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Review

Irradiation for better foods

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Food irradiation is a process exposing food to ionising radiations such as gamma rays emitted from the radioisotopes ^{60}Co and ^{137}Cs, or, high energy electrons and X-rays produced by machine sources. Depending on the absorbed radiation dose, various effects can be achieved resulting in reduced storage losses, extended shelf life and/or improved microbiological and parasitological safety of foods. However, hindering factors in the way of commercial implementation of the food irradiation process are politics and consumer advocacy. Similar situation occurred with the heat pasteurisation of milk in the past. The paper summarizes world-wide status of food irradiation.

Introduction

The potential application of ionising radiation in food processing is based mainly on the fact that ionising 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 (Table 1). 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 ^{60}Co and, to a much smaller extent, ^{137}Cs, 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 ionising radiations and electrons are equivalent in food irradiation.

The mechanism of microbial inactivation by ionising 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.

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Table 1. Guidelines for dose requirements of various applications of food irradiation

Preservative effects and types of application	Dose requirements (kGy)
Inhibition of sprouting of potatoes and onions	0.03–0.12
Killing and sterilising insects (disinfestation of food)	0.2–0.8
Prevention of reproduction of food-borne parasites	0.1–3.0
Decrease of after-ripening and delaying senescence of some fruit and vegetables; extension of shelf-life of food by reduction of microbial populations	0.5–5.0
Elimination of viable non-sporeforming pathogenic microorganisms (other than viruses) in fresh and frozen food	1.0–7.0
Reduction or elimination of microbial population in dry food ingredients	3.0–10
Reducing the number of viable microorganisms in enzyme-inactivated foods to such an extent that no microbial spoilage or food poisoning should occur (12D-reduction of botulinal spores by analogy with heat processing for shelf-stable foods)	25–60

Similar to heat resistance, the radiation response in microbial populations can be expressed by the decimal reduction dose (D_{10}-value). Summarizing data from a large number of references, Table 2 presents typical radiation resistances of a number of bacteria in non-frozen foods.

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).

Table 2. Typical radiation resistances of some bacteria in non-frozen foods of animal origin (Farkas, 2001b)

Bacteria	D_{10} value (kGy)
Vegetative cells	
Aeromonas hydrophila	0.14–0.19
Bacillus cereus	0.17
Brucella abortus	0.34
Campylobacter jejuni	0.08–0.20
Clostridium perfringens	0.59–0.83
Escherichia coli (incl. O157:H7)	0.23–0.35
Lactobacillus spp.	0.3–0.9
Listeria monocytogenes	0.27–1.0
Moraxella phenylpyruvica	0.63–0.83
Pseudomonas putida	0.06–0.11
Salmonella spp.	0.3–0.8
Streptococcus faecalis	0.65–1.0
Staphylococcus aureus	0.26–0.6
Vibrio spp.	0.03–0.12
Yersinia enterocolitica	0.04–0.21
Bacterial spores	
Bacillus cereus	1.6
Clostridium botulinum types A and B	1.0–3.6
Clostridium botulinum type E	1.25–1.40
Clostridium sporogenes	1.5–2.2

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).

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).

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-sporeforming 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 are also involved (Farkas, 2001a).

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