Food Irradiation: Microbiological Safety and Disinfestation

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Abstract
Irradiation can kill microorganisms, insects and parasites and this is a fundamental reason for applying the technology to improve the safety and quality of many foods and food products. This paper will discuss how various organisms can be affected by irradiation treatment. Factors affecting radiation sensitivity will also be discussed and how the use of irradiation in combination with other treatments can be beneficial in improving quality and safety.

Keywords: bacteria, spores, yeasts, moulds, insects, parasites

1. Introduction
Consumers worldwide are demanding foods that are wholesome and nutritious. However, foodborne diseases continue to be a widespread global problem and it is estimated that over two million people die annually from diarrhoeal illness resulting from consuming food and water contaminated with pathogenic microorganisms (WHO, 2005). In addition, much food is lost post harvest due to spoilage. For example, it is estimated that 5-10% of gain is lost because of infestation between harvest and consumption (Satin, 1993). A variety of strategies will need to be used to tackle these problems and there will not be one easy solution. One approach could be to use irradiation as a method for the inactivation of microorganisms, parasites and insects and so improve the safety and quality of certain foods.

2. International perspective relating to safety and wholesomeness of irradiated foods
The concept of irradiating food is not new and was the subject of a patent 100 years ago. Since then, the safety of irradiated foods for human consumption has continuously been the subject of extensive research. The data generated has been evaluated by expert committees on several occasions in the last 40 years. In 1981, the FAO/IAEA/WHO Joint Expert Committee on the Wholesomeness of Irradiated Food (JECFI) concluded that "the irradiation of any food commodity up to an overall average dose of 10 kiloGray (kGy) presents no toxicological hazard; hence, toxicological testing of
foods so treated is no longer required". The expert committee also found that irradiation up to 10 kGy "introduces no special nutritional or microbiological problems" (Anon, 1981). The conclusions of the JECFI report along with information available from national expert committees led the Joint FAO/WHO Codex Alimentarius Commission to adopt the Codex General Standard for Irradiated Foods and the Recommended International Code of Practice for the Operation of Radiation Facilities for the treatment of Food in 1983 (Anon, 1983). This view was reaffirmed in 1994 by WHO with the statement that "irradiated food produced in accordance with established good manufacturing practices can be considered safe and nutritionally adequate" (Anon, 1994). In more recent years, a Joint FAO/IAEA/WHO Study Group on High-Dose Irradiation concluded that food irradiated to any dose appropriate to achieve the intended technological objectives is both safe to consume and nutritionally adequate and no upper dose limit need be imposed (Anon, 1998a). This led to a revised Codex General Standard for irradiated foods, which states that “the maximum absorbed dose delivered to a food shall not exceed 10 kGy except when necessary to achieve a legitimate technological purpose” (Anon, 2003). Despite these recommendations, food irradiation is still distrusted by many consumers and the technology is not extensively used. Currently over 50 countries have given approval for the irradiation of over 60 types of food and food products, but the quantities treated remain relatively small. Spices, dried herbs and vegetable seasonings are most common food products to be treated, with over 90,000 tons being irradiated in 2000.

**Food irradiation applications**

Food irradiation can give a wide variety of beneficial effects including the inhibition of post-harvest sprouting of tuber and bulb crops, delay in ripening of fruits and vegetables and the destruction of insects, parasites, pathogenic and non-pathogenic bacteria, yeasts and moulds. This paper will focus mainly on the inactivation of microorganisms for the purposes of improving food safety.

