Food irradiation: An emerging opportunity for African countries

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ABSTRACT

The paper reviews the use of food irradiation technology and its potential in food processing and international trade for economic development of African countries. Provision of infrastructure along with technical expertise, private sector participation, effective collaborative ventures and networking with other countries and international agencies are considered crucial for Africa to harness the potential of food irradiation.

Subject review article. Received 27 Aug 2001; revised 8 Apr 2002.

RÉSUMÉ

ADU-GYAMFI, A.: *Irradiation des aliments: Une chance émergente pour les pays africains.* Cet article fait une révision de l'utilisation de la technologie d'irradiation et ses potentiels dans la préparation des aliments et le commerce international pour le développement économique des pays africains. La fourniture d'infrastructure avec la compétence technique, la participation du secteur privé, les entreprises efficaces et collaborées et la transmission du programme avec d'autres pays et agences internationales sont considérés critiques pour que l'Afrique puisse exploiter les potentiels de l'irradiation des aliments.

Introduction

Food irradiation is the treatment of food by controlled amounts of ionizing energy (gamma rays or electron beam) to achieve some desired technical benefit. Since the early pioneering works (Schwartz, 1921; Brasch & Huber, 1947), the technology has been used for a variety of purposes such as microbial decontamination and insect disinfestation. The first commercial use of the irradiation process was for spice decontamination in Stuttgart, Germany in 1957 (Diehl, 2001). Since then, the technology has gone through several years of critical appraisal on wholesomeness and toxicological studies. The efficiency of the technology has been well documented over the years. Despite such intense scrutiny, there has been hesitation by industry to use the process commercially. This is due to several reasons including a perceived consumer resistance or unwillingness either to upset the *status quo* or be the first to promote a technology that is often regarded as 'controversial'.

This situation is very unrealistic since from safety viewpoint, food irradiation is the most researched technology for processing food. The results of long-term animal feeding studies and short-term screening tests (WHO, 1981; Codex Alimentarius Commission, 1983) have culminated in endorsing food irradiation technology by international health and food authorities such as World Health Organisation (WHO), Food and Agricultural Organisation (FAO), International Atomic Energy Agency (IAEA), Codex Alimentarius Commission (CAC), United States Food and Drug Administration (USFDA), and the Scientific Committee for Food of the European Union.

Its benefits include elimination of pathogenic and spoilage microorganisms, disinfestation of insects and parasites, control of physiological processes such as sprout inhibition and delaying ripening. The technology is increasingly being applied alongside other traditional methods of processing and preserving food. In 40 countries, health and safety authorities have now approved irradiation of some 40 different foods ranging from spices, grains, fruits and vegetables to de-boned chicken meat. At least 500,000 t of food products and ingredients are irradiated worldwide annually (IAEA, 1999).

This paper looks at the role of food irradiation in ensuring food security, food safety, and expanding international trade worldwide. It also highlights the potential of harnessing the technology in African countries.

Food irradiation technology

The technology of food irradiation has been studied for over 40 years. It involves the use of ionizing radiation from ^{60}Co and ^{137}Cs sources or electron beams to kill pathogenic and spoilage organisms, and also to prevent germination and sprouting. The biological effect of radiation is achieved through the so-called 'direct effect' and 'indirect effect'. The 'direct effect' mechanism involves the direct action of ionizing radiation on deoxyribonucleic acid (DNA) and other organelles in living cells. The mechanism of the 'indirect effect' is the interaction of ionizing radiation with water to produce free radicals that damage DNA (IAEA, 1982; Grecz, Rowley & Matsuyama., 1983). The technology allows food to be irradiated in the packaged state without significant change in the chemical composition, nutritional value, taste or appearance of the food product. At a critical control point during processing of fresh foods, irradiation is easy to monitor, has quantifiable parameters and realistic critical limits (minimum and maximum doses), thereby, fitting well within the Hazard Analysis and Critical Control Point (HACCP) system of ensuring food safety by food industries. Since it is a physical process, it does not leave any residues in the treated food products.

