IRRADIATION DISINFESTATION OF STORED FOODS

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ABSTRACT

Irradiation is a physical method which uniformly disinfests stored food products from insect pests. It can complement or replace existing methods of chemical treatment, such as fumigation. Disinfestation studies conducted over the years show that radiosensitivity of stored pests varies from one order to the other. However, it is established that a dose of 0.5 kGy will disinfest all stored food products. Cereals are mostly infested with coleopteran and lapidopteran pests. They can be disinfested at a dose of 0.5 kGy. Bruchids in pulses and beans can be disinfested at a dose below 0.2 kGy. Dried foods of animal origin are heavily infested with dermestid beetles. A dose of 0.3 kGy can effectively control dermestids in dried foods. Similar dose of irradiation can be used to disinfest insects from dried fruits and vegetables.

Irradiation, unlike chemicals, leaves no residues in treated food. This treatment can be imparted to the final package of food with uniform dose to kill all insects in their developmental stages. Post irradiation storage of products should be prevented from reinfestation. This treatment meets the requirement of the obligatory fumigation of certain agricultural products, such as cocoa beans for export. Irradiation at the prescribed dose does not alter physical, chemical, organoleptic and technological properties of the treated products. Many countries around the world are either using irradiation processing or have approved irradiation disinfestation of stored foods.

Introduction

In recent years food irradiation has been drawn to the attention of the media because of its prospective use in the control of foodborne diseases. The Ministry of Agriculture, Fisheries and Food of the United Kingdom has decided to use food irradiation as a method to provide safe food supply to consumers. In May 1990, the US Food and Drug Administration (USFDA) has approved the use of irradiation to control pathogens in fresh, frozen and deboned poultry. This approval of the USFDA has been widely covered by the press in the USA. These are some of the recent events in the history of food irradiation; although its history began in 1916 when Runner (1916) conducted radiation sensitivity studies with tobacco beetle, Lasioderma serricorne. He showed that tobacco could be disinfested with X-rays; but further studies on a large scale were not possible due to unavailability of a suitable irradiation facility. Renewed interest in food irradiation was witnessed by the 1940's when large irradiation facilities were available.

Irradiation disinfestation is a physical method which has some unique advantages. The advantages and limitations of this technology were discussed by Cornwell,(1966). Owing to the huge loss of dried food in storage, this method deserves attention, particularly for its implementation in developing countries. Considering the protection of the environment from the use of toxic chemical substances such as pesticides, irradiation is desirable alternative; in some cases it can replace the use of pesticides. According to overwhelming scientific data available on this technology support irradiation as a physical process, which does not leave any residues in the treated products and which results in the food which is safe and wholesome after treatment. The method has been endorsed by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO), in addition to credible scientific bodies around the world. According to experts, no food processing has been so well investigated and well documented as food irradiation. The Codex Alimentarius Commission has recommended a dose up to an overall average of 10 kGy as safe and wholesome and recommended that further wholesomeness, toxicity or microbiological safety studies were not needed. Irradiation disinfestation needs a dose up to 1 kGy which is one tenth of the maximum dose recommended by the Codex based on wholesomeness data.

Radiation disinfestation

The major cause of loss of stored dried food is infestation by arthropod pests. Considerable work has been carried out on the radiation sensitivity of insect pests with particular emphasis on disinfestation. Results achieved through sensitivity studies show that disinfestation of stored pests by irradiation is technically feasible. These studies reveal that the dose response of stored product pests varies in different orders of insects. It also greatly varies in the different developmental stages. Eggs and larval stages of insects are more susceptible to irradiation compared to pupal and adult stages. In general, the effects of radiation are expressed in the shortening of life span, arresting normal development, lessening fecundity and inducing sterility. Apart from developmental stage and order of insects, radiation effects vary depending on certain physical factors, such as temperature. Other post irradiation behaviours which are affected by irradiation are the normal feeding and movement of insects. These factors are considered while establishing a disinfestation dose for certain foodstuffs.

