Introduction

The early history of irradiation processing of food was discussed by Diehl [1**] including the first commercial application for spices in Germany in 1957. The General Standard for Irradiated Foods was first published by the Codex Alimentarius in 1983 [2**]. This essentially stated that any irradiated food was safe, nutritionally adequate and posed no special microbiological problems. The 2003 revision [3] stated that the maximum dose should not exceed 10kGy except when necessary to achieve a legitimate technological purpose.

Since the Standard was issued, a consistent message has been provided by scientists and science-based organizations that irradiation can contribute efficiently and effectively to increasing the safety and the security of food and to reducing the need for chemical treatments such as those used for fresh produce moving across borders [4*].

A 2009 survey led to an estimate of 405,000 tonnes of food being commercially irradiated world-wide [5**]. This was probably an underestimate due to a reluctance of some companies to reveal commercially-sensitive information. Given a recent rapid expansion in China of garlic and chicken products treated by irradiation, a reasonable estimate of the total amount of food being irradiated annually is approximately 750,000 tonnes. On a global scale, this is still a trivial amount given global food production and the apparent potential of irradiation to benefit consumers and industry.

This review examines cases of successful retailing of irradiated foods and considers the reasons for, and implications of, the most frequently cited reason behind the slow uptake of irradiation processing by the food industry, namely the belief that consumers will not purchase irradiated food.

Irradiated foods in the market place

The volume of spices, condiments and dried vegetables irradiated has for many years been higher than any other food class [5]. During the 1990s, France [6] soon followed by other European countries started irradiating thousands of tons of mechanically deboned poultry meat for incorporation into sausages or raviolis. However, except for spices in South Africa, these irradiated products were not sold directly to consumers but were blended and used as ingredients in processed foods. As is usual for compound foods, the consumer was not informed of any processing treatment of the constituents and the consumer was not making a voluntary choice to purchase an irradiated product.

There are now many examples of a whole food sold with a label clearly indicating irradiation, thereby presenting consumers with the opportunity to purchase or reject the product.
Various types and quantities of irradiated food such as:

- Papaya, mango and poultry in the US [7, 8];
- Strawberries in France and South Africa [7, 9];
- Refrigerated shrimps in the Netherlands [10];
- Rehydrated dried fruit, chicken livers and gizzards in France.

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These tests, in which information on irradiation was usually made available and in which irradiated and non-irradiated products were offered side by side, were considered positive in the sense that they all showed that consumers do buy irradiated food.

Long term retail sale of a variety of irradiated fresh produce supplied from a facility in Florida began in a small Chicago grocery store in 1992 and continued for over 10 years [11]. Between 1995 and 2000, 400 tonnes of Hawaiian papaya and other fruits were shipped to an irradiation facility in the Chicago area and sold in several US states [12**]. After 2000 an irradiation facility in Hawaii became available to treat the fruits prior to shipment.

Several types of food were irradiated in European countries prior to an EU-wide Directive that restricted irradiation treatment to foods on a ‘positive’ list which initially comprised only herbs and spices [13]. The Directive opened the possibility to extend the list to other products, but this has still not happened after more than 15 years. Given the positive conclusions of the European Food Safety Authority about the safety of irradiated food [14], the delay and barrier to authorising the irradiation treatment of more foods do not appear to be science based.

Japan was an early adopter of irradiation when, in 1973, a cooperative on its northernmost island treated potatoes to inhibit sprouting. Since then, Japan has consistently rejected extension of irradiation to any other foods. However, irradiated potatoes are still sold over 30 years later although the volumes have gradually reduced to less than half peak volumes, standing at approximately 6,000 tonnes per annum [5**].

Thai people enjoy nam naem, a fermented pork sausage eaten raw. The pathogens and parasites risk is significant and a safe irradiated option has been available in convenience stores and supermarkets since the mid-1980s [15]. Most Thai consumers do not recognize the health risk and the irradiated product has a higher price. As a result, the quantity of irradiated product sold yearly is only a few hundred tons.

In 2000 an X-ray facility became available in Hawaii for phytosanitary treatment of fresh produce and irradiated sweet potato, papaya and other tropical fruits have been shipped for retail sale in mainland USA, a trade presently estimated at approximately 6,000 tonnes per year [19**].

EU countries that permitted irradiation of foods other than spices and herbs prior to the 1999 Directive still maintain the right to use their existing national legislation. However, given the negative regulatory climate in the EU, it is unsurprising that volumes of irradiated food in the EU have continued to fall. Nevertheless, EU member states still irradiate approximately 7000 tonnes of food per annum [20*]. Almost half of the food treated comprises frog legs sold with suitable labelling in Belgium, France and the Netherlands.