Food safety

In recent years, outbreaks of foodborne diseases have been very serious worldwide. These diseases are particularly serious for infants, pregnant women, the immuno-compromised, the hospitalised, and the elderly. In spite of great efforts at the national and international levels, progress in combating foodborne diseases has largely been offset by other global trends. Growing consumer demand for foods of animal origin, longer food distribution networks, and many basic changes in the way food is produced, transported, processed and consumed have contributed to the high levels of foodborne illnesses. Inadequate treatment and disposal of refuse/sewage also contribute significantly in transmitting foodborne diseases in developing countries.

Pathogens such as *Salmonella*, *Campylobacter, Yersinia, Listeria, Shigella, Vibrio, Escherichia coli* 0157, moulds and parasites such as protozoa, nematodes and trematodes cause contaminations which may result in fatalities (deaths) or severe chronic diseases with reduced productivity. The cost of such contaminations can be huge in terms of human suffering, healthcare expenditure, legal pursuits, and damage to international trade and tourism. From 1997 to 1999, there were massive recalls of 7,000 t of ready-to-eat meat and 10,000 t of ground beef in the USA alone due to contamination by *Listeria monocytogenes* and *E. coli* 0157:H7, respectively. Government sources in the USA estimated the cost of human illness due to the seven major foodborne pathogens at between US $ 5.6 and 37.1 billion (Etzel, 2001).

Food irradiation is an effective method for eliminating current and emerging foodborne pathogens from food, especially those eaten raw or minimally processed. The approval of the USFDA in 1997 and 1999 on irradiation of red meat for the control of pathogenic organisms and fresh eggs for *Salmonella* control are regarded as milestones in paving the way for extensive use of the technology worldwide (USDA, 1999; USFDA, 2000). African countries can use the technology to curtail the incidence of diseases such as cholera, salmonellosis (infection with salmonella bacteria), yersiniosis (infection with the bacterium *Yersinia* *enterocolitica*), listeriosis (infection with the bacterium *Listeria monocytogenes*), trichinellosis (parasitic worm infection), compylobacteriosis (infection with campylobacter bacteria), cysticercosis (parasitic worm infection), toxoplasmosis (infection with the protozoan *Toxoplasma gondii*), and mycotoxicosis (fungal toxin poisoning). This could help improve the health of the general populace and consequently reduce the burden on the already faltering healthcare delivery systems of these countries. It is envisaged that the introduction of irradiated food could become as important to public health as was the advent of pasteurised milk and chlorinated water at the turn of the century (Matin, 2000).

Food security

Estimates of quantities of post-harvest losses vary significantly. It has been noted that at least 25 per cent of the world food production is lost after harvesting, although losses can be as high as 50 per cent in developing countries where climatic conditions speed up deterioration of stored foods (Anon., 1989, 1993). Insect infestation, sprouting and microbial spoilage contribute greatly to losses of foods such as grains (maize, rice, millet, sorghum, barley, oats), pulses (beans, broad beans, soybeans, peas), root and stem tubers (yam, cassava, potato, taro, ginger), fruits (pawpaw, mangoes, banana, oranges), and dried and smoked fish (herrings, mackerel, tuna). Such food losses are now controlled with fumigants, chemical washes, and pesticides in most countries. The harmful effects of these preservatives are well documented (FAO/IAEA, 1997). Apart from emvironmental problems, the increase or continuous use of pesticides have contributed to the development of resistant strains of insects against most fumigants, including methyl bromide, phosphine, chloropyrifos-methyl, malathion, permethrin, and primiphos-methyl (Dyte, 1990; Ansell, Dyte & Smith, 1990; Haubruge, 1990).

