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Food irradiation is safe: Half a century of studies

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HIGHLIGHTS

- Food irradiation is safe and can benefit food safety, security and trade.
- Commercial use remains limited.
- The food trade tends to believe consumers will not buy irradiated food.
- There is good evidence that consumers buy irradiated food when it is offered.
- Demonstrating this evidence to industry is vital for commercial success.

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ABSTRACT

The potential benefits of food irradiation are yet to be realized due to slow progress in the commercialization of the technology. Processing food with ionizing radiation has encountered several barriers, one of which is the belief that consumers will not purchase irradiated food and a consequent caution among food retailers and producers. There is sufficient evidence that consumers will purchase irradiated foods when offered at retail in contrast to the data from many surveys of general public opinion. Communicating this evidence to food retailers and producers is essential if a major barrier to a greater use of the technology is to be overcome.

1. Introduction

Although the concept of irradiating food to bring about beneficial outcomes has been considered for a century, it was not until the 1960s that commercially feasible sources of radiation became available. Initial interest was in using relatively high doses of irradiation as a replacement for canning for military rations, for space foods and for hospital diets in immune-compromised patients. However, it soon became apparent that lower doses could be used more generally to improve food safety, increase food security (reduction of food losses and wastage) and offer another option as a phytosanitary treatment of food moving across international or national borders (Diehl, 1995; Fan and Sommers, 2013; Farkas et al., 2014; Hallman, 2011).

The beneficial effects of food irradiation resulted from the ability of radiation to bring about the effects shown in Table 1, which also provides some indicative applications. Irradiation is one of the many physical processes applied to food, but it has a number of practical advantages that include –

- Versatile (safety, security and trade (biosecurity) applications).
- Highly effective and efficient (it has broad-spectrum effectiveness against all non-sporing bacteria and against insects and many other pests).
- A cold process (advantageous for many foods).
- Penetrating (foods are treated in their final packaging, target organisms are not protected by package shape or position in the package, product distribution is relatively unimportant, and treating pallet loads is possible).
- Solid, raw foods can be treated.
- Treatment does not involve chemicals or chemical residues.
- The process is relatively easy to control (usually dependent only upon conveyor speed and the power/activity of the radiation source)
- Food can be immediately distributed into the food supply chain after treatment.

Despite these potential applications and advantages, irradiation has not become a major commercial food process. This paper

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Table 1
Effects and applications of food irradiation.

Dose range (kGy)	Effects	Example applications
0.1–1	Inhibit sprouting Delay ripening Pest disinfestation Parasite inactivation	Potato, onion, garlic Bananas Fresh produce, dried foods Pork (trichinella)
1–10	Reduce spoilage organisms (extend shelf-life Reduce non-sporulating pathogens	Strawberries, mushrooms, dried fish Meats, shellfish, spices
Above 10	Reduce pathogens to point of sterility	Spices; hospital diets, emergency rations.

discusses some of the issues that have, over the last 50 years, influenced food industry and public attitudes.

2. Safety

Since the 1960s, there have been many thousands of studies related to the safety of irradiated food. Most provide only a small link in the chain of evidence; some provide a major body of evidence, such as a study using 135 t of chicken meat (Thayer and Christopher 1987). Experts in toxicology, microbiology and nutrition reviewed the data at intervals and concluded that food irradiation presented no or minimal risk. International acceptance of the safety of irradiated foods stems from the work of international and national expert committees (see a review by Ehlerman, 2014).

A key report was the 1981 publication of a Joint Expert Committee on Food Irradiation (JECFI, 1981) established by the WHO/IAEA/FAO. Its main conclusions were that irradiation of food up to an overall average dose of 10 kGy presents no toxicological hazard and introduces no special nutritional or microbiological problems. Since 1981, several other international agencies have reviewed safety issues again, including the World Health Organization and the European Food Safety Authority (WHO, 1994, JSGHDI, 1999, EFSA, 2011). Broad reviews of the safety of food irradiation have also been conducted by national food safety agencies. Many reviews undertaken by the US Food and Drug Administration in response to petitions to irradiate various foods (eg., FDA, 2008) are notable. Food Safety Australia New Zealand has carried out several reviews as it operates a policy of approving food irradiation on a specified food and use basis (e.g., FSANZ, 2012). Health Canada (HC, 2008) and numerous other agencies have reviewed irradiated food safety over the years. Some specialist professional organizations such as the International Committee on Food Microbiology and Hygiene (ICFMH, 1982), the American Medical Association and public health organizations (Steel, 2001) and the American Dietetic Association (Wood and Bruhn, 2000) have also endorsed food irradiation as a safe process.

