Safety and nutritional adequacy of irradiated food

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Preface

Food irradiation has, in certain circumstances, an important role to play both in promoting food safety and in reducing food losses. Because the safety and availability of nutritious food are essential components of primary health care, the World Health Organization is concerned that the unwarranted rejection of this process, often based on a lack of understanding of what food irradiation entails, may hamper its use in those countries likely to benefit most.

WHO actively encourages the proper use of food irradiation in the fight against foodborne diseases and food losses. To this end, it collaborates closely with Member States and other international organizations, particularly through the Joint FAO/IAEA/WHO International Consultative Group on Food Irradiation.

This up-to-date report on food irradiation has been produced at the request of one of WHO's Member States. Scientific studies carried out since 1980 have been reviewed and evaluated in its preparation, as have many of the older studies which had already been considered by previous international and national expert committees. Such controversial issues as the Indian studies on malnourished children fed freshly irradiated wheat (leading supposedly to a pathological condition, polyploidy) and the many claims that irradiation destroyed the nutritional value of food were given particular consideration[1] and were evaluated by a group of experts who, with one exception, had not previously been called upon by WHO to undertake the evaluation of irradiated food.

The first draft of the present publication was prepared by Dr Gary Flamm, with the help of Dr George Burdock, Dr Allan Forbes, Dr John Little, Dr Pasquale Lombardo and Dr Warren Nichols. Following a consultation[2] to review and revise the text held in Geneva from 20 to 22 May 1992, Dr Flamm prepared a provisional report, which was issued by WHO in October 1992 as an unpublished document (WHO/HPP/FOS/92.2) in a limited number.

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[1] In the preparation of this report, the world's scientific literature was searched, electronically stored data were accessed and the contents of dockets and files at the Food and Drug Administration in the USA and the US Department of Agriculture, as well as the data stored in Karlsruhe, Germany at the Federal Research Centre for Nutrition, were reviewed.

[2] See Annex for a list of participants.

The present publication is the result of further review and refinement of the provisional report, taking into account in particular the comments of the observers from the National Food Authority of Australia and from the International Organization of Consumers Unions.

Executive summary

1. Applications

Food irradiation can have a number of beneficial effects, including delay of ripening and prevention of sprouting; control of insects, parasites, helminths, pathogenic and spoilage bacteria, moulds and yeasts; and sterilization, which enables commodities to be stored unrefrigerated for long periods.

The shelf-life of many fruits, vegetables and meats can be extended by irradiation. Sprouting in root crops such as potato, sweet potato, yam, turnip, carrot, onion, garlic, shallots, beets, and Jerusalem artichoke can be inhibited with irradiation doses of 0.05–0.15 kGy. Irradiation of tropical and subtropical fruits such as bananas, mangoes, papayas and guavas at doses of 0.25–1 kGy delays maturation and senescence. Ripening is suppressed in temperate-zone fruits such as apples, pears and stone fruits at doses in excess of 1 kGy, although this often results in some damage to the fruit. Mushrooms irradiated at doses up to 1 kGy may have their shelf-life extended by as much as 5–7 days. Strawberries are relatively resistant to damage by ionizing radiation, and irradiation at 2–2.5 kGy in combination with refrigeration can increase shelf-life by 1–2 weeks.

Levels of spoilage bacteria in poultry may be reduced sufficiently to prolong shelf-life by as much as 1–2 weeks following exposure at 3 kGy. Most of the spoilage organisms in meats can be killed by substerilizing doses of ionizing radiation, resulting in a significant extension of shelf-life. Many meats can tolerate relatively high doses of irradiation if appropriate precautions are taken. For example, blanching, freezing and the exclusion of oxygen together with doses in the 25–45 kGy range can result in sterilized food with a long shelf-life. Substerilizing doses of ionizing radiation can also extend the shelf-life of fish and shellfish.

Many important fresh fruit and vegetable pests, including fruit flies, the mango seed weevil, the navel orange worm, the potato tuber worm, the codling moth, spider mites and scale insects, may be controlled by doses of 1 kGy or less. Insect disinfestation of nuts and dried fruits can also be achieved, since most insects are killed by doses in the range 0.25–0.75 kGy.

Spices and related materials may contain large amounts of moulds, bacteria, and their heat-resistant spores. Doses of 3–10 kGy can significantly improve the hygienic quality of spices, dehydrated vegetables, herbs, and other dry ingredients. Doses of 1 kGy or less can prevent losses from insect infestation in stored grains, pulses, flour, cereals, and coffee beans.