Common fumigants such as ethylene dibromide, ethylene dichloride, and ethylene oxide have all been banned in USA, Japan and Europe due to their harmful side effects (Puridec, 1999). Methyl bromide, which is now the most widely used agricultural fumigant, has been earmarked under the Montreal Protocol for phasing out by 2005 in advanced countries and by 2015 in developing countries. This is due to its capacity to destroy ozone in the stratosphere (Marcotte, 1998). Since there are no immediate alternatives to these, irradiation can contribute immensely to reduce the post-harvest losses of staple grain crops, tubers, bulbs, vegetables, and fruits. Food losses due to insect infestation are severe in the tropical conditions of Africa. Fortunately, exposure of insects to low irradiation doses results in reduced fitness (i.e., higher percentage of sterility, lower fecundity and decreased life span) and eventual death. Studies so far suggest that insects do not develop resistance against irradiation (Matin, 1975).

African countries lose a significant proportion of their food products through spoilage (Table 1). Irradiation could be applied to disinfest and decontaminate grains, pulses, as well as spices, herbs, fish, meat and animal feed to improve quality and promote long-term storage. It can also inhibit sprouting in potatoes, yam, onions, garlic, shallots and ginger, and hence extend their shelf life. This could eliminate the use of chemical sprout inhibitors that leave residues which cause health hazards. Delay of ripening and senescence in fruits such as pawpaw, citrus, mangoes and bananas could be achieved through irradiation. This could facilitate long-term storage of these food items for longer and wider distribution networks. Food irradiation, therefore, has the potential of minimising post-harvest losses, maintaining quality, guaranteeing food availability, and improving the overall food security in Africa and other developing regions of the world.

Quarantine and international trade

Most developing countries, especially those in Africa, have agricultural-based economies which

TABLE 1

Annual Production, Exports and Losses of Some Food Products by Some African Countries

Country	Total food production[A] (MT × 1000)				Quantity exported[B] (MT × 1000)				Estimated losses[B] (MT × 1000)			
	Grains	Roots/ Tubers	Fruits	Fish	Grains	Roots/ Tubers	Fruits	Fish	Grains	Roots/ Tubers	Fruits	Fish[C]
Algeria	3031	1115	2617	92	2	-	14	1	505	113	100	12
Congo DR	1332	17350	641	178	-	-	-	0.1	114	2148	371	16
Côte d'Ivoire	1870	4891	534	67	8	2	399	115	209	696	317	7
Egypt	17929	2299	11869	365	246	327	93	2	1986	263	712	32
Ghana	1791	11096	413	442	7	24	180	56	284	2837	180	47
Kenya	3159	2030	668	172	223	-	145	41	132	115	110	18
Libya	322	135	790	33	-	85	137	6	23	15	114	4
Madagascar	2610	3349	357	114	12	26	11	34	247	244	90	11
Mauritius	-	19	75	12	29	-	-	22	29	-	-	1
Morocco	6610	1218	3735	708	35	79	591	249	19	106	177	64
Namibia	57	250	8	352	-	-	-	170	11	44	4	27
Nigeria	22724	51950	6060	334	53	-	1	8	4148	1872	210	34
Senegal	783	49	408	425	2	-	1	133	153	11	39	29
South Africa	9586	1608	2171	558	2237	28	1457	120	132	73	147	44
Sudan	4994	169	1120		317	-	1	0.1	256	16	136	5
Tanzania	4510	6853	1035	348	109	2	45	26	202	28	99	36
Tunisia	1663	290	1783	89	109	2	45	13	202	28	99	84
Uganda	1766	4535	497	221	91	-	2	22	210	634	826	19
Zambia	814	876	253	16	3	-	-	0.4	126	32	10	61

MT - metric tonnes
[A]Based on 1998 data. [B]Based on average of 1994-97 data: [C]Estimates are based on 10 % of 1996 production data.
- Data not available Sources: (FAO, 1998a/b, 1999, Konstapel and Noort, 1995).

produce large quantities of food and cash crops such as grains, nuts, fruits, cocoa, tobacco, vegetables, and fish. Most of these countries have intensified agricultural production to increase exports to lucrative North American and European markets. There is now a growing international recognition of the unique applicability of irradiation technology to control food-borne pathogens, parasites, and plant pests. Global trade in irradiated food products is increasing. This is amply shown by the global volume of irradiated spices which has increased from 7,500 t in 1987 to about 70,000 t in 1997 (Matin, 2000). The recent decision by Wal-Mart (the largest retail store in the world) to offer irradiated foods at its supermarkets in the USA should be seen as a significant turning point in the marketing of these foods (Matin, 2000).