**Effect of irradiation on vegetative bacteria**

From a microbiological viewpoint, food irradiation can be used to (a) reduce the number of pathogens and so increase food safety and (b) reduce the number of spoilage organisms, leading to an extension in shelf-life and a reduction in waste, due to spoilage. Microorganisms vary greatly in their response to irradiation, with viruses and bacterial spore formers being most resistant, followed by yeasts and moulds, with vegetative bacteria being more sensitive
Vibrio spp and Aeromonas hydrophila are among the most sensitive of the pathogens. For example, V. parahaemolyticus is reported to have a D_{10} value of 0.06 kGy in frozen shrimp homogenate. Thus, a dose of 1.0 kGy would give at least a 10^{15} reduction in numbers. Certain serotypes of Escherichia coli, especially E. coli O157:H7, have been linked to serious illness, and even death. The pathogen is thought to have a low infectious dose so its presence in any foods is a cause for concern. The recall of consignments of beef thought to be contaminated with E. coli O157:H7 is not uncommon in the US. Undercooked hamburger meat has been frequently implicated in outbreaks. The use of ionising irradiation to treat refrigerated or frozen raw meat and meat products to reduce the levels of foodborne pathogens has been permitted in the US since 2000, largely as a measure to control E. coli O157:H7 in ground beef. Salmonella spp. and Listeria monocytogenes are the most radiation resistant of the common vegetative pathogens with D_{10} values between 0.5 and 1.0 kGy, depending on the substrate and radiation conditions. Therefore, irradiation doses designed to give a significant reduction in numbers of these pathogens in foods will also be appropriate for other vegetative cells.

**Effect of irradiation on bacterial spores**

The endospores of spore-forming bacteria are resistant to most preservation treatments and irradiation is no exception (table 1). Doses used to “pasteurise” foods, i.e. below 10 kGy may only give a 2-3 log_{10} reduction in spore numbers. This is not sufficient to produce shelf-stable foods. The spores of Clostridium botulinum cause most concern in these foods. In thermal sterilisation, the 12D concept is applied commercially to ensure the microbiological safety of shelf-stable foods. If this concept is applied to radiation-sterilised foods (radappertisation), then the dose must be sufficiently high to reduce numbers of viable spores of the most resistant strain of C. botulinum by 10^{12}. C. botulinum type A and B spores are regarded as being most resistant to radiation while type E are more sensitive. A 12D irradiation dose for C. botulinum type A in beef can be calculated to be 43.2 kGy at 25°C and 52.08 kGy at –50°C. However, this theoretically determined dose may not be what is actually required in practice. For example, radappertised foods are frequently given a mild heat treatment that is sufficient to inactivate enzymes and viruses. The heating may also sensitise the spores to subsequent the irradiation treatment. Also preservatives, such as salt or nitrite may also be added, depending on the food. These also may influence the survival of the spores and/or their ability to germinate and produce toxin. This has to be taken into account when determining the appropriate radiation-sterilising dose.
The presence of *Clostridium botulinum* spores in non-sterile foods must also be considered. They are normally present in low numbers but the potential for them to survive, grow and produce toxin in foods treated with low doses of radiation has been investigated. The main microbiological safety issue with these foods is whether sensory spoilage occurs prior to toxin formation. When assessing the risk of this happening the factors which have to considered include the probability of spores being present in the food prior to treatment, the dose applied and the likelihood of removing significant spoilage microorganisms before botulinum toxin is produced, particularly if the product suffers temperature abuse. *C. botulinum* type E (which are non-proteolytic) and some non-proteolytic type B spores are of particular concern as they can grow and produce toxin in foods at temperatures as low as 4°C. *C. botulinum* type E in irradiated fish has been the subject of a number of studies. In general, results suggest that the irradiation doses used for fish products should be chosen with care. The use of a low dose (no greater than 2 kGy) should be sufficient to reduce the general microflora but ensuring that sufficient spoilage organisms survive to grow and cause spoilage before botulinum toxin is produced. Temperature control is also very important, as it is with all vacuum packaged fish products.

Like staphylococcal toxin, botulinum toxin itself is extremely resistant to irradiation. Even doses of 25 kGy have little or no effect on toxin inactivation. Botulinum toxin can be relatively easily destroyed by heating but staphylococcal toxin is more heat stable and can survive boiling for several minutes.

