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Irradiation as a method for decontaminating food

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Food irradiation is one of a set of processing technologies that can be used to increase the microbiological safety and shelf life of a wide range of foods. Ionizing radiation is used to generate highly active chemical species within the food that react with DNA. Under normal usage conditions, the food receives a pasteurizing treatment that gives a valuable reduction in common food-spoilage organisms and food pathogens. Decontamination of food by ionizing radiation is a safe, efficient, environmentally clean and energy efficient process. Irradiation is particularly valuable as an end product decontamination procedure. Candidates of radiation decontamination are mainly poultry and red meat, egg products, and fishery products. It is a unique feature of radiation decontamination that it can also be performed when the food is in a frozen state. Irradiation in combination with other processes holds a promise for enhancing the safety of many minimally processed foods.

1. Introduction

The development of food preservation processes has been driven by the need to extend the shelf-life of foods whilst maintaining their safety. Preservation methods that have long been accepted by consumers, however, frequently have associated disadvantages, in particular adverse changes in organoleptic characteristics and loss of nutrients.

Heat processing can cause significant deterioration in the sensory properties of food. Even mild heat treatments cause substantial flavor changes in products. Freezing causes severe textural deterioration in foods such as strawberries. Pickling causes similar sever sensory changes, and is limited to a relatively restricted range of foods. Even more modern minimal processing techniques, such as modified-atmosphere packing and sours-vide cooking, each of which gives relatively small changes in sensory quality, add to product cost and can carry microbiological hazards.

Food irradiation produces organoleptic changes that are much less serious than those quoted above, and carries no serious side-effects when a controlled process is applied to appropriate foods. It is therefore surprising that there is still considerable reluctance to introduce the technology in many countries.

2. The irradiation process

Ionizing radiation is sufficiently high in energy to remove an electron form water, which is the main component of foods and living organisms, and to create highly reactive species, including free radicals such as the hydroxy radical, and hydrogen peroxide.

The predominant useful effects of irradiation rely on reaction of these species with the DNA of microorganisms, causing death. It has been estimated that an absorbed radiation dose of 0.1 kGy results in 2.8% of the DNA being damaged; this is mainly from indirect ionization of water, rather than direct DNA hits (Diehl, 1990). The high reactivity of free radicals in aqueous foods results in very short lifetime, and they can only persist, in low concentrations, in a solid matrix such as bone. Free radicals are naturally present in living tissues, and the chemical changes involving free radical reactions are similar to those found in processes such as autooxidation in fat containing foods.

Three sources of ionizing radiation are used in commercial radiation processing plants (IAEA, 1982). Gamma-radiation plants use a radioactive source, usually cobalt-60, generating γ-radiation with energies of 1.17 and 1.33 MeV. A major characteristic of γ-radiation is its high penetrating power, which facilitates its use in treatment of bulk items such as chickens and drums of food. Anther radiation source, caesium-137, is also permitted in some national legislation but is highly unlikely to be used, owing to practical difficulties in handling this isotope. The second main source of ionizing radiation is high-energy electrons from machines all have the advantage that they can be switched off when not in use, leaving no radiation hazard. A major limitation of electron beams for food use is their limited penetration depth, up to a maximum of about 8 cm in food for the maximum permitted energy of 10 MeV. Despite this limitation, electron beam treatment can be used for products such as grain on a conveyor or low-density foods such as ground spices, and it can also be used to remove surface contamination on prepared meals. A third, but less well-developed radiation source is X-rays generated from bombardment of a metal target by electrons. Although

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common technology in hospitals, at present it is not used for food treatment because of the low conversion efficiency of electrons to X-rays. X-rays however, carry the dual advantage of high penetration power and switch off capability. All three source types require a large plant for economic viability. Much of the high cost of such plants is associated with the need for heavy concrete shielding to protect the external environment when the source is in use.

3. Applications

The processes used for food irradiation have been used for many years for a number of purposes, and continue to be used for applications such as medical diagnosis and therapy, sterilization of medical supplies and to modify and improve the physical properties of polymeric materials. Irradiation can also be used to decontaminate animal feed and treat food for hospital patients requiring sterile diets.