Coleopteran and lepidopteran pests are the most important orders of insects affecting stored foodstuffs. Therefore, most of the disinfestation studies are carried out with these groups of insects. Technological feasibility of irradiation shows that any dried product could in practice be disinfested by this process. Experiments have been carried out on a wide spectrum of products such as cereals, pulses, beans, oil seeds, dried fruits, dried vegetables and dried animal products. A summary of prospective uses of irradiation disinfestation of some groups of food products are given below:

Cereals: Extensive disinfestation studies in insects attacking cereals have been carried out. The important coleopteran pests of cereals are rice weevil, Sitophilus oryzae; grain weevil, Sitophilus granarius; rust-red flour beetle, Tribolium castaneum; confused flour beetle, T. confusum; lesser grain borer, Rhyzopertha dominica; long headed flour beetle, Latheticus oryzae; saw-toothed grain beetle, Oryzaephilus surinamensis, and maize weevil, Sitophilus zeamais. The minimum effective dose for sterilizing pupae and adults of the grain weevil (S. granarius) is 0.16 kGy, death occurring 2-3 weeks after treatment. When infested grain contains all developmental stages a dose of 0.16 kGy could control further development of all the stages with the exception of late pupae which emerge as sterile adult and soon die off (Cornell, 1966). A dose of 0.20 kGy kills adults of L. oryzae in 22 days. Ahmed and Huda (1977) reported 100% mortality of R. dominica at 0.25kGy within 30 days of treatment. Radiation also induces deformity in emerged adults which cannot produce normal progency (Beck, 1966). A summarized result to control stored product pests by irradiation is given in Table I.

Major lepidopteran pests of stored cereals are Mediterranean flour moth (Anagasta kuehniella), Indian meal moth (Plodia interpunctella), tropical warehouse moth (Cadra cautella), Angoumois grain moth (Sitotroga cerealella) and rice moth (Corcyra cephalonica). Moths require higher dose of radiation to sterilize due to diffused centromeres in their chromosomes. A dose of 0.60 kGy sterilizes males of E. kuehniella and in females same dose of radiation inhibits laying of eggs. Larvae of this insect do not produce pupae at 0.18 kGy (Bande and Westrijne, 1960). Cadra cautella is more susceptible to irradiation. When six days old pupae were irradiated at 0.30 kGy 100% mortality is achieved within 6 days after emergence. A dose of 0.30 kGy could be considered as sterilizing dose of males and females of C. cautella (Amouko-Atta and Partida, 1974). Although about 1 kGy is the sterilizing dose of Angoumois grain moth, a dose 0.3 kGy sterilizes the mated females (Ahmed et al., 1976). A lower dose of irradiation induces sterility to all moths and as a result, further propagation is controlled. Therefore, for practical application, a dose of 0.50 kGy or below could be considered for disinfestation of all insects including lepidopterans in cereal grains.

Pluses and beans: These constitute a major part of the daily requirement of foods in many parts of the developing world. They are also a major source of protein. Bruchid species i.e. Callosobruchus chinensis, C. analis, C. maculatus, etc. are most susceptible to irradiation. A dose of 0.20 kGy is adequate to disinfest this group of insects from pulses. C. analis and C. chinensis can be sterilized at a dose of 0.04 kGy (Begum, et al., 1979-81). A disinfestation dose of 0.40 kGy is considered effective in controlling Bruchus rufimanus and Bruchidius incarnatus in broad beans and cow peas (El-Kady, 1985).

Dried fishery products: Insects associated with dried fishery products are the species of Dermestes, Necrobia and Lasioderma. These foodstuffs are heavily infested with insects and usually after a few months of infestation products loose their value. Extensive studies on irradiation disinfestation of dried fish carried out by Ahmed et al., (1989). The experimental results also show that a dose of 0.30 kGy could control this insect. However, the feeding behaviour of these pests can be controlled by 0.20 kGy.