**Effect of irradiation on viruses**

There is relatively little research on food virology, compared to food bacteriology, although outbreaks of foodborne illness associated with viruses such as Norwalk and hepatitis A have been well documented. Viruses are relatively resistant to irradiation (table 1) with D_{10} values are typically 2-7 kGy at irradiation temperatures around 20°C. The D_{10} value increases further as the temperature during irradiation decreases. Thus, foods given low doses of irradiation (<10 kGy) may still contain infectious viruses. This is not unique to irradiation. Other non-sterilising preservation treatments, such as high pressure processing and freezing, will also allow the survival of viruses. Viruses can be inactivated by heat so the combination of heating with irradiation can be used successfully.

**Effect of irradiation on yeasts and moulds**

In general yeasts are more resistant to radiation than vegetative bacteria (Table 1). Yeasts reproduce by budding. Relatively high doses are needed to kill cells outright but lower doses are
sufficient to prevent them from reproducing. Although yeasts can be found in most foods, they are generally only a significant spoilage problem in fruit and vegetables, cereal grains and baked products. They tend not to be a major problem in fresh meats and poultry during chilled storage because initial numbers are generally low and they are out competed by the faster growing psychrotrophic bacteria. However, as yeasts tend to be more radiation resistant than most bacteria they can become important in the spoilage of irradiated meat products, such as sausages, stored at refrigeration temperatures.

Fungi can vary in their radiation resistance. *Fusarium* spp. and *Alternaria* spp. tend to be more resistant than *Penicillium* spp. and *Aspergillus* spp. The “multiple hit” theory has been proposed to explain this difference in radiation resistance. This theory assumes that the target within the organism, usually DNA, must be hit a number of times before the organism is destroyed. Spores of *Fusarium* spp. and *Alternaria* spp are multicellular. The multiple hit theory suggests that even if only one cell escapes damage, the spore may still have the ability to germinate. Thus, these spores are more radiation resistant as higher doses will be needed to destroy all the cells. This is in contrast to the unicellular spores of *Aspergillus* spp. and *Penicillium* spp.

Fungal spoilage can be a problem in most fruits. This can be controlled by irradiation doses around 2 kGy. For example, fresh strawberries normally have a short shelf-life due to the growth of moulds such as *Botrytis*. An irradiation dose of 2 kGy followed by storage at 5°C can control of such fungi to give a shelf-life of 14 days compared to < 7 days in the non-irradiated controls. Some fruits are sensitive to irradiation and doses above 1 kGy can result in loss of sensory quality, such as tissue softening. However, 1 kGy is not sufficient to significantly inhibit fungal growth in many fruits and in these cases combination treatments involving hot water dipping along with very low radiation doses can be used successfully.

**Effect of irradiation on insects**

Irradiation has been shown to be effective in killing insects outright or sterilizing them so that they can no longer reproduce (table 2). Death or sterility both fulfil the requirements of a quarantine treatment. Outright killing of insects is preferable, from a practical point of view, as it is not possible to tell if a live insect is sterile or not by visual inspection. However, the doses required to kill many insects may be significantly higher than those required for sterility. Some fruits do not respond well to irradiation and there can be a loss in sensory quality even at relatively low doses.
**Effect of irradiation on parasites**

Foodborne parasitic infections caused by these organisms are widespread throughout the world. The infections are frequently associated with the consumption of raw or undercooked food of animal origin. Fortunately, parasites of public health significance are relatively sensitive to irradiation (table 3). In general, lower doses are required prevent ingested parasites from reproducing in the human intestine than are needed to kill the parasite outright.