China has leapt ahead in its use of irradiation for several foods such as garlic. Of special note is the disinfection of spicy pickled chicken feet and wings, a snack packed under vacuum and kept at room temperature, of which more than 120,000 tonnes of labelled product were sold in 2014 [Gao Mei Xu, personal communication 20 May 2015]. The market leader is building an in-house gamma irradiator in the region of Chongqing solely for their production.

In 2014, the total global volume of fresh produce irradiated for phytosanitary purpose was approximately 22,000 tonnes [21**, 22**]. New Zealand was the first country to accept irradiated fresh food from another country (Australia) in 2004. For over 10 years labelled mangoes and litchis irradiated to meet strict New Zealand import quarantine requirements have been available in shops and supermarkets. Volumes have grown steadily and since 2013, irradiated tomatoes and capsicums have also been available. The total volume of irradiated fresh product imports in 2014 was approximately 2000 tonnes [21**].

Consumers in the USA are also finding irradiated fruits imported from overseas in their supermarkets. Seven countries are sending a variety of fruits sold at retail into the US, totalling nearly 14,000 tonnes in 2014 [22**], adding to the 6,000 tonnes of irradiated Hawaiian produce.
The predominant interest in food irradiation in Australia and New Zealand legislated to be a nuclear free zone. Following the Chernobyl accident and after New Zealand conducted a government-led public enquiry into food insect pests are not exported along with fresh produce. Both New Zealand is as a phytosanitary treatment to ensure viable treatments. Objections during the public comment period conducted limited to some initial letters to newspapers and on-line comment. Adverse public reaction was watched the reaction to display in smaller independent stores. There has been opposition to the importation but it has come from local tomato growers, not from consumers. Arguments have been based on whether imports are needed and on the adequacy of the labelling requirements not on the safety of irradiated tomatoes.

In 2013 and 2014 over 400 tonnes of irradiated tomatoes were imported. However these were only sold in the independent stores. There has been opposition to the importation but it has come from local tomato growers, not from consumers. Arguments have been based on whether imports are needed and on the adequacy of the labelling requirements not on the safety of irradiated tomatoes.

Australia has strict quarantine rules on fresh produce moving across the borders of its States and Territories. Queensland fruit fly is the pest of greatest significance but there are many others. Queensland also is the site of Australia’s sole facility licensed to irradiate food. In 2011 a protocol accepting the phytosanitary use of irradiation was agreed by all States and Territories [24]. There is a slowly growing trade in Queensland mangoes, tomatoes and capsicums being sold at retail in Western Australia and trialled in South Australia [21**].

Summary of retail experience
There is now sufficient experience to show that when labelled irradiated foods are offered for retail sale, consumers will purchase and re-purchase it, implying that irradiated foods may be marketed profitably and without risk to reputation. The experience has been gained in several countries including those with sophisticated, well-informed consumers with active lobby groups who favour ‘natural’ and minimally processed foods, such as the USA and New Zealand.

Though vocal at times, opposition seems to have little impact on most consumers who at the moment of purchase make decisions on the basis of what they see in front of them and price. This does not imply unanimous acceptance of irradiated food. No food is purchased or wanted by all consumers. Also, consumers do not decide the new products that are offered to them. This decision is made by the retailers who assess afterwards if the sales are acceptable or not.

Understanding consumer attitudes
It is not hard to conceive why it was originally thought that consumer resistance was the major barrier to the uptake of food irradiation. Post-Chernobyl uptake was slow, and anti-food irradiation lobbyists declared that irradiated products were neither wanted nor needed, a position seemingly justified by the slow uptake. The public may often equate irradiated food with radioactive food and any new technology involving radiation or radioactivity has been mistrusted despite the long term use of such technologies in medicine and industry.

The question is why, in view of the significant examples of successful retail sale that now exist, the belief in consumer re-
sistance persists among food producers and retailers? The an-
swer probably lies in the early surveys of consumer opinion
about food irradiation, an overly simplistic interpretation of the
results and their use by anti-nuclear and anti-irradiation lobbies.

The literature on surveys of consumer opinions on food irradia-
tion has become extensive. Articles on the US consumers’ per-
ception of food irradiation and irradiated meat pre-dominate
[25] and have been reviewed by Eustice and Bruhn [18**].
There are now data from the EU, Canada, Brazil, Australia,
New Zealand and a few developing countries [26-33]. The
methodologies, the size of the studies and the rigour of the
analyses vary widely but there are some clear trends.