Food irradiation offers the unique opportunity for African countries to meet strict quarantine requirements for their various exports. In so doing, the technology prevents the introduction of harmful agricultural pests into non-infested areas. It has been recognised by FAO, WHO, International Plant Protection Convention (IPPC), International Office of Epizootics (IOE), World Trade Organisation (WTO), and many other notable and credible national, regional and international organisations. It has an important role in quarantine treatment and control of parasites and pathogenic microorganisms in fresh and processed food and ingredients. The Animal Plant Health Inspection Service (APHIS) under the United States Department of Agriculture (USDA), which is undoubtedly the major trading partner in food and agricultural products of many developing countries, has taken several actions which will facilitate application and acceptance of irradiation in national, regional and international trade. The recent European Union Directive on the marketing and use of irradiated spices, dried aromatic herbs, and vegetable seasoning is also seen as a further measure of expanding trade opportunities in irradiated commodities (EC Directives, 1999). Irradiation is now accepted and applied as a legitimate sanitary and phytosanitary treatment under the provisions of the Sanitary and Phytosanitary (SPS) Agreement of the WTO.

Opportunity

Over the years, the non-harmonisation of national food irradiation regulations created potential barriers to trade in irradiated foods. The International Consultative Group on Food Irradiation (ICGFI), however, has eventually attained harmonisation of food irradiation regulations for Asian and Pacific, Africa, Middle East and Latin American regions. The Codex General Standard on Food Irradiation by the CAC and the Recommended International Code of Good Irradiation Practices drafted by the ICGFI recognize that irradiation is a physical process and should be regulated in the same way as other physical processes. Consequently, any non-tariff barriers to foods by importing countries solely because of an irradiation treatment are no longer justified, and may be subject to challenge under WTO procedures.

This new development, besides the globalization of food trade, allows the movement of products across national and international boundaries with all its implications. Health authorities in most countries now require zero tolerance of pathogens such as *Salmonella* and *Vibrio cholerae* in seafoods and other products (FAO/WHO/IAEA, 2001). The irradiation of food has the potential of increasing international trade in agricultural commodities, judging from the quantity of some exports by African countries (Table 1). This is due to the ability of irradiation to reduce or eliminate food-borne pathogens and accordingly extend the shelf life of many perishable foods. African countries could use the application of food irradiation to improve their economies through international trade.

African countries are now in different stages of awareness and acceptance of food irradiation. South Africa has been applying the technology since 1968 and turned out 12,500 t of irradiated products in 1999 (du Plesis, 2001), while Ghana also produced 60 t of irradiated spices and dried seasonings in 1998 (Adu-Gyamfi, 1998). Ghana and Egypt are in a comparatively advanced stage of awareness and are virtually on the verge of implementing the technology commercially. Other countries such as Morocco, Tunisia, Zambia, Algeria, Côte d'Ivoire, Kenya, Libya, Uganda, Democratic Republic of Congo, Senegal, and Nigeria are conducting research and development as well as pilot scale studies. Several other countries such as Sudan, Tanzania, Namibia, Congo, Madagascar, and Mauritius are yet to initiate food irradiation projects.

A great potential exists for African countries to use irradiation technology to improve long-term storage of agricultural products such as cereals, pulses/beans, fruits, spices, fish, meat, yam, potato, taro, vegetables, cocoa and coffee beans, gum arabic, and medicinal plant products to meet the stringent quarantine requirements of the lucrative American and European markets. This would certainly encourage more export to earn foreign exchange for these countries (Tables 1 and 2).

