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Food irradiation: a call for caution

Raghul M
Affiliation: Anna University, Chennai, Tamilnadu, India
Email:raghulkrishvanth30@gmail.com

Abstract

The irradiation method has been widely used in treating food for its many advantages, perhaps giving inadequate attention to its dark side. Based on many scientific studies, irradiation has a direct impact on food components, affecting the food's attributes. But could consuming irradiated food for a long period of time have adverse health effects? The aim of this paper is to provide a brief overview of the scientific background of the use of radiation in the food industry and its effects on human health.
Keywords: food irradiation, food safety, mutagen.

Introduction

Food preservation techniques have been widely developed to control food spoilage, extend shelf life, and enhance food safety and quality. The oldest methods of preservation include fermentation, drying, and pickling. Modern techniques include pasteurization, canning, freezing, and chemical preservation. Ionizing radiation is used in food irradiation, also known as the cold pasteurisation method of minimal processing, to reduce microbial load and inhibit microbial proliferation.

Food irradiation is a physical treatment in which food commodities are exposed to a defined dose of ionizing radiations such as gamma rays, electron beams, and X-rays in order to control food borne pathogens, reduce the microbial load and insect infestation, inhibit the germination of root crops, delay the senescence of fruits and extend the life of perishable products (Farkas, 2006).Irradiation creates free radicals which are responsible for most of these effects, improving the safety of the food products, reducing the chances of food poisoning, and adding more value to the commodity. Irradiation has been intensively studied for more than half century.

In 1963, the FDA authorized the first use of irradiation to treat food in the United States. Wheat and wheat flour were first irradiated to rid them of insects. Then in 1986, irradiation was approved to inhibit growth and ripening in fruits, vegetables, and grain (Stanley, 1997). Irradiation is now also used in meat products (Nam, 2016), fruits and vegetables (Arvanitoyannis et al., 2009) and for sterilization of spices and herbs (Sádecká, 2007).Currently, food irradiation is approved for use in over 55 countries. However, many take a more cautious approach because this technology modifies food properties and forms dangerous substances (Maherani et al., 2016).

What is food irradiation?

The food irradiated with ionizing radiation is called irradiated food (Kobayash, 2018). The mechanism of microbial inactivation by ionising radiation consists mainly of damage to nucleic acids, either direct or indirect, caused by oxidative radicals originating from the radiolysis of water (Farkas, 2006). The unit of absorbed dose of radiation by a material is denoted as the gray (Gy), with one gray being equal to the absorption of one joule of energy by one kilogram of food. For the treatment of food, the following ionizing radiations have been approved: (1) gamma radiation from cobalt-60with maximum energy of 1.17 and 1.33 Mega electron volt (MeV), or from cesium-137 with energy of 0.662 MeV; (2) accelerated electrons (forming electron beams) with a maximum energy of 10 MeV; and (3) X rays with a maximum energy of 5 MeV (Codex Alimentarius, 2003).

With electron beams, electrons are accelerated to the speed of light by a linear accelerator and transferred to an e-beam gun, which subsequently passes the high energy electrons onto the product, resulting in microbial inactivation (Jaczynski et al., 2003). Electron beams utilize a different mechanism, with high-energy electrons pasteurizing/sterilizing the product. The source for electron beams is regular electricity, not radioactive materials (Luchsinger et al., 1996). Another source of ionizing radiation is from X-rays generated from bombardment of high energy electrons on a metal target (Lee, 2004). For treatment of food, the US FDA and regulatory bodies in several countries currently limit the electron energy for the production of X-rays to 5MeV (US FDA, 1999). Several important characteristics of X-rays improve as the energy increases (Gregoire et al., 2003). The electron beam and X-rays when not in use can be switched off and the direction of emission of radiation is controlled, whereas gamma rays cannot be switched off and the direction of radiation cannot be controlled (International Atomic Energy Agency, 2015). The intensity of the ionizing radiation to be applied primarily depends on the food product and intended end result to be achieved. Applications of food irradiation are usually organized into three categories according to the range of delivered dose. (See Table1.)

Is it safe?

The U.S. Food and Drug Administration have approved food irradiation as a safe and effective process. FDA has also evaluated food irradiation for safety for over 30 years. Various other international agencies and organizations including the Environmental Protection Agency, the U.S. Department of Agriculture, World Health Organization, and the International Atomic Energy Agency have stated the safety and effectiveness of food irradiation (Centres for Disease Control and Prevention, 2022). A report published by Joint Expert Committee on Food Irradiation (JECFI, 1981) established by the WHO/IAEA/FAO, concluded that a dosage up to 10KGy have no toxicological hazard.

The European Food Safety Authority asserted that food irradiation is safe (EFSA, 2011) and concluded (i) that there are no microbiological risks for the consumer linked to the use of food irradiation, and (ii) that most of the chemical substances formed during irradiation were also formed in food that has been subjected to other processing treatments and that the quantities in which they occur in irradiated food were not significantly higher than those being formed in heat treatments. Broad reviews of the safety of food irradiation have also been conducted by various national food safety agencies. Food Safety Australia New Zealand has carried out several reviews and approved food irradiation on specified foods.

