is produced and distributed. The more efficient the food supply system is, the more vulnerable it is to the spread of disease. Diseases caused by contaminated food is perhaps the most widespread health problem in our contemporary world and an important cause of reduced economic activity [1].

Radiation technology can do much to help ameliorate the vulnerability of our food supply system. Radiation is a very versatile form of processing energy and has unique properties which allow for processing options not possible by any other means. Radiation processing refers to the treatment of foods with ionizing energy to achieve some desired benefit [2]. Action cascade of irradiation on food is a chain of events which begins with the physical process of energy deposition and ends with the manifestation of biological effects of irradiation. Differential sensitivities of microorganisms on irradiation allow beneficial effects of irradiation to be possible. Technical benefits are insect disinfestation, microbial decontamination (pathogens, spoilers), sprout inhibition (tubers, bulbs), delay of ripenning or maturation, and modification of some functional properties such as more rapid rehydration, reduction in cooking time and increased digestability [3]. Because damage occurs randomly throughout foodstuff some undesired effects will result as well. Such potential deleterious effects are the altered taste or smell, the loss of desirable functional properties, the production of radiolytic products. Therefore, it is best to develop the following protocol: "Selection of treatment parameters to achieve the desired benefits of irradiation in a particular application, while avoiding unacceptable deleterious effects."

2. History

Treatment of food with ionizing radiation is, with the exception of quick freezing, the only thoroughly novel means of food preservation that has been applied on an industrial scale this century. After the 1950s, large programmes for food irradiation were initiated, particularly at the US Army Laboratories at Natick and the Massachusetts Institute of Technology. These programmes concentrated on the microbiological aspects of food irradiation but also, extensive toxicological studies were undertaken in order to evaluate the safety of food irradiation for human consumption [4,5,6]. The important aspects of toxicological safety and 'wholesomeness' of irradiated foods were reviewed at a meeting sponsored by the FAO, IAEA and WHO held in Brussels in 1961 [7]. Studies were subsequently set out in 1964 by a FAO/IAEA/WHO Joint Expert Committee (JECFI) on Irradiated Food in Rome [8].

Following the JECFI meeting in 1976 [9], unconditional or provisional acceptances were recommended for a wide range of irradiated foods after a large number of animal feeding studies. In 1980, JECFI considered all available data in view of toxicology and radiation chemistry and concluded that the food-by-food approach was unnecessary and that irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard [10]. These conclusions and recommendations represented a milestone in the acceptance and progress of food irradiation, and led to the adoption by the Codex Alimentarius Commission, represented by 130 governments, of the Codex General Standard for Irradiated Foods and a Recommended International Code of Practice for the Operation of Radiation Facilities Used for Treatment of Food [11]. This has encouraged, to date, 37 countries to approve more than 40 irradiated foods.

3. Ionization of Water

Cooking, baking and frying are methods used to produce chemical reactions that kill bacteria and inactivate enzymes in food. Heating is usually obtained by direct contact with hot surfaces or hot liquids, or by exposure to infrared rays emitted by hot filaments. Food may also be cooked by exposure to the longer wave lengths of microwave ovens. Microwave heating is due to polarization of the medium, and depends therefore on the dielectric constant. Water has a very high dielectric constant, and so the free water in food heats up first and then transfers this heat to other molecules of the food. Ultraviolet radiation has often been used to sterilize surface food. The sterilization effect is due to quanta with energies greater than 4 electron volts (eV). These quanta are able to alter or break even the strong chemical bonds in DNA, and are therefore very effective at killing bacteria. In general, we may say that the entire electromagnetic spectrum, from very long television waves to the short waves of ultraviolet radiation, have in the past often been used for processing food.

Use of shorter wave lengths, such as X-rays and gamma-rays, are relatively new. Gamma rays emitted from radionuclides, and X-rays and high-energy electrons generated by machine, are all forms of ionizing radiation. Such forms of radiation are sufficiently high in energy to cause ionization. Ionization is the creation of positive and negative ions by the removal of an orbital electron from an atom. Charged ions, which are formed by the energy absorption of ionizing radiation in the medium, decompose rapidly to form very reactive molecular species known as free radicals, which have an unpaired electron in one of their outer orbitals. Free radicals react with each other and with uncharged molecules and thus act as intermediaries between ionization and the final stable chemical products (radiolytic products) [12-14]. The lifetime of most free radicals is short, usually less than one thousandth of a second, but in hard materials, such as bone, much longer lifetimes are possible. Based on the detection of trapped free radicals, electron spin resonance (ESR) is used to identify irradiated food [15].

Many changes in foods are initiated by free radical formation in water [16]. Initially, a water molecule is ionized by an energetic photon or a charged particle. For aqueous solutions or materials containing water such as food materials, these highly reactive products formed by the radiolysis of water can produce an indirect effect with substances dissolved in the water.

Chemical changes may occur as a result of the direct action of ionizing radiation. In such cases, a sensitive target, e.g. DNA in a living cell, is damaged directly by ionizing radiation. In addition, the radiolytic products of water may cause indirect changes by reacting with the organic molecules, e.g. protein, DNA, of insects, parasites or microorganisms present in the food system. Dried foods are more resistant to radiation-induced changes because of the absence of water.

4. Effect of Irradiation on Microorganisms

Microbial cells can be easily and quickly destroyed by irradiation, leaving them unable to replicate, transport and metabolize nutrients, and grow. Thus foods can be made safer by destroying pathogens, since irradiation breaks bonds in the DNA of these cells, making it impossible for normal replication to take place. Since DNA is the key target molecule in many applications of food irradiation, it is logical that DNA damage should be a focus for attempts to derive methods to detect whether or not a food has been irradiated, and to quantify the dose received. Microgel electrophoresis of DNA detects change in the mobility of DNA fragments produced by irradiation and may form the basis of methods that are reasonably specific for irradiated foods [17].