Dried fruits and other dried foods: Dried fruits eg. apricots, dates, figs and raisins, can be disinfested at a dose below 1 kGy (Khan et al., 1985). Insects associated with these dried fruits are C. cephalonica, T. castanesum, C. cautella and T. castaseum. Similar results are also reported in irradiated dried dates by Ahmed et al., (1985), who have conducted extensive work on disinfestation of dates.

Similar experimental results have been obtained in other dried foods. Dried mushroom infested with the moth Nemapogon granellus is disinfested at 0.5 kGy (Kovács et al., 1985). A dose level of 0.50-0.75 kGy is needed to control copra beetle (N. rufipes) in copra within 10 days of treatment and coffee bean weevil (Araecerus fasciculatus) at a dose level of 0.75 - 1 kGy within 14 days in coffee beans (Manoto et al., 1985). Cocoa beans are heavily infested with C. cautella and C. cephalonica in storage. Disinfestation by irradiation at a commercial level can be achieved at a dose of 0.50 kGy, which can effectively replace the terminal fumigation treatment of these products.

Packaging and storage

A foodstuff is liable to reinfestation after irradiation treatment as it does not leave any residual effect. Therefore, appropriate packaging is necessary to prevent the products from the reinfestation by insects. In addition to certain properties considered essential for a food packaging material, it should also be resistant to insect penetration. Therefore, the success of irradiation disinfestation depends on proper storage of irradiated foodstuff after having been suitably packaged. Studies have been conducted to develop suitable packaging materials in order to reap the benefit of irradiation treatment. Highland (1985) discussed the behaviour of insects, which can penetrate readily in different packaging materials. Stored product insects which can penetrate through packages, include the lesser grain borer, R. dominica, cigarette beetle, L. serricorne, Cadelle, Tenebroides mauritanicus, rice moth, C. cephalonica and almond moth, C. cautella. The lesser grain borer can bore through any common packaging material, except glass or steel (Highland and Wilson, 1981). Therefore, selection of a packaging material depends on the type of insect present in the food. Selection of packaging materials should also include the possibility of impregnating the packaging materials with fumigants with a view to repelling the incoming insects from the products.

Bhuiya et al., (1985) used gunny bags, gunny bags lined with polyethylene (0.1 mm), polyeethylene (0.1 mm) and polyvinyl chloride (PVC) (0.25 mm) as packaging materials to check reinfestation of irradiated pulses by C. analis and C. chinensis. Bhuiya et al, (1987) also observed that PVC materials and gunny bags lined with polyethylene (0.1 mm) and impregnated with permethrin (80-100 mg/m^2) on the outer layer gave complete protection of irradiated pulses in commercial storage for 8 months from the invading insects without any detectable pesticide residues in food. The hide beetle, Dermestes maculatus is a very strong borer. Traditional packaging materials, such as gunny bags, are not suitable for checking reinfestation of dried fish by this insects. Packages made of gunny bags, polyethylene only, and polypropylene lined with kraft paper are not suitable to check reinfestation of hide beetle. High density polyethylene, both white and clear can check reinfestation of dried fish. Rigid materials such as tin containers and plywood boxes are excellent packaging materials, for long term storage of irradiated dried fish. Good management practice in storage in order to keep the product clean from incoming insects can reduce the incidence of the reinfestation of irradiated foodstuffs.