Much of the raw poultry sold for human consumption is contaminated with *Salmonella* and *Campylobacter,* both of which can be effectively controlled by irradiation, as they are readily destroyed by doses in the range 2–3 kGy. Irradiation of pork at doses of 0.3 kGy or less can kill the larvae of the parasite *Trichinella spiralis,* and low-dose irradiation may also reduce the risk of cysticercosis caused by the pork tapeworm. Infections resulting from the consumption of undercooked beef containing beef tapeworm cysts may be prevented by irradiation at a minimum dose of 0.4 kGy.

It is most unlikely that all these potential applications will prove commercially acceptable; the extent to which such acceptance is eventually achieved will be determined by practical and economic considerations.

2. Chemistry

There are many forms of radiation, but only high-energy radiation can produce ions or charged particles after being absorbed by matter. This type of radiation is called ionizing radiation, and comprises gamma rays from decaying radioisotopes, X-rays, and machine-generated electrons. Absorption of ionizing radiation by food molecules results in the breaking of chemical bonds and the generation of free radicals and charged ions, leading to the formation of radiolytic products. The study of the chemistry of food irradiation has largely focused on the nature of these products.

Each of the three major macronutrients in food—carbohydrates, proteins and lipids—gives rise to different types of radiolytic products when exposed to ionizing radiation. Water plays a key role in influencing the nature and yield of the products from carbohydrates which, in the presence of water, react chiefly with hydroxyl radicals, producing ketones, aldehydes and acids. Sugars are also formed from starches. Amino acids undergo reactions including abstraction of hydrogen, reductive deamination, disproportionation, decarboxylation, and reaction of intermediates with the highly reactive products of water radiolysis. When proteins are irradiated in the presence of water, all the reactions that amino acids undergo may also take place in proteins containing these amino acids. As a result, large numbers of different radiolytic products may be formed. Degradation of proteins to smaller polypeptides may occur, but aggregation of proteins is also possible. In a food matrix, the amino acids contained in a protein are much less subject to attack than in pure solution because they are relatively inaccessible. In contrast to carbohydrates and proteins, the irradiation chemistry of lipids does not involve water, as they are virtually insoluble. A wide range of radiolytic products may be formed, including fatty acids, esters and diesters, aldehydes, ketones, alkanes and alkenes, diglycerides and shorter-chain triglycerides. In a meat matrix, oxidative changes in lipids are relatively minor because of possible antioxidant effects of proteins with increasing radiation dose. It is important to emphasize that, while a wide range of radiolytic products may be formed in the three major macronutrients, with good manufacturing practice radiation affects less than 1–2% of the macronutrients in food.

The study of the chemistry of the effects of irradiation on vitamins has focused chiefly on the extent of nutrient loss. In pure solution, vitamin destruction is far greater than that observed in foods. With some exceptions, the destruction of vitamins caused by the irradiation of food is relatively small, resulting in little change in overall nutritional value. The extent to which vitamins are lost through irradiation depends on both food type and storage conditions.

There has been much discussion over whether irradiation of foods produces unique radiolytic products, i.e. compounds not found in foods either in the natural state or as a result of conventional food processing. As it will be difficult to establish that such products exist, concern about their toxicological potential is speculative.

The United States Army has produced detailed analyses of 65 volatile chemicals in irradiated beef. Also in the United States, the Food and Drug Administration (FDA) reported that six of these chemicals could not be identified in volatile fractions of nonirradiated foods, and therefore suggested that they might be unique. Further investigation showed that only three of the six (undecyne, pentadecadiene, and hexadecadiene) had not been found in non-irradiated foods. These chemicals are not unusual; compounds differing from them by only one carbon atom have been detected in nonirradiated foods. The existence of such very close homologues suggests that the three apparently unique radiolytic products probably exist at some level in non-irradiated foods, and might be found if more sensitive analytical techniques were to become available. In the same way, more sensitive analytical techniques might eventually reveal the existence of unique radiolytic products at extremely low levels.

The example cited above concerns reaction products associated with a volatile fraction, and this is probably typical of the relationship of nonvolatile radiolytic products and possibly of unique radiolytic products to one another, and to radiolytic products that are constituents of nonirradiated foods. Whether radiolytic products are unique or not, enzymatic hydrolysis would be expected to transform most of them into common compounds, such as fatty acids, amino acids, monosaccharides, and other products resulting from the human digestive process.