Public misconceptions

The potential of food irradiation cannot be over-emphasized. The technology has been repeatedly demonstrated to have the capacity of addressing food safety issues, challenges of food security,

TABLE 2

Commodities with Prospects for Commercial Irradiation Processing in Africa

Product	*Objective*	*Country*	*Market*
Citrus	Phytosanitary	Morocco	USA
Pawpaw	Phytosanitary	Ghana, Morocco	USA
Mangoes	Phytosanitary	Senegal, Côte d'Ivoire	USA, EU
Cocoa beans	Disinfestation	Ghana, Cameroon, Nigeria, Côte d'Ivoire	USA, EU, Japan
Coffee beans	Disinfestation	Uganda, Ghana, Kenya, Côte d'Ivoire, Cameroon, Ethiopia, Tanzania	USA, EU, Japan
Dry dates	Disinfestation	Egypt, Tunisia, Algeria, Morocco, Sudan, Namibia	USA, EU, Japan
Spices and dried vegetables, herbs	Hygienisation	Most African countries	USA, EU, Japan
Frozen fish and fish products	Microbial decontamination and shelf-life extension	Morocco, Ghana, Sudan, Tanzania, Namibia	USA, EU, Japan
Gum arabic	Hygienisation	Sudan	EU, Japan
Dried fish and dried meat	Disinfestation	Nigeria, Ghana, Sudan, Tanzania, Namibia, Cameroon, Uganda, Zambia	Local, interregional
Pulses	Disinfestation	Most AFRA countries	Local, export
Potatoes, onions	Sprout inhibition	Most AFRA countries	Local, export
Yams	Sprout inhibition	Côte d'Ivoire, Ghana, Nigeria, Cameroon	Local, export

Source: (FAO/IAEA, 2000)

and some complexities of international trade. Despite the potential of food irradiation, it still remains under-utilized, especially in Africa and other developing countries. This is largely due to ignorance which has created several public misconceptions suggesting that food processed by radiation becomes radioactive. Induced radioactivity has never been observed for foods treated with radiation doses of up to 50 KGy (Diehl, 1990). This has been attributed to the use of recommended safe energy sources and levels, i.e., fast electrons ≤ 10 MeV and X-rays ≤ 5 MeV. The maximum energy of gamma radiation emitted by the commonly used radioactive sources is too low to induce radioactivity in the constituent elements of food, i.e., Co = 1.33 MeV and Cs = 0.66 MeV (Diehl, 1990). There is also wide public misunderstanding of what the process is, how it works, and what it will do and will not do. The process does not induce any special nutritional problems in food and, in fact, the loss of vitamins due to irradiation is even less than that in canning and heat treatments (Diehl, 1990; WHO, 1994). These issues relating to public acceptance have adversely affected its large-scale commercial exploitation, even after the positive recommendation of the technology by the FAO/IAEA/WHO Joint Expert Committee on Food Irradiation (JECFI) in 1980 (WHO, 1981).

It is in these respects that the Ghana Atomic Energy Commission (GAEC) has over the years worked for public acceptance and eventually secured a legislation to regulate the production, sale, and use of irradiated foods in the country. The GAEC has carried out several public educational activities aimed at correcting misconceptions and outlining the potentials of food irradiation. These activities include radio and television programmes, food fairs and other exhibitions, workshops and seminars, newspaper publishing and journal review articles, as well as encouraging excursions and visits by the public to the premises housing the nuclear facilities. Through a joint collaborative effort with the Ghana Standards Board, a regulation (GS 210) governing Food Irradiation Trade and Practices was put in place in 1997.

Harnessing the potential

Food safety is one of the leading health issues concerning consumers, the food industry, academia, and government officials worldwide. There is, therefore, mounting consumer demand for healthy foods in many countries. Food irradiation is now increasingly seen as a versatile, environmentally friendly, and wide-spectrum technology that can effectively contribute to promoting food safety, security and facilitate trade in food and agricultural commodities. Although the cost of irradiation depends on many variables, the process is quite economical. In addition, sufficient toxicological data are available to demonstrate safety and wholesomeness of irradiated foods.