Table1. Various dose levels of irradiation and their application (Ahmad Shah et al., 2014)

Dose level	Purpose	Food items
1. Low Dose (up to 1 kGy)	Prevent sprouting (potatoes, onions, garlic etc); Kill insects and larvae in wheat, flour, fruits and vegetables after harvesting. Slow ripening process. Kill certain harmful parasites associated with foods.	Potatoes, onions, garlic, ginger, bananas, mangoes and other non-citrus fruits, cereals and pulses, dehydrated vegetables, dried fish and meat, fresh pork.
2. Medium Dose Pasteurization (1-10 kGy)	Drastic reduction of the number or elimination of certain microbes and parasites that cause food spoilage. Reduction or elimination of many pathogenic microorganisms.	Strawberries, grapes, dehydrated vegetables, fresh or frozen seafood, fish, raw or frozen poultry and meat.
3. High Dose Sterilization (10-50 kGy)	Sterilization of food for special uses, such as meals for immunocompromised patients. Elimination of some disease causing viruses.	Sterilized food for immunocompromised patients.

Animal trials on consumption of irradiated food

Irradiation has been extensively used to exclude food borne pathogens, thus reducing the potential for food borne breakouts. Gamma rays are utilized for purpose of sterilizing solid, liquid and semi solid food products. Since radiation can inactivate microorganisms in frozen foods without defrosting, it can be used for sterilization of a final packed product, ensuring that the irradiated product remains sterile until package removal (Farkas., 1998).

Despite its widespread application, various experimental trials and findings have shown that consumption of irradiated foods has detrimental effects on human health. Consumption of irradiated food reduces the longevity and inhibits the growth of rats and significant radioactivity is noted in kidney and intestine (Tinsley et al., 1970).

Effects of ionizing radiation are due to direct impact on cells, resulting eventually in cell death. There is evidence that some of the effects may be due to post-irradiation radiotoxinemia and auto-immune responses arising from the radiolysis of proteins, polypeptides, and amino acids, termed as radio-toxins (Kusin et al., 1983).

Quinoid radio-toxin (QRT) products from the oxidation of polyphenols particularly *o*-quinones stabilized by peptides, induce metabolic changes in mice. At high doses they clearly demonstrate a progression of hypoxia in liver and brain tissues (Ibragimova, 2008). Irradiated foods have also been linked to unexplained weight loss; dogs eating irradiated diets weighed 11.3% less than dogs fed unirradiated diets (Spiher, 1968).

2-Alkylcyclobutanones are known as unique radiolytic products generated from the major fatty acids and triglycerides in irradiated food (Beom-Seok Song et al., 2014). Neoplastic growth expansion (including normal, preneoplastic, and neoplastic) in colon epithelia were found in rats ingesting them (specifically from the fatty acids present in beef and poultry) (Horvatovich, 2002).

Irradiation of polyunsaturated fats produces peroxides, which oxidize benzopyrenes in the food to benzopyrene quinines. Rats feed with irradiated fat containing carcinogen of pyrene cause a change in metabolism and which can initiate intestinal carcinogenesis (Gower, 1985).Organic peroxides may act by catalyzing the depolymerisation of deoxyribonucleic (DNA) and ribonucleic acid (RNA) and inducing mutagens (Kotin et al., 1963).

Food substances especially rich in sugars readily undergo radiolysis and produce many organic peroxides and amino acid-peroxide adducts. Several of these are known to be carcinogenic and possibly mutagenic (Kesavan et al ., 1971).In vitro studies on the irradiation of sucrose showed genome instability in human lymphocytes, chromosomes may have been damaged and permanent chromosomal rearrangements induced (Shaw et al., 1966).

Malondialdehyde, formaldehyde and acetaldehyde are formed by the irradiation of fructose, sucrose and glucose (Fan et al., 2003). Formaldehyde may have effects on the central nervous system, which appear acutely in the form of headache, malaise, insomnia, anorexia, and dizziness (Harris et al., 1981). Increasing Formaldehyde concentration by irradiation will increase the mutagenic burden and may increase the incidence of neoplasia (Tritsch, 2000). Increasing concentrations of malonaldehyde initiate skin carcinogenesis in mice (Shamberger et al., 1974).

Consumption of irradiated wheat was linked to an increased incidence of polyploid cells in the bone marrow of rats (Vijayalaxmi, 1975), monkeys (Vijayalaxmi, 1978), and human children (Bhaskaram et al., 1975). Children also showed signs of protein deficiency. Abnormal or polyploid cells transmitted chromosomal abnormalities to offspring and also there was a significant reduction in reproductive cells in rats (Narender et al., 1975).

Conclusion

Some animal studies on food irradiation demonstrate that irradiated foods have a detrimental effect on chromosome structure; however, most of these changes are reversible after the discontinuation of consumption of the irradiated foods. However, the initial rearrangements in the chromosomal structure may, if continued over long periods of time, induce oncogenesis. Validating such long-term effects more intensive research must be done to show significant evidence of an increase in the occurrence of cancer in humans. Animal studies are too short to provide relevant evidence, due to the short life span of

experimental animals. In the meantime, high levels of consumption of such foods may be inadvisable. Furthermore, irradiation does not inactivate the harmful microbial toxins present in food and indeed may increase the incidence of food intoxication.
The flag bearers of irradiation use it as a tool to mask and quick fix poor quality, safety, and hygiene practises sometimes found in food production. The type or dose of radiation used to treat foods is not mentioned in product labelling, which raises questions about the reliability and integrity of the process.

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