All foods are to some extent radioactive, generally at extremely low levels. There is some concern that irradiation of foods may result in induced radioactivity. Based on worst-case assumptions, the estimated induced radioactivity would be considerably below the level occurring naturally in food; irradiation in the commercially useful range is not expected to generate measurable additional radioactivity in foods.

3. Post-irradiation detection

Ideally, analytical methods to detect whether, and to what extent, foods have been irradiated should be simple, rapid, and reliable, use ordinary instruments and small samples, and be applicable to all food types. Realistically, such methods will not be available in the near future, and methods of analysis will almost certainly vary with food type and with the nature of the analyte.

The detection of chemical changes in food has been the basis of a number of analytical approaches. Much progress has been made over the past 10 years in the development of techniques to detect and measure changes in proteins, lipids, carbohydrates and other food components. Physical properties have also been investigated, including changes in electrical impedance, electric potential, and viscosity. Techniques using thermal analysis, near-infrared analysis, and electron spin resonance have had some success, and measurement of induced luminescence shows promise. Biological changes are also being studied as a means of detecting food irradiation.

Many of these approaches have been or are being tested in international collaborative studies. While no truly specific methods of detecting food treated by irradiation exist as yet, future work, especially that involving DNA, may well lead to such methods applicable to nearly all food types. Several methods tested in collaborative trials have been found to be suitable for a number of foods.

4. Toxicology

Very large numbers of animal studies have been carried out over the past few decades, but no evidence has been found of adverse effects resulting from the consumption of irradiated food. Where differences have been noted between control and test animals, no consistent patterns have been observed in type of abnormality, type of food, amount consumed, duration of study and radiation dose.

Hundreds of studies covering all aspects of toxicology, including chronic and subchronic effects, reproduction, teratology, and mutagenesis, have been evaluated. Despite some deficiencies in a number of the studies reviewed, the consistency with which the studies report the absence of adverse toxicological effects following consumption of irradiated food is remarkable.

The studies carried out by Raltech, a well known testing laboratory in the USA, in which 134 tonnes of irradiated chicken meat were fed to laboratory animals, are among the most comprehensive ever conducted, and included chronic studies in two species, teratology studies in four species, a dominant lethal study, a sex-linked recessive test, and an Ames mutagenicity test. The results showed a general lack of effects associated with the treatment, providing further evidence that the consumption of irradiated food does not pose a hazard.

A large number of animal feeding studies have been carried out by the International Project in the Field of Food Irradiation (IFIP). The project was in existence from 1970 to 1982 and produced over 70 reports describing the feeding studies undertaken, none of which demonstrated any adverse effects of irradiation.

In 1987, a collection of toxicity studies was submitted to the FDA in support of a petition proposing the use of irradiation of poultry products to extend shelf-life and reduce the risk posed by *Salmonella*. The submission included three feeding studies carried out in the Netherlands, at the Central Institute for Nutrition and Food Research. The investigations included a multigeneration study in rats, a chronic study in rats, and a 1-year toxicity study in dogs. No treatment-related adverse effects were noted.

Considerable attention has been given to several studies reporting the induction of polyploidy following the consumption of irradiated wheat by mammalian species or malnourished children. The results of these studies were found, after careful examination, not to be materially different from those of more extensive and statistically valid studies showing no effect of consumption of irradiated wheat on polyploidy.

Overall, no adverse effects of feeding irradiated foods to animals have been observed, and it is concluded that the irradiation of foods in accordance with established good manufacturing practices raises no unresolved questions of safety.

5. Microbiology

Ionizing radiation produces chemical changes that may kill or inactivate microorganisms. Most applications are at dose levels insufficient to kill all the microorganisms present, but sufficient to cause significant reductions in their number and variety. Doses between 2 and 7 kGy result in extensive destruction of common foodborne microorganisms, virtually eliminating organisms such as *Salmonella*. The shelf-life of foods can thereby be extended, and the threat of illness from pathogenic organisms eliminated or greatly reduced.

On the other hand, doses up to 50 kGy are necessary to eliminate highly resistant spores of organisms such as *Clostridium botulinum*. Comprehensive studies on chicken and fish inoculated at extremely high levels have shown that enough spoilage organisms remain after irradiation to produce the tell-tale signs of decomposition if the food is subsequently stored improperly. Although differential growth is possible, this does not represent a hazard unique to irradiation, nor one that cannot be effectively managed by using microbiological and other conventional techniques.