The applied irradiation dose is measured in kilograys (kGy), where 1 Gy = 1 J/kg. For polymer treatment and medical sterilization purposes, doses of 25 kGy and above are used, whereas for food irradiation maximum doses of 10 kGy are usually used. For most food applications, doses considerably lower than this give useful effects. At low irradiation doses-of less than 1 kGy- sprouting in products such as potatoes and onions is inhibited, and insect infestation in grains and citrus fruits, is prevented through sterilization of the insects and interruption of the breeding cycle. Low irradiation doses can also delay ripening of certain fruits. This effect is not applicable to all fruits, however, and can also vary with the cultivar type and growing conditions. At slightly higher doses, of 1-3 kGy, the numbers of spoilage microorganisms present in foods are reduced. Reduction in the normal spoilage microflora can give extension to shelf-life of produce such as soft fruit, meat and fish. Food-poisoning organisms such as *Salmonella*, *Campylobacter* and *Listeria* are slightly more resistant, but reductions in counts of practical value can be achieved within this dose range. Spores form sporulating bacteria such as *Clostridium botulinum* are much more radiation-resistant, and ate unlikely to be affected at practical food irradiation doses. Viruses are highly resistant to irradiation and are unaffected at the highest doses, of 10 kGy, that will be permitted for food. The sensitivity of microorganisms to irradiation depends on both species and strain, and also on environment-for example food type and pH. The resistance also increases at reduced temperatures, and reduction in microbial loading of frozen foods requires doses of up to 7kGy. It is important to prevent recontamination of irradiated food, and a major advantage of food irradiation is that most foods can be irradiated successfully in the final packaging (Farkas, 1998).

4. Changes in food components

The changes in sensory properties result mainly from three types of chemical reaction. Firstly, irradiation initiates the normal process of autooxidation of fats, which gives rise to rancid off-flavors. Secondly, irradiation of proteins that have sulphur-containing amino acids causes a slight breakdown in the amino acids, resulting in unpleasant off-flavors. Thirdly, irradiation can break high-molecular-weight carbohydrates into smaller units. This process is responsible for the softening of fruits and vegetables through breakdown of cell wall materials, for example pectin. Other trace components such as essential amino acids, essential fatty acids, minerals and trace elements are unaffected under practical irradiation conditions, although some vitamins, such vitamin C and vitamin B1, are partially lost (Kilcast, 1995).

Undesired changes in organoleptic characteristics can be minimized by combining irradiation with other preservation treatments, and such combination processes can also have the advantage of enhancing the effects on microorganisms. Typical processes that can be used in combination with irradiation are refrigeration, modified-atmosphere packaging and mild heat treatment.

5. Current uses of food irradiation worldwide

Food irradiation has been approved by 36 countries for more than 40 different foods (IAEA, 1989), and by the end of the 1990s about fifty-five facilities are expected to be in use for food. Many countries, especially in the Third World, are developing food irradiation to reduce the post-harvest food losses that are fundamental causes of food shortages. Uses include disinfestations of grain, reduced spoilage of tropical fruits and elimination of fruit flies as a disinfestations treatment. East European countries, South American countries and eastern countries are using irradiation to reduce losses of tuber crops such as potatoes, onions and garlic through sprouting inhibition.

TABLE 1. Examples of current uses of food irradiation

Region	Country	Food	Maximum dose (kGy)
The Americas	USA	Pork	1.0
		Poultry	3.0
	Canada	Potato	0.1
		Spices	10.0
	Brazil	Strawberries	3.0
		Fish	2.2
Europe	France	Camembert cheese	3.5
		Egg white	4.0
	Netherlands	Frog-legs	5.0
		Dried fruits	1.0
	UK	Roots and tubers	0.2
		Shellfish	3.0
Asia and Africa	China	Garlic	0.1
		Rice	1.0
	Thailand	Mango	1.0
		Fermented sausage	4.0
	South Africa	Avocado	3.0
		Fruit juices	3.0

TABLE 2. Detection methods of potential importance in the near future

Food	Technique
Herb, spices, dehydrated vegetables	Thermoluminescence Chemiluminescence
Contaminant minerals in spices, grains, fruits and vegetables, bulbs and tubers	Thermoluminescence
Chicken	Electron spin resonance Lipid-derived volatiles
Strawberries	Electron spin resonance
Potatoes	Electrical impedance
Seafood	DNA strand-breaks *o*-Tyrosine
Spices, herbs, dehydrated vegetables	Viscometry
Citrus and other fruits	Inhibition of seed germination

Some examples of current uses are shown in Table 1 (Farkas, 1988; Kilcast, 1995).