A Joint Study Group (JSGHDI, 1999) found that from the viewpoint of safety any food may be irradiated at any dose and this was reflected in a revision of the Codex General Standard for Irradiated Foods (CAC, 2003)

Despite these international reviews, some critics of food irradiation still question its safety (PC, 2003). Some seek 50 year tests in humans; most quote old data, often selectively, that superficially appear to raise doubts about safety but which have been considered and addressed by international panels. A fruitful topic for critics has been the identification of specific products of irradiation (radiolytic products) that were not known at the time of the early international reviews. Identification of extremely low concentrations of products has become possible with new analytical methods capable of identifying products at the ppb level.

The most celebrated of these 'new' radiolytic products were 2-alkylcyclobutanones (reviewed in Sommers et al., 2013), in part because they could be unique to radiation as opposed to any other food process, although there are reports that cyclobutanones can be found naturally in some nuts and nut products. Some preliminary and simple in vitro studies indicated that further safety studies were required, and critics used the findings to re-open the safety question even though the authors of the studies cautioned against such over-interpretation of their data (e.g., Delincee and Pool-Zobel, 1998).

More detailed and in vivo studies were eventually conducted and reviewed (Sommers et al., 2013), and cyclobutanones are not considered a toxicological hazard by food safety authorities (for example FDA, 2008; EFSA 2011). It is also pertinent that, in all the food irradiation safety studies, 2-alkylcyclobutanones would have been present in those fat-containing foods in which they may be produced even though their presence was not suspected at the time.

3. Global use of food irradiation

As a result of the JECFI conclusions of 1981, Codex Alimentarius issued a General Standard for the Irradiation of Food, which was subsequently revised in 2003 (CAC, 1983, 2003). The Codex provisions (any food and any dose for a legitimate technical purpose) are rarely implemented totally, but over 50 countries have approved the use of irradiation for at least one food or food class with a maximum dose dependent upon the purpose of treatment. Approximately 30 countries have facilities that irradiate food, but in many countries the facilities treat only research or pilot scale quantities. Most irradiated food is consumed in the country of treatment. The only irradiated food that is traded internationally are fruits treated for quarantine purposes, a small trade that has developed only in recent years between several Asian countries and the USA and between Australia and New Zealand.

Trends in the amount of food irradiated globally are difficult to evaluate for several reasons. The large volumes of grain treated in a single facility in the Ukraine from the 1980s that was subsequently decommissioned distort the totals, and commercial sensitivity probably leads to significant underestimation of the true amounts relative to amounts revealed in surveys. The best data come from studies in 2005 and 2010 reported by Kume et al. (2009) and Kume and Todoriki (2013). It is clear that food irradiation is decreasing in Europe, increasing substantially in parts of Asia and increasing slowly in the USA, Australasia and other regions. The 2010 survey data indicated a global total for irradiated food of approximately 400,000 t. However, the rapid increase in use in China, particularly, and some other Asian countries since 2010, and the likelihood of underestimation, suggest that the true total is nearly 1 million tonnes per annum today. This is still a minute fraction of the world-wide production and consumption of food.

4. Barriers to the greater use of irradiation

The remainder of this paper considers experience mainly in North America, Australasia and Asia in recent years and is substantially the view formed by the author. Europe is in a different situation as in the major regional bloc, the EU, political influences have shaped the discussion to a far greater extent than in other regions. Several barriers have been suggested, often informally, for the limited uptake of food irradiation. Some appear plausible, but do not match experience. The barriers are considered from the perspective of general public and consumer perceptions, which then shape industry reaction.

4.1. Association with radioactivity

Radioactive cobalt-60 has been the only practical radiation source until very recently, when reliable electron beam and X-ray sources came onto the market. Unsurprisingly, the public often associate irradiation with inducing radioactivity in the food, a physical impossibility with the sources permitted for food irradiation (Diehl, 1995). However, when informed, the public appears to accept the lack of induced radioactivity and even the most vocal critics of the process no longer put it forward as a reason to reject irradiation. However, a more subtle campaign against the process is still mounted by associating irradiation with radioactivity by way of references to ‘nuclear radiation’, ‘nuked food’, ‘zapped food’ or even ‘sources using radioactive waste’ (for example, Hauter and Worth 2008).

