

History and future of food irradiation

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Treatment of food by specific ionizing radiations to improve microbiological safety and storability is one of the most extensively studied technology of the XXth century. However, much of the research has been carried out in laboratories and it is still relatively underutilized commercially. Its application potential is very diverse, from inhibition of sprouting of tubers and bulbs to production of commercially sterile food products. The safety of consumption and wholesomeness of irradiated food have been extensively studied in international cooperations. Numerous international expert groups set up jointly by the FAO, the IAEA and the WHO, or the Scientific Committee on Food of the European Commission concluded that foods irradiated with appropriate technologies are both safe and nutritionally adequate. A Codex General Standard for Irradiated Foods and a Recommended International Code of Practice for Radiation Processing of Food have been developed. Specific applications of food irradiation are approved by national legislations in over 55 countries worldwide. Commercial use of irradiation, however, is still limited. In spite of pioneering past R&D activities in Europe and North-America, the utilization of the process growing faster and increasingly, mainly for sanitary purposes, in fast-developing countries in the (South-East) Asian region and some Latin-American countries. Progress in the European Union is decidedly slower. In the EU, food irradiation is regulated since 1999 by a General Directive, but its implementing directive, the Community list of EU approved irradiated foods contains only a single class of items: “dried aromatic herbs, spices and vegetable seasonings”. This slow progress is mainly due to psychological and political factors, misinformation created

by various activist groups, and the reluctance to implement the process by the industry is discouraged by such forces. The future of food irradiation will depend on an informed public and better understanding of the role the process can play in the control of food-borne pathogens.

Introduction

Food irradiation has about 100 years of history and it was developed as a scientifically established technology and safe food process during the second half of the XXth century (Molins, 2001). It is the ultimate minimal processing technology, which has been mainly initiated and profoundly studied, but the least utilized in Europe. Although food is commonly irradiated for example with microwaves, the term food irradiation is used to describe a process where food is exposed to ionizing energy, utilizing gamma photons emitted by ⁶⁰Co (or much infrequently by ¹³⁷Cs) radioisotopes, machine-generated X-rays (“Bremsstrahlung”) of max. 5 MeV, or, accelerated electrons of max. 10 MeV kinetic energy (Farkas, 2004). The electromagnetic radiations of the first two types of sources have good penetration ability, while accelerated electrons have low penetrability. None of these energy sources induce radioactivity in the food or its packaging, and the treatment has many technologically and technically feasible applications including significantly improving microbiological safety and/or storage stability of foods.

Main potential applications and general dose requirements of food irradiation are listed in Table 1 (Farkas, 2004), where the unit of absorbed radiation doses are given in kilo gray (kGy) units (1 Gy is equal with 1 J/kg absorbed energy).

History of food irradiation

Selected historical milestones of progress in food irradiation research and developments are summarized in Table 2.

The first half of the last century could be called as the age of inventors (Diehl, 2002) because in that period radiation facilities were not of suitable capacities for practical applications. However, from the middle of the XXth century, systematic research efforts, several national research programmes and international cooperations together with technical developments established a solid scientific and technical background for the utilization of this technology. Due to its uniqueness, lack of application history and

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Table 1. Main potential applications and general dose requirements of food irradiation (Farkas, 2004).

Application	Dose requirement (kGy)
Inhibition of sprouting	0.03–0.12
Insect disinfestation	0.2–0.8
Parasite disinfestation	0.1–3.0
Shelf-life extension (“radurization”)	0.5–3.0
Elimination of non-sporeforming pathogenic bacteria (“radicidation”)	1.5–7.0
Reduction of microbial population in dry food ingredients	3.0–20
Production of meat, poultry and fishery products shelf-stable at ambient temperature (“radappertization”)	25–60

experience, it was important and necessary to also clarify the wholesomeness (toxicological and microbiological safety and nutritional adequacy) of irradiated food. This required an unprecedentedly careful and wide-ranging effort of such testing, which was beyond even the capability of the most developed countries. Therefore, specific research programmes and international projects supported by specialised agencies of the United Nations such as the Food and Agricultural Organization (FAO), the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO) were important partners in assisting progress. The most extensive one of such international cooperations was the International Project in the Field of Food Irradiation (IFIP, Karlsruhe) with the involvement of up to 24 countries between 1970 and 1982.