Potential of irradiation disinfestation

Cornwell (1966) discussed in detail the advantages and disadvantages of both fumigation and irradiation treatments. Among some of the advantages of irradiation are: (1) residue free treatment, (2) uniform penetration into grains killing all stages of insects, (3) no resistance development by insects, (4) no hazard to operators and (5) instantaneous treatment . Limitations of irradiation processing are (1) high initial investment, (2) need for centralized facility and (3) slow acceptance by the end-users. Developing countries can attain significant benefit in adopting this technology in checking post-harvest loss of grain and other food products. Experimental results show that pulses, beans, oil seeds and other grains, which are major components of the dietary requirements in many developing countries, can be disinfested by irradiation. In several countries these crops are grown in one season; irradiation can check the loss in storage and increase availability of these grains to consumers, in some countries in Asia and Africa. Cereals like maize are heavily infested during storage (i.e. Ghana, Zaire, Nigeria). Irradiation disinfestation can be used as an alternative to fumigation and it can improve the export potential of a number of products in many countries. Ghana, Côte d'Ivoire, Nigeria and Malaysia are major exporters of cocoa beans. In Ghana cocoa beans are routinely treated by fumigation, i.e. methyl bromide. As ethylene dibromide has been already banned in the USA since 1984 and other fumigants, including methyl bromide are suspected to be carcinogenic, irradiation can be used as an alternative to fumigation. Other exportable products, such as coffee beans, dates and dried fruits can also be treated by irradiation and could earn more foreign exchange for many developing countries. People of Asia and the Pacific get about 80% of their animal protein from fish and fishery products. A large quantity of fish is dried for off-season consumption. Insects cause serious problems during storage; if no precaution is taken, loss can be as high as 55%. Insecticides are used most injudiciously to control pest in dried fish. Semi-commercial experiments with irradiation processing of dried fish in Bangladesh have shown that this process may be the only scientific method to control insects in dried fish.

These are some of the examples of the potential use of irradiation processing for the disinfestation of stored foods. Other products, which can benefit from irradiation, are dried spices, condiments, herbs and vegetables. As mentioned earlier, all dried food can be disinfested with irradiation at a low dose.

Practical application

The practical application of food irradiation processing has been on the increase since 1980. This trend started after the the Joint FAO/IAEA/WHO Expert Committee on Wholesomeness of Irradiated Food (JECFI) found that food treated up to an overall average dose of 10 kGy is safe and wholesome. The recommendations of JECFI were accepted by the Codex Alimentarius Commission (CAC) and incorporated into the Codex General Standard for Irradiated Foods in 1983 and recommended for acceptance by its member countries. Codex also published Recommended International Code of Practice for the Operation of Radiation Facilities for the Treatment of Food. These recommendations of the CAC accelerated the approval of irradiated foods in member states. At present 37 countries have approved one or more food item for human consumption. There are 47 demonstration/commercial irradiators in 24 countries that are irradiating foods. The list of countries which have approved disinfestation of some foodstuffs is given in Table 2.

It is expected that within the next few years the number of countries irradiating food will increase to around 30; and another 20 irradiation facilities will be in operation. The Joint FAO/IAEA Division for Nuclear Techniques in Food and Agriculture has estimated from the results of a questionnaire that these facilities irradiate approximately 500,000 tonnes of food per annum. The irradiation facilities in Odessa port of the USSR alone treat 400,000 of grains for disinfestation.

Role of International Organizations

International Organizations such as FAO, IAEA and WHO have an important role to play in harnessing the maximum benefit from any technology which can contribute to the reduction of food losses and to ensuring the availability of wholesome food supplies. Since its inception in 1964 the Joint FAO/IAEA Division has been assisting developing member states of both these organizations in facilitating the introduction of food irradiation. FAO/IAEA run co-ordinated research programmes (CRPs) specially on the disinfestation of food and agricultural products. At present this Division is assisting in the development of the research capabilities of African countries through a CRP, and transfer of technology is being affected through regional projects on food irradiation in Asia and the Pacific; Europe and the Middle East and Latin America and the Carribbean. The FAO and the IAEA have also technical assistance projects with several developing countries that support research and development leading to practical application of food irradiation processing.

In order to establish the wholesomeness of irradiated foods, the FAO, IAEA and WHO established the JECFI which has been convened periodically since 1964. The recommendations of the Codex Standard and Code of Practice were the outcome of convening JECFI by the International Organizations. These three international Organizations further agreed to collaborate through the establishment of the International Consultative Group on Food Irradiation (ICGFI) in 1984.