Associations with radioactivity can be countered effectively by pointing out that food irradiation uses exactly the same methods as used for medical product sterilization, and the acceptance of nuclear diagnostics and medicine within health-care systems. The association is useful to anti-irradiation campaigns in generating initial support, but it is not a barrier to food irradiation that lasts, and decision-makers in regulatory agencies and industry are not influenced by it.

4.2. Added costs

The capital cost of a new irradiation facility (US$5–12 million) is high although operational costs are relatively low. Cost is suggested to be a barrier to food irradiation as food producers will not want the capital outlay and the treatment costs would be passed on to the consumer. Such arguments do not account for several factors. For some uses of irradiation, notably phytosanitary use, non-treatment is not an option and an alternative treatment has to be used. The cost of the alternative, usually but not always less than irradiation, has to be considered. Facilities are not usually dedicated to a single food or food sector. Indeed most are operated by independent irradiation companies. Treatment costs are dependent upon dose, throughput and other factors but are generally in the range US$0.02–0.40 per kg (Morrison, 1989). This is not a significant cost except for cheap bulk commodity food.

The ‘opportunity cost’ of not treating a food is also worth remembering. Australian tomato and capsicum growers had a winter market in New Zealand worth approximately US$11 million per annum. This market was lost when an insecticide that was an accepted phytosanitary treatment was de-registered on the grounds of unacceptable human health risks. Irradiation treatment at a contract facility to recapture that market costs US 5–7 cents per kg (Steritech, private communication).

Food-borne disease has an annual cost estimated at 48 million illnesses, 3000 deaths and US$78 billion in the USA (CDC 2011, Scharff 2012) and, even in a small country such as New Zealand it is US$135 million p.a. (FSANZ 2010). Even a relatively small contribution from irradiation in lowering the economic costs of food-borne disease can make extra costs worthwhile without even considering the human toll.

4.3. Nutritional losses

The statement ‘irradiation destroys vitamins’ is often used in an attempt to persuade consumers that irradiation produces inferior food. It is true that some vitamins are relatively radiation sensitive compared to food constituents such as carbohydrates, proteins, fats and minerals (refer to Diehl (1995) for reviews of the effect of irradiation on nutritional adequacy).

The vitamin loss argument was a consistent concern mentioned in Australia and New Zealand during considerations of applications to use irradiation for phytosanitary purposes on fresh produce. The responsible authority (Food Safety Australia New Zealand) reviewed data on local produce and concluded there was no discernible effect on the concentrations of irradiation sensitive vitamins and pro-vitamins such as vitamin C and β-carotene at the highest dose permissible (1 kGy). FSANZ concluded that any potential effects on vitamins are less than the effects of storage and of the natural variations in vitamins that occur between varieties or that are caused by different growing and harvesting conditions (FSANZ 2012).

FSANZ also used the data and literature values for vitamin loss after irradiation to estimate the potential dietary impact of irradiation on fresh produce. FSANZ assumed that the total production of tomatoes, capsicums and 10 other tropical fruits that may be legally sold after irradiation in Australia and New Zealand was treated at the maximum dose limit of 1 kGy. In fact, biosecurity agencies have set minimum doses of between 250 and 400 Gy). An upper estimate of vitamin C and vitamin A loss was set at 15%. Even with these conservative assumptions, the mean dietary intake of these vitamins for a person with an average diet would decrease by less than 2% and remain above estimated minimum requirements.

4.4. Consumer acceptance

It is generally thought that a great majority of consumers are, at the least, wary of food irradiation, and that most actually oppose it and would not purchase irradiated foods. There is considerable evidence for this view from many surveys of consumer opinion, mainly from the USA (Eustice and Bruhn, 2013, and references therein). Less well known is that the opinion polls also show that consumers become more accepting of irradiation after a relatively short explanation about irradiation and alternative processes, and that irradiation is preferred to treatments that involve exposure of the food to chemicals and chemical residues.