International groups of experts, the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI), evaluated periodically (in 1964, 1969, 1976, and 1980) the results of wholesomeness testing. The JECFI reached a “landmark” decision at its 1980-meeting, reporting its main conclusions as “...the irradiation of any food commodity to an overall average dose of 10 kGy

presents no toxicological hazard, hence, toxicological testing of food so treated no longer required...”, and “...irradiation of foods up to an overall average dose of 10 kGy introduces no specific nutritional or microbiological problems...” (WHO, 1981). The JECFI recognized that higher doses of radiation were needed for certain applications (see Table 1) but did not consider the toxicological evaluation and wholesomeness assessment of them because insufficient data sets for this purpose were available that time. In 1997, an FAO/IAEA/WHO Study Group on High Dose Irradiation examined the results of safety studies carried out on foods irradiated in the dose range 25–60 kGy to achieve the intended technological objective of radappertization. The conclusion was that such foods are both safe to consume and nutritionally adequate (Diehl, 2002; WHO, 1999).

The JECFI recommendations were taken up soon after by the FAO/WHO Codex Alimentarius programme, which developed a “Codex General Standard for Irradiated Foods” and a “Recommended International Code of Practice for the Operation of Radiation Facilities Used for the Treatment of Foods”. These documents have been revised later (Codex, 2003a, 2003b) and became widely adopted by the UN member states.

It is an important development that the role of Codex and Codex General Standards has changed in the light of world trade requirements, Codex Standards are no longer for adoption by national governments, but now form part of the international framework for world trade (Boutrif, 2003).

From 1983 till 2004, an additional cooperation of experts and other representatives delegated by governments of 38 countries formed an International Consultative Group of Food Irradiation (ICGFI) established under the aegis of FAO, IAEA, and WHO, to assist governments in considering the authorization of applications of radiation processing of food, ensuring its control and marketing irradiated food products. A series of ICGFI documents on compilation of

Table 2. Historical milestones of food irradiation.

Age of inventors
1905: J. Appleby & A.J. Banks: British patent: “to bring about an improvement in the conditions of foodstuffs” and in “their general keeping quality by radiation of radioactive substances”
1921: B. Schwartz (US): published use of X-rays for inactivating trichinae in raw pork
1930: O. Wüst: French patent: kill bacteria in packaged food with X-rays
Radiation facilities not yet suitable for practical application
1957: First commercial application: electron beam irradiation of spices in Germany
From the middle of the XXth century, systematic research efforts, national research programmes and international cooperations developed:
1966: First International Symposium on Food Irradiation, Karlsruhe, Germany
1970–1982: International Project in the Field of Food Irradiation (IFIP) (19→24 countries + FAO/IAEA, OECD→WHO)
1980 (1964, 1969, 1976): Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI). Landmark decision, doses up to 10 kGy
1983–1984: Codex Alimentarius “General Standard for Irradiated Foods” and “Recommended International Code of Practice for the Operation of Radiation Facilities”
1979–1990: Assisting developing countries by training and demonstration: FAO/IAEA International Facility for Food Irradiation Technology (IFFIT), Wageningen, The Netherlands
1983–2004: International Consultative Group on Food Irradiation (ICGFI)

technical data of irradiation of various foods have been published by the IAEA, Vienna, as IAEA-TECDOC documents (Molins, 2001).

Assisting mainly developing countries by training and demonstration, the FAO/IAEA and the Dutch Government sponsored a specific international project called International Facility for Food Irradiation Technology (IFFIT) between 1979 and 1990 in Wageningen, The Netherlands (Farkas, 1985).

Considering the potential role of food irradiation in the safety of food supply, the World Health Organization formed a positive attitude towards the utilization of food irradiation. For example, in collaboration with the FAO, the WHO published in 1988 a booklet entitled “Food Irradiation. A technique for preserving and improving the safety of food” (WHO, 1988). In its “WHO Golden Rules for Safe Food Preparation”, the WHO as Rule No. 1 (“Choose foods processed for safety”) states among others that “...always buy pasteurized as opposed to raw milk, and if you have the choice, select fresh or frozen poultry treated with ionizing radiation...”.