At present the Group is composed of experts nominated by 36 governments and assisted by representatives of three organizations. The main functions of the Group are: (a) to evaluate global developments in the field of food irradiation, (b) to provide a focal point of advice on the application of food irradiation to member states and organizations, (c) to furnish information as required, through the organizations to the JECFI and the CAC. Under the scope of the declaration establishing ICGFI the areas of activities considered by the group are: (1) to provide safety assurance of the process, (2) to assist national authorities in preparing national legislation, (3) to assist providing public information i.e. holding seminars, providing publications, films, etc., (4) to assist in techno-economic feasibility studies, (5) to organize training courses and (6) to assist in international trade of irradiated food in conducting inter-country transportation studies and market trials and considering problems arising in marketing and international trade. ICGFI is playing a significant role in facilitating transfer of technology of food irradiation in its member states.

Conclusions

Food irradiation has been accepted in several countries as a physical process. Disinfestation by irradiation has several advantages over fumigation treatment. It is a process which can be applied to products after final packaging. A low dose of 1 kGy has been recommended by the international bodies for disinfestation of foods. In practice most of the cereals, pulses, beans, dried fish, etc could be disinfested at a dose of 0.5 kGy. Irradiation does not change the chemical, physical, nutritional and technological properties of irradiated food (WHO, 1981). Storage trials have shown that reinfestation of the irradiated foodstuffs can be prevented through the use of proper packaging and packaging materials.

Irradiation will replace fumigants used in some commodities intended for international trade. Countries exporting cocoa beans, coffee beans and dried dates would benefit by the application of irradiation processing. Huge losses of dried fish can also be checked by the use of irradiation. Semi-commercial application of this processing technology has shown that it is an alternative method to fumigation and has inherent advantages to consumers.

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Table 1: Radiation Doses to Control Stored Product Insects

	Species	Stage	Dose (kGy)
Coleopter			
	Sitophilus oryzae	all	0.16
	S. granarius	all	0.16
	S. zeamais	all	0.16
	Tribolium castaneum	all	0.20
	T. confusum	all	0.20
	T. destructor	all	0.20
	T. madeus	all	0.20
	Rhyzopertha dominica	larvae	0.25
	Latheticus oryzae	adults	0.20
	Oryzaephilus surinamensis	all	0.20
	O. mercator	all	0.20
	Callosobruchus chinensis	all	0.20
	C. analis	all	0.20
	C. maculatus	all	0.20
	Bruchus rufimanus	all	0.40
	Bruchidius incarnatus	all	0.40
	Trogoderma granarium	all	0.25
	Dermestes maculatus	all	0.30
	Lasioderma serricorne	all	0.50
	Necrobia rufipes	all	0.30
	Araecerus fasciculatus	all	0.75
Lepidoptera			
	Anagasta kuehniella	larvae, pupae	0.60
	Plodia interpunctella	larvae	0.45
	Cadra cautella	larvae, pupae	0.30
	Sitotroga cerealella	all	0.60
	Nemapogon granellus	all	0.50