Concern that irradiation will result in increased induction of mutants that may possess increased pathogenicity, virulence, or radiation resistance has been expressed, but there is no scientific evidence that such transformations take place. Irradiation is by no means unique in its potential to increase the rate of mutation. Conventional processing techniques may also increase mutation rates, yet no evidence has been found to show that they have increased the pathogenicity or virulence of pathogenic organisms.

Finally, there has been concern over possible increased production of aflatoxin following irradiation. The evidence is mixed, but the overall scientific information indicates that irradiated food stored under typical conditions does not generate elevated aflatoxin levels.

In summary, there is no reason to suppose that irradiated food need be subjected to controls different from those regularly applied to food processed by conventional means.

6. Nutrition

Among the most important issues to be considered in assessing the acceptability of irradiated foods is whether such foods are nutritionally equivalent to those processed by traditional means. Food irradiation can cause changes in both macro- and micronutrients, but these changes are small. Irradiation is not alone in its ability to produce nutritional changes. Many food processes, notably cooking and heating in general, also cause nutrient loss, often to a greater extent than irradiation. The energy value of foods depends on the proteins, carbohydrates, and fats in them. At irradiation doses up to 10 kGy, no significant destruction of these macronutrients has been observed. While chemical analyses do show effects with doses up to and including sterilizing doses (50 kGy), they are small and nonspecific.

The view that irradiated foods are generally nutritionally equivalent to nonirradiated foods subjected to normal processing is supported by many animal studies, including some in which the protein efficiency ratio for many irradiated high-protein foods was measured. Proteins are of special concern, as they provide essential amino acids needed by the body to build its own protein. No significant effects on essential amino acids have been observed in beef, fish, or many other foodstuffs, in some cases at sterilizing doses.

The effect of irradiation on vitamins varies depending on the food type, the vitamin in question, and the process and storage conditions. Some vitamins are fairly insensitive to irradiation; others are more easily destroyed. The importance of a vitamin loss in any particular food depends on the contribution of that food to the total diet. For example, loss of vitamins from spices would not be a cause for concern, but loss of thiamine (vitamin B_1) from pork could be detrimental to populations where pork is an important component of the diet.

There is no loss of minerals and trace elements as these nutrients are unaffected by irradiation.

Irradiation temperature, exposure to air, and storage conditions may all affect nutrient content. In many cases, low-temperature irradiation in the absence of oxygen helps to reduce any losses of vitamins in foods, and storage of irradiated foods in sealed packages at low temperature also helps to prevent future decomposition.

7. Conclusions

A review of the available scientific literature indicates that food irradiation is a thoroughly tested food technology. Safety studies have so far shown no deleterious effects. Irradiation will help to ensure a safer and more plentiful food supply by extending shelf-life and by inactivating pests and pathogens. As long as requirements for good manufacturing practice are implemented, food irradiation is safe and effective. Possible risks resulting from disregard of good manufacturing practice are not basically different from those resulting from abuses of other processing methods, such as canning, freezing and pasteurization.

Contents

1.
Introduction

All governments bear direct or indirect responsibility for ensuring sufficient supplies of safe, nutritious, and acceptable food to meet the needs of their people. Such supplies should be of high quality and comprise a wide variety of foodstuffs.

Achieving the objective of sustaining or expanding high-quality food supplies is made difficult by agroclimatic conditions, the lack of technology, the seasonality of production, and the perishable nature of many crops. All countries depend to some extent on food processing and preservation technology. The need for treatment and preservation of food is currently being met through a variety of processes, some of which, such as drying and salting, are of considerable antiquity, while others, such as fumigation, canning and pasteurization, are of more recent origin.

Treatment by ionizing radiation is now beginning to be used to supplement existing technologies for certain applications. One such application, which has potential public health benefits, is the reduction of the numbers of pathogenic microorganisms in solid foods. Irradiation, as a process used to meet quarantine requirements, also has great promise as an alternative both to other physical methods and to fumigation.

Before this new food processing technology could be introduced, clear evidence and assurance had to be obtained that not only would it produce the desired results but also that it would not have any unacceptable toxicological, nutritional, and microbiological effects. The task of gathering this information at the international level was coordinated by the International Project in the Field of Food Irradiation (IFIP), which began in 1970. The data generated by this project and obtained from other sources were reviewed at a series of international meetings organized by the World Health Organization (WHO), often jointly with the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA). In 1980, these international deliberations culminated in the convening at WHO headquarters in Geneva of a Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food.

In their landmark report (WHO, 1981), the Committee concluded that the "irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard; hence, toxicological testing of