First, most respondents have never seen irradiated food. Their
opinion is sought about an abstract concept. Generally it is
found that:

• The majority of respondents have not heard of irradiation
or know no very little about the process.
• The initial reaction of most consumers asked if they would
purchase irradiated food is negative.
• When provided with factual evidence, the number of re-
spondents willing to consider purchasing irradiated food
increases, often then comprising a majority of consumers
even if asked to consider paying a premium. Providing
negative information at the same time as positive infor-
mation offsets the increase in acceptance.
• For fresh produce, irradiation is viewed more favourably
than chemical treatments when a similar level of infor-
mation is provided about the technologies [31, 33].
• Irradiation is viewed much less favourably than other phys-
ical processes such as cold storage with which the respond-
ents feel they are familiar.

Social scientists have now examined consumer reactions to
novel technologies in greater depth through studies in which
geneic modification, nanotechnologies or high pressure are
assessed together with irradiation [34**, 35*-37]. These studies
show that irradiation is not unique in engendering both general
and organized opposition. A full discussion of these important
recent findings is beyond the scope of this review but the stud-
ies show clearly that:

• The issue of acceptance of a new food technology has
much to do with trust in the systems in place to regulate
and deliver the technology. The issues are greater than risk
perception per se.
• Technologies that are not perceived as “natural” or which
are thought to alter the character of the food generate
greater opposition than technologies that are familiar or
perceived as more “natural”.
• Labelling can help to provide some degree of control, al-
though one-third of respondents in a US survey would con-
sider the word “irradiated” on a label to be a warning [37].
• Information can be valuable in increasing positive respons-
es to novel technologies, but the information must be fo-
cussed on the benefits to consumers. Technical details of
the process often lead to consumers feeling they cannot
understand the process and that it will be out of their con-
trol. New technologies which are perceived as being of
benefit mainly to the food industry tend to be distrusted.

Future directions
Food irradiation should contribute appropriately to safer food,
a more secure food supply and facilitated trade in fresh pro-
duce. As a result of the early marketing trials of irradiated food,
several authors noted that the willingness of consumers to pur-
chase irradiated food may be greater than indicated by their
initial response to a general survey when irradiated food was
not actually available [7, 8, 38**]. Nevertheless, an unsubstanti-
ated belief in massive consumer resistance to irradiated food
continues to the present day and has discouraged efforts to
interest key sectors of the food trade in the technology. The
response of irradiation advocates has often been to stress the
need to provide consumers with more information about the
process.

The now overwhelming success of actual retail of irradiated
foods and the evidence from sophisticated studies of consumer
attitudes to novel food technologies suggest future strategies
for increasing the commercial uptake of food irradiation. Ele-
ments of a future strategy should include:

• Taking every opportunity to place in front of food produc-
ers and retailers the evidence of successful, long-term re-
tailing of labelled irradiated foods.
• Increasing the amount of irradiated food on retail shelves
through seeking the cooperation of entrepreneurial retail-
ers, who are likely to be small or medium-sized.
• Developing coalitions of stakeholders that believe in the
value of food irradiation and that would have the trust of
consumers. Food producers and retailers will be seen by
consumers as less biased than irradiation processors.
• Providing information and support to producers and retail-
ers on a technology that is very unfamiliar to them. This
must come from regulatory authorities, academics and,
despite the caution above, the irradiation industry. The role
of regulatory authorities is crucial. The US and New Zea-
land cases benefited from the attitude of food authorities
that make science-based rules. Wherever food irradiation is
considered too sensitive an issue to make science-based
decisions, the public debate is dominated by vocal oppo-
nents.

• Stressing the benefits of irradiation that are focussed on
the food and the consumer rather than the technicalities
of the process. For example, in the case of meat, giving con-
sumers a guarantee that they will not be poisoned by a
pathogen is what will matter most. Consumers can relate
to a non-chemical phytosanitary treatment that protects
local agriculture and the environment as well as providing
produce that is exotic or out-of season. However, exten-
sion of shelf-life of fresh produce is not necessarily seen as
a benefit by consumers who have become used to the no-
tion of fresh (meaning just harvested) produce.
• Taking into consideration that both positive and negative
points of view will coexist in any public debate on food
irradiation.
• Ensuring that labelling of irradiated food is both consisten-
t and fair. Labelling is a very difficult issue to balance. Con-
sumers see mandatory labelling as empowering them and
providing greater control over what they buy. An assurance
that irradiated foods would be labelled played a significant
role in decreasing opposition to irradiated foods in Australia and New Zealand. The food industry, however, sees labelling as a barrier to irradiation since consumers are likely to perceive it as a warning given that competing technologies are often not required to label (for example, competing phytosanitary treatments) and it carries some extra costs.

- Ensuring consistency in national regulations on the labelling of food in which an irradiated ingredient is only a minor constituent. Requiring that the tiniest quantity of irradiated ingredient in a processed food be mentioned on the label is extreme.
- Adjusting promotional strategies to recognize that irradiated food can appear to run counter to some recent shifts in consumer opinion, specifically towards minimal processing, attraction to naturalness and ‘organic’ and for locally produced food.