African and other developing countries can dream of harnessing this unique technology. However, for this to become a reality, academia, government, industry, and activists should work together to bring irradiated foods to the marketplace. Governments in Africa need to prioritize the use of irradiation technology and subsequently provide the appropriate infrastructure and professional expertise. Private sector investment should be encouraged. Co-operation and collaboration among African Regional Co-operative Agreement (AFRA) countries of the IAEA with other developed countries and the IAEA should be vigorously pursued and strengthened. Interaction and networking should be initiated and sustained among the various countries to facilitate transfer of the technology. Additionally, promotional work has to be intensive to popularise and improve the acceptance of irradiated foods in African countries. Journalists may have to play a prominent role in this endeavour, as it is being done in the Asia/Pacific region through the Irradiation Network For Mankind (INFORM).

Conclusion

Food irradiation is a proven and safe technology that can be used by African countries to curtail food-borne diseases, combat post-harvest losses, and overcome quarantine barriers in international trade. African countries need to redouble their efforts at acquiring and using the technology. There is the need for these countries to strengthen collaborative efforts with advanced countries, widen inter-regional networking, improve public awareness, and increase investment in the field of food irradiation. The time has finally arrived for serious efforts by governments, food industries, trade associations, and hopefully radiation-processing companies to fully exploit the technology. The technology can definitely improve the quality and quantity of food production that will ensure economic and political stability in these countries.

REFERENCES

Adu-Gyamfi, A. (1998) *Technical Rep.* BNARI, Ghana Atomic Energy Commission.

Anon. (1989) Workshop on the use of irradiation to reduce post-harvest food losses. *Food Irradiation*

Newsletter **13** (2).

Anon. (1993) Report and recommendations of a working group in cost-benefit aspects of food irradiation. *Proceedings of an IAEA/FAO/WHO International Symposium.* Axi-en-Provence, 1993. 481 pp.

Ansell, M., Dyte, C. E. & Smith, R. H. (1990) Inheritance of phosphine resistance in *Tribolium casteneum* and *Rhizopertha dominica.* In *Proceedings of 5th International Working Conference on Stored-Product Protection,* Bordeaux, France, 9 - 14 September 1990, pp. 961 - 970.

Brasch, A. & Huber, W. (1947) Ultrashort application time of penetrating electrons: A tool for sterilisation and preservation of food in raw state. *Science* **105,** pp. 112. In *Safety of irradiated foods* (ed. J. F. Diehl) (1990), pp. 1 - 7. New York: Marcel Dekker Inc.

Diehl, J. F. (1990) Safety of irradiated foods. New York: Marcel Dekker Inc. 345 pp.

Diehl, J. F. (2001) Achievements of food irradiation during the 20th Century. In *Proceedings FAO/IAEA/WHO International Conference on 'Ensuring the Safety and Quality of Food Through Radiation Processing',* Antalya, Turkey, 19 - 22 October 1999, pp. 1 - 7. Technomic Publishing Com.

du Plesis, T. A. (2001) The establishment of industrial radiation processing in a developing environment. *Paper presented at the AFRA Regional Workshop on Good Management Practices for Optimal Utilization of Radiation Facilities of the International Atomic Energy Agency, Accra, Ghana, 14 - 18 May 2001.*

Dyte, C. E. (1990) Living with resistant strains of stored pests. In *Proceedings of 5th International Working Conference on Stored-Product Protection.* Bordeaux, France, 9-14 September, 1990, pp. 947-960.

EC Directive (1999/2) EC of the European Parliament and of the Council of 22nd February on the approximation of the laws of the member states concerning foods and food ingredients treated with ionising radiation. *Official Journal of the EC* (13 March 1999), L66/16-L66/23.

EC Directive (1999/3) EC of the European Parliament and of the Council of 22nd February on the approximation of the laws of the member states concerning foods and food ingredients treated with ionising radiation. *Official Journal of the EC* (13 March 1999), L66/24-L66/25.

Etzel, R. A. (2001) Epidemiology of foodborne diseases - Role of food irradiation. In *Proceedings of FAO/IAEA/WHO International Conference on 'Ensuring the Safety and Quality of Food through Radiation Processing',* Antalya, Turkey, 19-22 October 1999, pp. 50-54. Technomic Publishing Com.