A key point is that the surveys are a sounding board for the opinions of consumers who have not had the opportunity to see, purchase or even consider irradiated food. Perhaps a more useful yardstick of whether irradiated food would be purchased is the experience within the retail trade when irradiated food has been offered for sale for several years even though it must be recognized that the total volume remain small (EC 2012; Kume and Todoriki, 2013). In the USA, irradiated hamburger, Hawaiian papaya and sweet potato have been successfully sold for at least 10 years and, more recently, irradiated exotic fruits from Mexico and several Asian countries have been available. In New Zealand, irradiated mango and litchi have been imported and sold since 2005. There are other examples from around the world where irradiated food is successfully retailed such as frog's legs (France and Belgium), fermented sausage (Thailand) and spicy chicken feet (China). The food, with labels stating the fact it is irradiated, is sold with repeat purchases. Actual opposition has been limited to initial complaints from some food campaigners or special interest groups and has rapidly dissipated.

This author's personal opinion, based on both surveys and retail experience, is that a minority of consumers will reject irradiated food for a variety of principles and a minority will actively look for irradiated food where available. The majority of consumers, however, will purchase irradiated food if the perceived quality and price is right and will accept the decision of regulatory authorities on the products' suitability for sale. I am unaware of any market failure of an irradiated food offered at retail due simply to consumer opposition.

4.5. Labeling

The Codex General Standard for Irradiated Foods requires such foods to be labeled (CAC 2003), but countries differ considerably in their interpretation of this requirement. In the US, labeling is not required for irradiated ingredients as long as the whole food has not been irradiated, and labeling is not required at restaurant/catering establishments (USEPA, 2014). In New Zealand, in contrast, labeling is required for even minor ingredients and in restaurant/catering establishments (MPI, 2013). These strict requirements are simply based on the consumer's right-to-know, and not on safety grounds. However, it is probable that such a distinction is lost on most consumers.

The New Zealand experience is interesting as two divergent consequences have occurred. Opposition to irradiated foods has decreased as consumers who do not want to consume irradiated food know that they will be informed. Opponents also realize that their right to avoid irradiated food has a corollary; there are consumers with a right to prefer and consume irradiated foods. On the other hand, the very draconian labeling requirements have made industry more reluctant to consider irradiation when alternative processes, possibly less safe, are not subject to labeling.

4.6. Retail and food industry inertia

Past reluctance by retailers and the food industry generally to trade in irradiated food has been understandable given the strictest interpretation of the labeling requirements of the Codex General Standard (CAC, 2003) in some countries, and given the results of opinion surveys and the tactics of some irradiation opponents quoting the surveys and threatening boycotts. A cliché has been that industry is 'rushing to be second' to adopt irradiation. However, this continuing reluctance of industry is now less understandable given the long term success of some irradiated foods in several countries and the absence of any long-term or serious opposition to the food when offered at retail. This reluctance within the food industry, particularly at retail, is now the greatest barrier to the increased use of a useful, versatile process.

5. Overcoming industry resistance to food irradiation

It is re-iterated that this section is the opinion of the author. A number of strategies should be initiated if industry and retailers are to adopt a more open attitude to irradiation. These include actions by irradiation proponents to –

- Stress the benefits to the food rather than the smartness of the technology (safer, reduced chemical residues, longer shelf-life etc. as appropriate; note that the modern consumer, who values 'fresh', does not always see increased shelf-life as a virtue).
- Use labeling positively: always include the main benefit of the treatment on the label to offset any perception that the label is a warning.
- Discuss over-stringent labeling requirements with regulators.
- Recognize that food is a perishable commodity and that business models and attitudes that were satisfactory for sterilization of medical products may not be adequate for food irradiation.
- Build greater partnerships with the food industry so that some of the genuine practical barriers to food irradiation (such as centralized facilities, limited capacity, seasonality, temperature control, supply chain logistics and having a mix of irradiated and non-irradiated products in the marketplace) can be minimized.

6. Conclusions

Over the last decade the commercial retail of irradiated food has been growing slowly in a number of countries without any damaging consumer backlash or resistance. However, the food trade generally, and retailers particularly, are slow to recognize this fact. If the potential benefits of irradiation for food safety and security and for trade are to be fulfilled, then it is time for irradiation processors to bring these commercial successes to the attention of the food industry in a more concerted and forceful manner. Failure to do so will leave the field open to those quoting surveys of general public opinion which do not appear to be consistent with consumer purchasing behavior.

It is time for the food industry to acknowledge that consumer opposition to irradiated foods is not the barrier it may have thought. It is also time for the irradiation processing industry to recognize that there are some other practical issues that concern the food trade about irradiation processing. It is certainly time to develop an atmosphere of greater discussion and potential partnership between the two industrial sectors and then to move jointly towards ensuring that regulatory authorities remove any unwarranted barriers to the wider adoption of a safe technology.

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