Noting that unwarranted rejection of the food irradiation process, often based on a lack of understanding, may hamper its use in those countries likely to benefit most, WHO set up again a WHO Consultation on Food Irradiation in 1992, and published its detailed report in 1994, endorsing that “food irradiation is a thoroughly tested technique, that it has not been shown to have any deleterious effects when performed in accordance with good manufacturing practice, and that it can help to ensure a safer and more plentiful food supply by extending shelf-life, eradicating pests and inactivating pathogens” (WHO, 1994). These efforts assisted a worldwide development of clearances and food irradiators, which can be noted from the IAEA/nucleus databases (<http://nucleus.iaea.org/apps/FICDB/Browse.aspx>, and <http://nucleus.iaea.org/apps/FIFDB/Browse.aspx>, respectively). It can be noted from these databases that food irradiation is currently approved for use in over 55 countries, and 68 food irradiation facilities registered worldwide, at least 25 of them being situated in Asia and Australia.

In spite of these encouraging data, it is true that, due to opposing attitudes of certain activist groups forming “public opinion”, inducing unfounded fears by misinformation, and unwillingness of legislators and industrial stakeholders to act, the implementation of the food irradiation process is seriously hampered, particularly in the European region.

Situation of food irradiation in the European Union as compared to other parts of the world

Japanese authors have published recently two papers (Kume, Furuta, Todoriki, Uenoyama, & Kobayashi, 2009a, 2009b) on the results of a survey performed by the Cabinet Office of the Japan Atomic Energy Commission on the status of food irradiation in the world in 2005, dividing the collected data in four regions of that study: (1) “America”, (2) “Europe”, (3) “Asia and Oceania”

and for (4) “Africa and other countries, including Ukraine and Israel”. The quantities of irradiated foods in these “regions” are listed in Table 3, while the “global” irradiated quantities of irradiated food items can be seen in Table 4. The main countries applying radiation disinfection of spices and dried vegetables were USA, China, Brazil and South Africa. Radiation disinfestation of grains and fruits was used most extensively in the Ukraine. Irradiation of meat and seafood was mainly carried out in Vietnam, USA, and Belgium. Irradiation for sprout inhibition was most frequently used in China and Japan, while China also irradiated a range of other foods including “health foods”, mushrooms, honey. This survey shows that commercial food irradiation in “Europe” is lagging behind very much the development of other parts of the world, mainly because of the restrictive legislation in the European Union. It is rightly stated by Dr. Ehlermann, eminent German expert on food irradiation: “It is the responsibility of governments to make available and to promote any technology contributing to hygiene and safety of food, including processing by ionizing radiation” (Ehlermann, 2005).

The European Commission asked its Scientific Committee of Food (SCF) to evaluate food irradiation to assist the EU legislation. The SCF in its three reports (already in SCF, 1986, 1992, 1998) evaluated a number of food classes and specific food commodities and radiation doses as acceptable from a public health standpoint. They are listed in Table 5. In spite of this, EU legislation was issued first in February 1999 when the European Parliament and the Council adopted a “Framework Directive on the general and technical aspects of food and food ingredients treated with ionizing radiation” (EC, 1999a), “and an “implementing Directive” establishing a Community List of foodstuffs authorised for irradiation treatment” (EC, 1999b). The latter contains only a single food category permitted EU-wide: “dried aromatic herbs, spices and vegetable seasonings”. It was expected that this “positive list” would be extended by the end of 2000 to take account of the national authorizations that existed at that time and also the opinions of the Scientific Committee for Food. However, the EU legislation is still in a dormant state since 1999. Until the implementing directive is finalized (until there is an agreed final Positive List of foods allowed to be irradiated in the EU), its Member States may keep their national authorizations for irradiated foods. At present, several countries in the

Table 3. Quantities of irradiated foods in 2005 in four global “regions” (Kume *et al.*, 2009a).

Regions	Quantity in tons	Percentage, %
“Asia and Oceania”	183.309	45
“America”	116.400	29
“Africa, Ukraine and Israel”	90.035	22
“Europe”	15.060	4
Total	404.804	100

Table 4. The “global quantities” of irradiated food items in 2005 (Kume *et al.*, 2009b).