6. Detection of irradiated food

No simple method has yet been developed for detecting whether food has been irradiated, reflecting the minute chemical changes that occur. Opponents of food irradiation insist that detection methods are needed to protect consumers from the safety hazards that result from the process, despite 30 years of research that have demonstrated the safety of the process (Delincee, 1991).

Electron spin resonance (ESR) measures very small concentrations of radicals produced on irradiation of a solid matrix such as bone. The method is currently limited to foods containing bone, such as poultry and fish, but may have some application in other foods containing a solid matrix. The ESR technique requires expensive instrumentation and specialist expertise, which may limit its practical application, but dedicated ESR equipment claimed to need no specialist knowledge is now available (Strevenson and Gray, 1990).

The team at Belfast has developed a method for detecting lipid breakdown products (akylcyclobutanones and hydrocarbons) from poultry (Stevenson & Gray, 1990). The method has potential uses for all fat-containing foods, and has recently been shown to be suitable for detecting irradiation in eggs. Thermoluminescence (TL) relies on light emission from dried products such as herbs and spices on heating (Sanderson, 1990). Other propose detection methods based, for example, on hydroxylation of aromatic rings have yet to exhibit the uniqueness and reliability that will be required for control and enforcement purposes. Methods based on changes to DNA may have the most general applicability, but require much more development. A summary of potentially useful methods is shown in Table 2 (Delincee, 1998).

7. Current legislation

The FDA has found irradiation of food to be safe under several conditions. Authorizing regulations have been issued both in response to petitions and at the FDA's initiative (Table 3) (Morehouse, 2002). Irradiation can cause chemical change in packaging, as well as food, and this can affect migration of the package component to food. The FDA has three ways in which a food contact substance may be regulated for use during the irradiation treatment of foods. The packaging material must be part of an applicable food additive regulation (21 CFR 179.45), or an exemption form regulation (threshold of regulation policy, 21 CFR 170.30) or an effective food contact substance notification. Also, FDA requires that the label bear the radura symbol and the phrase "treated with radiation" or "treated by irradiation". If irradiated ingredients are added to foods that have not been irradiated, no special labeling is required on retail packages because it is obvious that such foods have been processed (Morehouse, 2002).

TABLE 3. Foods permitted to be irradiated under FDA's regulations

Food	Purpose	Dose
Fresh pork	Control *Trichinella sporalis*	0.3 kGy min–1 kGy max
Fresh foods	Growth and maturation inhibition	1 kGy max
Foods	Arthropod disinfection	1 kGy max
Dry enzyme preparation	Microbial disinfection	10 kGy max
Dry spices/seasonings	Microbial disinfection	30 kGy max
Poultry	Pathogen control	3 kGy max
Frozen meats (NASA)	Sterilization	44 kGy max
Refrigerated meat	Pathogen control	4.5 kGy max
Frozen meat	Pathogen control	7 kGy max
Shell eggs	Pathogen control	3 kGy max
Seeds for sprouting	Pathogen control	8 kGy

8. Safety of food irradiation

The various safety issues have been addressed in many expert reviews over many years, and have all concluded that food irradiation, properly carried out, is a safe process (Diehl, 1990).

Conclusion

Food irradiation has become a highly emotive issue in many countries, in which, unfortunately, reliable scientific information has often been ignored or distorted in irresponsible statements made by anti-nuclear and anti-food industry pressure groups and which achieve high profile in the media. The many benefits of the process have remained submerged in suspicion of the activities of the food industry. Despite the claims of its critics, food irradiation has been one of the most thoroughly researched food preservation processes in the past 40 years, but little of the results of this research has been communicated effectively to the consuming public.

In order that consumers can make any judgment on the quality of irradiated food, it must be available for purchase, suitably labeled, alongside non-irradiated produce. The attitude of the retail chains is therefore vital, and if retailers are to continue a policy of giving consumers a choice then we would hope to see test marketing of irradiated foods, along lines already successfully pioneered in the USA and in France. Regardless of the attitudes of proponents and opponents of food irradiation, the consumer should be given the choice of making the final decision.

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