**References**


### Table 1: Radiation resistance of selected microorganisms.

<table>
<thead>
<tr>
<th>Organism</th>
<th>D$_{10}$ value (kGy)</th>
<th>Substrate</th>
<th>Irradiation conditions</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Campylobacter jejuni</em></td>
<td>0.13-0.19</td>
<td>Raw chicken</td>
<td>3-4°C; air</td>
<td>Patterson, (1995)</td>
</tr>
<tr>
<td><em>Clostridium botulinum</em> (spores)</td>
<td>3.45-3.60</td>
<td>Cooked beef</td>
<td>25°C; Type A spores</td>
<td>Grecz et al (1971)</td>
</tr>
<tr>
<td><em>Escherichia coli</em> O157:H7</td>
<td>0.28</td>
<td>Beef</td>
<td>5°C; vacuum packed</td>
<td>Thayer (1995)</td>
</tr>
<tr>
<td><em>Escherichia coli</em> O157:H7</td>
<td>0.44</td>
<td>Beef</td>
<td>-5°C; vacuum packed</td>
<td>Thayer (1995)</td>
</tr>
<tr>
<td><em>Listeria monocytogenes</em></td>
<td>0.49</td>
<td>Chicken</td>
<td>12°C; Packaged in air</td>
<td>Patterson (1989)</td>
</tr>
<tr>
<td><em>Salmonella Enteritidis</em></td>
<td>0.70</td>
<td>Low (3.3-5.6%) fat beef</td>
<td>Packaged in air</td>
<td>Maxcy &amp; Tiwari (1973)</td>
</tr>
<tr>
<td><em>Vibrio parahaemolyticus</em></td>
<td>0.04-0.06</td>
<td>Shrimp homogenate</td>
<td>Frozen</td>
<td>Bandekar et al (1987)</td>
</tr>
<tr>
<td><em>Candida zeylanoides</em></td>
<td>0.68</td>
<td>Chicken skin</td>
<td>10°C; in air; D$_{10}$ value</td>
<td>Hughes (1991)</td>
</tr>
<tr>
<td><em>Penicillium expansum</em></td>
<td>0.32</td>
<td>grain</td>
<td>10°C; in air;D$_{10}$ value</td>
<td>O’Neill et al (1991)</td>
</tr>
<tr>
<td><em>Fusarium culmorum</em></td>
<td>8</td>
<td>grain</td>
<td>10°C; calculated as dose required to reduce count from log 5.5 to &lt; than log 1/ g.</td>
<td>O’Neill et al (1991)</td>
</tr>
<tr>
<td>Coxsackie virus</td>
<td>6.8</td>
<td>Cooked beef</td>
<td>-30</td>
<td>Sullivan et al, (1973)</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>2.4</td>
<td>Clams and oysters</td>
<td>Not given</td>
<td>Mallet et al (1991)</td>
</tr>
</tbody>
</table>

### Table 2: Radiation quarantine treatments proposed for selected insects.

<table>
<thead>
<tr>
<th>Insect</th>
<th>Dose (kGy)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melon fruit fly (<em>Bactrocera cucurbitae</em>)</td>
<td>0.21</td>
<td>Seo et al (1973)</td>
</tr>
<tr>
<td>Mediterranean fruit fly (<em>Ceratitis capitata</em>)</td>
<td>0.225</td>
<td>Seo et al (1973)</td>
</tr>
<tr>
<td>Sweetpotato weevil (<em>Cylas formicarius eleganultus</em>)</td>
<td>0.165</td>
<td>Hallman (2001)</td>
</tr>
</tbody>
</table>
Table 3: Radiation treatment required to control selected parasites.

<table>
<thead>
<tr>
<th>Parasite</th>
<th>Lethal dose (kGy)</th>
<th>Control dose to prevent infectivity (kGy)</th>
<th>Substrate</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Trichinella spiralis</em></td>
<td>5</td>
<td>0.15-0.7</td>
<td>Pork</td>
<td>Cited by Roberts &amp; Murrell (1993)</td>
</tr>
<tr>
<td><em>Toxoplasma gondii</em></td>
<td>Not known</td>
<td>0.3-0.7</td>
<td>Lamb and pork</td>
<td>Cited by Roberts &amp; Murrell (1993)</td>
</tr>
</tbody>
</table>