Food items	Quantity in tons	Percentage, %
“Spices and dry vegetables”	186.000	45
“Garlic and potato”	88.000	22
“Grains and fruits”	82.000	20
“Meat and seafood”	33.000	8
“Others”	17.000	4
Total	406.000	100

EU can allow the irradiation of a variety of foods and can allow the import and sale of a range of irradiated foods. However, these foods must have been irradiated at approved facilities within the EU or one of the EU approved facilities in countries outside of the EU. In practice, however, few irradiated foods are on sale in the EU.

Is there a need to improve microbiological safety of critical food items?

This question can be answered by looking e.g. at the epidemiological statistics of food-borne diseases in the European Union mirrored by the recent “Community Summary Report” of the European Food Safety Authority regarding zoonoses and zoonotic agents (EFSA, 2009). According to this document, the five most frequently confirmed human zoonoses cases were in 2007:

Campylobacteriosis	200,507
Salmonellosis	151,995
Yersiniosis	8792
VTEC	2905
Listeriosis	1554

Table 5. General food classes and specific food commodities and radiation doses evaluated as acceptable by SCF (SCF, 1986, 1992, 1998).

Food class/commodity assessed by the SCF	Overall average radiation dose (kGy)
Fruits ^a	Up to 2
Vegetables ^a	Up to 1
Cereals ^a	Up to 1
Starchy tubers ^a	Up to 0.2
Spices & condiments ^a	Up to 10
Fish & shellfish ^a	Up to 3
Fresh meats ^a	Up to 2
Poultry ^a	Up to 7
Camembert cheeses manufactured from raw milk ^b	Up to 2.5
Frog's legs ^c	Up to 5
Shrimps ^c	5
Gum arabic ^c	3
Casein/caseinates ^c	Up to 6
Egg white ^c	Up to 3
Cereal flakes ^c	10

^a 1986.
^b 1994.
^c 1998.

An increase of 14.2% was recorded in 2007 in the confirmed campylobacteriosis cases compared to 2006 (Germany accounted for 56% of the increase). These bacteria are among the principal causes of food-borne diseases worldwide (Moran, Scates, & Madden, 2009). It is generally estimated that for every reported case more go unreported.

In foodstuffs, the highest proportion of *Campylobacter* positive samples reported EU-wide was once again for fresh poultry meat, where on average 26% of samples were found positive. *Campylobacter* was also commonly (25.2%) detected from live poultry flocks. No overall trend was observed in the proportion of the positive broiler meat samples during the years 2004–2007.

The economic costs of campylobacteriosis caused by retail poultry are estimated to be of € 10.9 million for Belgium alone (Gellynck *et al.*, 2005). Current risk assessments of *Campylobacter* in foods indicate that cross contamination contributes the major portion of the burden of illness of this pathogen (Malekar & Barker, 2008).

Considering the above situation, the high efficiency of the radiation treatment due to the radiation sensitivity of food-borne non-sporeforming bacteria (Table 6, Farkas, 2005), it is clear that radiation pasteurization of poultry meat is one of the critical food items for those radiation pasteurization as an intervention to improve their microbiological safety would be clearly justified (Farkas, 1998). A radiation dose of about 2 kGy in fresh state, and 3–5 kGy in frozen state would be more than enough to eliminate the radiation sensitive pathogenic bacteria (more than 6-D reduction) and to destroy at least 2–3 log cycles of even the most resistant ones without “off-flavour” formation (Klinger & Lapidot, 1993; Sudarmandji & Urbain, 1972). A detailed compilation of all necessary information for irradiation of poultry meat and its products are given e.g. in one of the ICGFI IAEA-TECDOC documents (Klinger & Lapidot, 1993). Irradiation can be viewed as an effective critical control point in a Hazard Analysis and Critical Control Points (HACCP) risk management system e.g. for meat and poultry processing (Farkas, 2005; Smith & Pillai, 2004).

The increasing application of irradiation as a quarantine treatment (phytosanitary applications) can be mentioned, too (Luckman, 2002).