Table 2: List of countries approved irradiation disinfestation of foods

Country	Product	Dose permitted (kGy)	Date of approval
Bangladesh	Wheat and ground wheat products	up to 1	28 December 1983
	Fish	up to 2.2	28 December 1983
	Rice	up to 1	28 December 1983
	Pulses	up to 1	28 December 1983
	Spices	up to 10 (includes decontamination)	28 December 1983
Brazil	Rice	up to 1	7 March 1985
	Beans	up to 1	7 March 1985
	Maize	up to 0.5	7 March 1985
	Wheat	up to 1	7 March 1985
	Wheat flour	up to 1	7 March 1985
	Spices	up to 10 (includes decontamination)	7 March 1985
	Fish and fishery products	up to 2.2 (includes decontamination)	8 March 1985
Canada	Wheat, flour, whole wheat flour	up to 0.75	25 February 1969
Chile	Wheat and ground wheat products	up to 1	29 December 1982
	Rice	up to 1	29 December 1982
	Teleost fish and fish products	up to 2.2 (includes decontamination)	29 December 1982
	Cocoa beans	up to 5 (includes decontamination)	29 December 1982
	Dates	up to 1	29 December 1982
	Pulses	up to 1	29 December 1982
	Spices and condiments	up to 10 (includes decontamination)	29 December 1982
Bulgaria	Grain	0.3	30 April, 1972
	Dry food concentrate	1	30 April, 1972
	Dried fruits	1	30 April, 1972
China, P.R.	Peanuts	up to 0.40	30 November 1984
	Grain	up to 0.45	30 November 1984
France	Dried fruits	1 max.	6 January 1988
	Dried vegetables	1 max.	6 January 1988
Indonesia	Cereals	1 max.	29 December 1987
Israel	Grains, cereals, pulses, cocoa and coffee beans, nuts, edible seeds	1 average	January 1987

Table 2 contd.

Korea, Rep. of	Fresh and dried mushrooms	1 max. (includes growth inhibition)	28 September 1987
Pakistan	Spices	up to 10 (includes decontamination)	13 June 1988
South Africa	Dried bananas	0.5 max.	28 July 1977
	Almonds	1-4	25 August 1978
	Cheese powder	1-4	25 August 1978
Thailand	Dates	1 max.	4 December 1986
	Wheat, rice, pulses	1 max.	4 December 1986
	Fish and fishery products	1 max.	4 December 1986
	Spices and condiments dehydrated onions and onion powder	1	4 December 1986
USSR	Grain	0.3	1959
	Dried fruits	1	15 February 1966
	Dry food concentrates (buckwheat mush, gruel, rice pudding)	0.7	6 June 1966
Vietnam[1/]	Green beans	1 max	3 November 1989
	Maize	1 max	3 November 1989
	Ground paprika	1 max	3 November 1989
	Dry fish	1 max	3 November 1989
Yugoslavia	Creals	up to 10	17 December 1984
	Legumes	up to 10	17 December 1984
USA	Wheat	0.2-0.5	21 August 1963
	Food	Not to exceed 1	18 April 1986

All unconditional clearances

[1/]experimental

DESINFESTATION PAR IRRADIATION DES DENREES STOCKEES

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RESUME

L'irradiation est une méthode de lutte physique contre les insectes ravageurs qui désinsectise uniformément les produits stockés. Elle peut compléter ou remplacer les méthodes existantes de traitement chimique telle que la fumigation. Les études portant sur la désinfestation menées pendant des années ont montré que la radiosensibilité des ravageurs des stocks varie d'un ordre à l'autre. Cependant, il est établi qu'une dose de 0,5 kGy désinfeste tous les produits. Les céréales sont surtout infestées par les coléoptères et les lépidoptères. Elles peuvent être désinsectisées avec une dose de 0,5 kGy. Les bruches des légumineuses et des haricots peuvent être éliminées avec une dose inférieure à 0,2 kGy. Les produits alimentaires secs d'origine animale sont fortement parasités par les dermestides. Une dose de 0,3 kGy peut efficacement éliminer les dermestides des denrées sèches. Une même dose d'irradiation peut être utilisée pour désinfester les fruits secs et les légumes.

Contrairement aux produits chimiques, l'irradiation ne laisse pas de résidus dans les aliments traités. Ce traitement peut être fait au stade final de l'emballage et peut tuer tous les insectes à tous les stades de leur développement avec une dose uniforme. Le stockage après irradiation doit empêcher toute réinfestation. Ce traitement peut remplacer la fumigation obligatoire pour certains produits agricoles, comme les graines de cacao destinées à l'exportation. L'irradiation aux doses prescrites n'altère pas les propriétés physiques, chimiques, organoleptiques et technologiques du produit à traiter. De nombreux pays du monde utilisent le procédé d'irradiation ou l'ont approuvé pour la désinfestation des aliments stockés.