We have made the point that for too long the food trade has believed that consumers will not purchase irradiated foods. Equally, food irradiation advocates may have concentrated on consumer acceptance for too long at the expense of other barriers that need to be addressed. Briefly, these include:

- Producers do not relate easily to irradiation processing. Contrast the likely reaction of a fruit grower who for years has used hot water treatment in the packing shed or an insecticide spray in the field with a new requirement to send his fruit to a distant facility that requires special authorization and has hazard signs. The sterilization of health-care products can be a useful analogy for growers.
- At present irradiation requires the shipment of products to a specialised contractor during which time they are out of the control of the producer with a transportation time and a cost that comes on top of the price charged by the irradiation company. Food generally being a perishable commodity, smooth operation of supply chain logistics is even more essential than for health-care products.
- Affordable irradiation devices that could be placed on-line in, for example, a fruit packing house or meat processing line would go a long way to encourage the adoption of the process. Such equipment is a research concept at present but would be the ideal answer for the final step in a HACCP or quarantine system; it would also empower the user.
- The number of irradiation facilities is limited and since most are located to capture non-food products, they are not necessarily in the right place for food manufacturers or traders. Also these facilities are often optimized to treat at much higher doses than those required for food. These factors result in a lack of capacity to treat food at present and keep commercial volumes low. The result is to feed doubts about the potential for food irradiation to expand.
- Food generally involves high volumes. If only a fraction of a specific food can be treated this creates problems for the trade. These include practical issues of having two production streams and can include perception issues. For example, meat produced under GMP is rightly regarded as safe, but what would be the issues for a dual market, one with safe meat and one for irradiated meat that is even safer?
- Gamma irradiation is currently the predominant technology for food irradiation. Gamma facilities are safe and able to irradiate up to pallet size of products of high densities. They will undoubtedly continue to have an important role for many years. However, accelerator facilities producing electron and X-ray beams have several advantages. These include independence from the supply of cobalt-60 and the ability to ‘switch-off’ the emission of radiation. This can result in greater ease of obtaining permission to build traditional centralized facilities and opportunities to develop the on-line, in-house treatment systems that would excite the interest of food producers and, as they do not involve radioactive material, probably improve public perceptions of the technology.

Conclusions

Evidence from several countries shows that labelled irradiated foods (fresh and processed meats, fresh produce) have now been sold over a long period by food retailers without disruptive opposition. There is no record of any irradiated food having been withdrawn from a market simply because it has been irradiated. Although there are some consumers who choose not to purchase irradiated food, a sufficient market has existed for retailers to have continuously stocked irradiated products for years.

The long-standing belief among food producers and retailers that consumer resistance is the major barrier is no longer justified and there are lessons to be learned from the successful experiences. Provision of factual, positive information on the benefits of food irradiation to consumers and the food trade is still necessary. However, strategies to increase retail sales of irradiated foods should be modified in light of recent studies on consumer attitudes to novel food technologies generally.

Studies show that it is trust in the systems and institutions rather than perceptions of risk that dictate consumer attitudes and govern the adoption of a new technology. Retailers play an essential role in communicating the benefits of new products to consumers and it is likely that positive messages on irradiated food from retailers and food producers will generate the most favourable response from consumers.

Historically, the large retail food chains have only engaged to a limited extent with food irradiation experts. It is vital to ensure that the message about successful retailing of irradiated food is continuously presented to leading retail stakeholders, and to take every opportunity to put irradiated food on retail shelves.

If food irradiation proponents are persuaded that trying to convince consumers directly to accept the process should not be their sole strategy, then more effort can be put into working collaboratively with the food trade to address issues such as lack of irradiation capacity, optimising supply chain reliability, developing facilities to treat food where food is finally packaged and to encourage the use of non-radioactive, accelerator-based sources.

References

* Papers of interest have been highlighted as:
  * Marginal importance
  ** Essential reading

**A recent review of the research on most aspects of the technical, safety and benefits of food irradiation.**

**An article that demonstrates that initial consumer attitudes to irradiated food may**

**A review of the early history of food irradiation, key safety studies and commercialisation.**

**An account of the expanding trade in irradiated fresh produce imported from Australia.**

**A seminal account of consumer perceptions of novel food technologies.**

**A useful account of the value of irradiation as a tool in food safety.**

**A recent and thorough review of consumer acceptance studies, mainly in the USA.**


**The latest official compilation of commercially irradiated food in the EU.**

**An account of the expanding trade in irradiated fresh produce exported from Australia.**