Table 6. D₁₀-values of some non-spore forming bacteria (Farkas, 2005).

Bacteria	Non-frozen food	Frozen food
<i>Vibrio</i> spp.	0.02–0.14	0.04–0.44
<i>Yersinia enterocolitica</i>	0.04–0.21	0.20–0.39
<i>Campylobacter jejuni</i>	0.08–0.20	0.18–0.32
<i>Aeromonas hydrophila</i>	0.11–0.19	0.21–0.34
<i>Shigella</i> spp.	0.22–0.40	0.22–0.41
<i>Escherichia coli</i> (incl. O157:H7)	0.24–0.43	0.30–0.98
<i>Staphylococcus aureus</i>	0.26–0.57	0.29–0.95
<i>Salmonella</i> spp.	0.18–0.92	0.37–1.28
<i>Listeria monocytogenes</i>	0.20–1.0	0.52–1.40

Future of food irradiation?

The key of changing the sluggishness of implementation of the manifold potential use of food irradiation technology is a better appreciation of its potential role in controlling food-borne diseases and spoilage, as well as the willingness to pay for processing for food safety (Mosssel & Drake, 1990). Further progress in food irradiation legislation, particularly in the European Union, should encourage a wider acceptance of the process by all relevant stakeholders.

Consumer acceptance is a matter of education, and proper communication diminishing the unfair image that food irradiation is a nuclear technology (Teisi, Fein, & Levy, 2009). We consider misinformation on food irradiation as a form of terrorism, preventing the utilization of a safe and advantageous process and inhibiting consumers to have a choice between alternative technologies. The challenge represented by consumer acceptance and regulatory approval requires the demystification of food irradiation (Crawford, 2001). Marketing trials showed that increasing number of consumers are willing to purchase irradiated food if they are properly informed about the process and its effects on food (Eustice & Bruhn, 2006).

Further developments in design and adaptation of uses of machine radiation sources (e-beam facilities and X-ray machines) (Arthur *et al.*, 2005; Cleland, 2006; Pillai, Braby, & Maxim, 2006) can also assist altering the image of the process into one kind of electrical technologies (see the success of household uses of microwave ovens, or the TV utilities).

Epilogue

This presentation was devoted to all those scientists who were involved in exploring this challenging field of food research, and especially those deceased European leading experts of this subject, whom one or both of the present authors were fortunate to be associated with during certain periods of their professional life. Five names are mentioned here with especially great respect.

Prof. Károly VAS (1919–1981), former Director of the Central Food Research Institute, Budapest, Hungary and Head of the Food Preservation Section of the Joint Division of the FAO/IAEA, Vienna, one of the pioneers of modern food science in Central Europe and mentor of the first author of this paper (Vas & Farkas, 1960).

Prof. Johann KUPRIANOFF (1904–1971), former Director of the Federal Institute of Food Preservation, Karlsruhe, Germany and author of one of the first European book on food irradiation (Kuprianoff & Lang, 1960).

Prof. Maurice INGRAM (1912–1977), former Director of the Low Temperature Research Station, Cambridge, later the ARC Meat Research Institute, Langford/Bristol, U.K., one of the founders of microbial ecology and a world authority of radiation microbiology of food (Ingram & Farkas, 1977).

Prof. D. A. A. MOSSEL (1918–2004), co-founder of microbial ecology of food (Mosssel & Ingram, 1955), who assisted the IFFIT Courses by his remarkably suggestive lectures and his phenomenal foreign language abilities, also accepting for post-gradual training of the second author of the present paper in his renowned department at the University of Utrecht, The Netherlands. Prof. J. F. DIEHL (1929–2008), former General Director of the Federal Research Center for Nutrition, Karlsruhe, author of the most authoritative reference work “Safety of Irradiated Food” (Diehl, 1995) and Chairman of the Scientific Committee of the International Project in the Field of Food Irradiation (IFIP).

Concerning their manifold efforts devoted for progressing food science in general and food irradiation research in particular, we hope that the dedication statement written by Dr. Ricardo Molins in the book he edited (Molins, 2001) will come true: “Ignorance dies hard, and progress sometimes comes slowly but both are inevitable”.

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