Resistance to irradiation is expressed as the D value, or the dose required to reduce the microbial population in a given medium (or food) by 10-fold. Destruction of microorganisms by irradiation is logarithmic and affected by several factors. Microorganisms differ in their sensitivity to irradiation, depending on morphological variations, just as they differ in their sensitivity to heating, drying, and freezing. Viruses are usually more resistant than the spores of bacteria, which are more resistant than the vegetative cells of bacteria, which in turn are more resistant than yeasts and molds. In general, the more simple the lifeform is the more resistant to radiation. Another factor that affects the survival of microorganisms to irradiation is temperature: the lower the temperature is, the higher the D value becomes. Since not as many water radicals are formed at freezing temperatures, it takes a higher dose to destroy the cells [18]. The composition of the medium in and of itself also has an impact on the susceptibility of microorganisms to irradiation [19], as does the atmosphere in which a product is packaged [20-23].

The vegetative bacteria which cause the most food-poisoning concern are all very radiation sensitive, which means that low-dose irradiation will effectively eliminate them from contaminated food (e.g. *Salmonella species*).

Bacillus cereus was the most sensitive to irradiation, with D values within the range 0.13 to 0.29 kGy, followed by *Staphylococcus aureus* (0.25 to 0.43 kGy), *Listeria monocytogenes* (0.30 to 0.65 kGy), *C. perfringens* (0.34 to 0.59 kGy) and *Salmonella typhimurium* (0.37 to 0.70 kGy) [24-35]. Many of the common Gram-negative spoilage bacteria (e.g. Pseudomonas) and members of the Enterobacteriaceae, including pathogens (e.g. *Escherichia, Salmonella, Shigella*) are radiation-sensitive [36,37]. Bacteria that proved resistant are those with cells having very efficient DNA repair systems, such as those able to repair numerous double strand breaks, for example *Deinococcus radiodurans* [38] and related species.

Reduction or elimination of parasites by irradiation can be achieved by using doses that will simply sterilize these pests, rendering them unable to reproduce, or by killing the cysts, eggs, or larvae produced by these organisms [39,40]. Viruses are very radiation-resistant but are sensitive to heat, like most radiation-resistant bacteria [41].

5. Promising Technology for Public Health

Much has been written about the impact of food-borne diseases on our society, from a medical, as well as economic perspective [43,44]. Outbreaks have been caused by the consumption of practically every type of food commodity, from meats to eggs, dairy products, fruits, vegetables, and seafood. Food is the vehicle for transmission of diarrheal diseases, which cause about 25% of the deaths in developing countries. The Centers for Disease Control of the Public Health Service noted that *Salmonella* illnesses in the United States are vastly underreported; estimates are that the actual number of outbreaks is between 800,000 and 4 million cases a year [45]. The resulting costs approach billions of dollars in the United States, when considering medical costs, insurance costs, and time lost from work. Even so, there is speculation that only 10% of all food-borne disease cases are reported, most patients choosing not to see a physician, and allowing the disease to run its course [46-50]. Therefore, the potential role of food irradiation in reducing those costs is not fully appreciated.

Due to recent outbreaks of food-borne diseases associated with the ingestion of undercooked food containing *Escherichia* coli O157:H7 in the United States and Japan, there has been renewed interest in the use of ionizing radiation to ensure the microbiological safety of foods. Studies have shown that irradiation can be an effective means of controlling human pathogens, such as salmonellae, *Campylobacter jejuni, E. coli* O157:H7, *Listeria monocytogenes* and, at much higher doses, *Clostridium botulinum* [51] in poultry.

In the case of poultry products, food irradiation offers a cost-effective method for assuring consumer protection against food-borne diseases, particularly salmonellosis and campylobactriosis. Improvements in production methods can reduce the level but not eliminate the contamination of raw products. In the case of Camembert cheese made from raw milk, radiation processing of the ripening cheese appears to be the only practical alternative to meet the microbiological standard for international trade and to assure the continued availability of this product [52]. With the safety of irradiated food established, the process offers the possibility of destroying or reducing the largely unavoidable pathogens that contaminate foods, especially raw food of animal origins. Irradiation provides additional safety to the product.

6. Conclusions

Substantial advances have been made in understanding the basis of efficacy of food irradiation for the reduction of food spoilage and for the improvement in food safety. Food safety is increased by virtue of destruction of microbial pathogens, many of which can be eliminated from fresh products by irradiation at 1.5 kGy.

The Hazard Analysis Critical Control Points (HACCP) is a system designed to solve the problem of contaminated foods by pathogenic organisms, and regards irradiation as an essential component of food processing and preservation [53-55]. Within the HACCP, determination of critical control points (CCPs) is one of the significant steps required to prevent or control hazards inherent in a product. It would be easy to imagine the introduction of irradiation as the last CCP in the processing of foods after packaging and before shipping to a retail operation. Because products are irradiated after packaging, this technology ensures that the food is delivered in as clean a fashion as possible, since the problems of postprocessing contamination in the plant are eliminated. In fact, with this technology in place, outbreaks due to undercooking would be significantly minimized, since pathogens that cause food-borne disease would not be present in the product. Adherence to good manufacturing practices (GMPs), however, would still be the rule, just as with any other process. In addition, proper refrigeration would be carried out for irradiated products. Irradiation, as with most other processes, is not an all-encompassing solution to the problem of microbial contamination. It is simply one of several solutions, which, together with GMPs and HACCP, will work to make foods safe. It should be noted, however, that food irradiation may be one of the most important food technologies to protect human health since the introduction of milk pasteurization nearly a century ago.

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