FAO/IAEA (1997) Irradiation as an alternative treatment to methyl bromide fumigation of Food and agricultural commodities. In *Proceedings of a FAO/IAEA Consultants Meeting, 1995. IAEA.* pp. 172. Vienna, Austria.

FAO (1998a) *Food balance sheets.* Statistics Division, Rome.

FAO (1998b) Yearbook. *Fishery Statistics* **86/1**. Rome.

FAO (1999) *Quarterly Bulletin of Statistics* **12,** 1-4. Rome.

FAO/IAEA (2000) Report of Regional Training Workshop on the Industrial and Public Acceptance of Food Irradiation (AFRA IV - 19/RAF/8/028): Radiation Processing of Food and Industrial Products, Accra, Ghana, 11-15 September 2000. pp. 8-9.

FAO/WHO/IAEA (2001) Summary Report of Conference. In *Proceedings of FAO/WHO/IAEA International Conference on 'Ensuring the Safety and Quality of Food through Radiation Processing',* Antalya, Turkey, 19 - 22 October, 1999. Technomic Publishing Com. 216 pp.

Grecz, N., Rowley, D. B. & Matsuyama, A. (1983) The action of radiation on bacteria viruses. In *Preservation of food by ionising radiation,* **2** (ed. E. S. Josephson and M. S. Peterson). Boca Raton, FL: CRC Press. 167 pp.

Haubruge, E. (1990) Permethrin resistance of the larger grain borer, *Prostephanus truncatus (*Horn). In *Proceedings of 5th International Working Conference on Stored-Product Protection,* pp. 1009-1018. Bordeaux, France, 9-14 September 1990.

IAEA (1982) *Training manual on food irradiation technology and techniques.* Technical Report Series No. **114,** 2nd edn. IAEA, Vienna. 205 pp.

IAEA (1999) International Consultative Group on Food Irradiation. *Facts about food irradiation. A Series of Fact Sheets from the ICGFI, IAEA,* Vienna.

Konstapel, K. & Noort, L. (1995) *Fisheries in developing countries.* Ministry of Foreign Affairs, DVL/OS, The Hague, Netherlands.

Marcotte, M. (1998) Irradiation as a disinfestation method - Update on methyl bromide phase out, Regulatory actions and emerging opportunities. *Radiat. Phys. Chem.* **52** (1 - 6), 85 - 90.

Matin, A. S. M. A. (1975) On the possible development of radioresistance in *Sitophilus oryzae* (L) following exposures of successive generations to ionizing radiation. *International Journal of Applied Radiation and Isotopes* **26**, 625 - 626.

Matin, M. A. (2000) Wholesomeness and safety of irradiated foods. *Paper delivered during Training Workshop on the Industrial and Public Acceptance of Food Irradiation (AFRA IV -19/RAF/8/028): Radiation Processing of Food and Industrial Products, Accra, Ghana,* 11 - 15th September 2000.

Puridec (1999) Setting new standards-Food irradiation. *A Publication of Puridec Irradiation Technologies.* REVISS Services (UK) Ltd. 14 pp.

Schwartz, B. (1921) Effect of X-rays on Trichinae. *J. Agric. Res.* **20** (1921), 845. In *Safety of irradiated foods* (ed. J. F. Diehl). Marcel Dekker Inc., New York, 1990, pp. 1-7.

USDA (1999) Irradiation of meat food products; Final Rule, CFR Parts 381 and 424. *Federal Register* **64** (246), 72151 - 72165.

USFDA (2000) United States Food and Drug Administration, Final Rule on Amending Food Additives Regulations to Provide for the Safe Use of Ionizing Radiation for Reduction of *Salmonella* in Fresh Eggs. *Federal Register* **65** (141).

WHO (1981) Wholesomeness of irradiated food: *WHO Technical Report Series* **659**. Geneva.

WHO (1981) *Technical Report Series* No. **659**. Geneva.

WHO (1994) *Safety and nutritional adequacy of irradiated food.* World Health Organisation, Geneva.