Paper-2: Principles of the Food Processing and Preservation

Module 35: Effect of Ionizing Radiations on Food Nutrients

35.1 Introduction

Ionizing radiation is high energy irradiation which has the ability to break chemical bonds in a molecule. The energy of these ionizing radiations can be transferred to other atomic particle thus they knock anelectronfrom an atomcreating ions or free radicals.These high energy ionizing radiations can be used to kill microorganisms in foodto prevent their spoilage and make them safer which is the basic concept behind food irradiation.High energy (low wave length) radiations such as X-rays, ɔ-rays and accelerated electrons are the examples ionizing radiations used for food irradiation processing. During irradiation process, food is exposed to a controlledsource of ionizing radiation for the purposes of reduction ofmicrobial load, destruction of pathogens, extension of productshelf life, and/or disinfestation of produce. Irradiationis often called ñcold pasteurizationò because of its remarkable reduction of a number ofdangerous microorganisms, and because of a negligible loss of nutrients and low degree ofsensory changes. Food irradiation is not new; way back in 1905 patents have been filed in US and in Great Britain to use irradiation for improving the quality of food. Irradiation of foods must be approved by the U.S. Food and DrugAdministration (FDA).FDA approval comes only after extensivetesting demonstrates that the proposed dose of irradiation effectively eliminates the pathogen orinsect of concern and does not generate toxic or carcinogenic chemicals in the food.At present irradiation has been approved for about 50 different types of food and at least 33 countries are using the technology commercially. However, the toxicity of the chemicals generated andthe change in nutritional quality of food products afterirradiation is still a considerable debate.

35.2 Sources of ionizing radiations

According to the Codex General Standard for Irradiated Foods, ionising radiations recommended for use in food processing are: I. gamma rays produced from the radioisotopes cobalt-60 (60Co) and cesium-137 (137Cs); II. Machine sources generated electron beams (maximum level of 10 MeV) and X-ray (maximum level of 5 MeV).

35.2.1 **Gamma rays:** Cobalt-60 is produced in a nuclear reactor via neutron bombardment of highly refined cobalt-59 pellets, while cesium-137 is produced as a result of uranium fission. Cobalt-60 and cesium-137 emit highly penetrating gamma rays that can be used to treat food in bulk or in its final packaging. At present, Cobalt-60 is the most extensively employed radioisotope for gamma irradiation of food.Over a period of years the cobalt60 or cesium137 slowly decay to nonradioactive nickel and non-radioactive barium, respectively. The half lives of 137Cs and 60Co are 30 years and 5.2 years, respectively.

35.2.2 Electron beams and X-ray: Electron beams are produced by electron-beam machines which use linear accelerators. Electron beams have limited penetration power and are suitable only for foods of relatively shallow depth. X-rays are produced by bombardment of electron beams with a metallic target. X-rays are more penetrating than gamma rays but the efficiency of conversion from electrons to X-rays is generally less than 10% and this has hindered their use. A major advantage of machine-sourced ionising radiation is that no radioactive substance is involved in the whole processing system.

35.3 Food irradiation process

During food irradiation process, food product is transferred by conveyorto an irradiation chamber where the food is exposed to ionizing radiations such as gammarays or X-rays or electron beams at acontrolled rate. The ionizing radiations evenly penetrate thefood product,killing harmful microorganisms, parasites,or insects without altering the nature of the food. These radiations do not remain in the food. Because of their shorter wave lengths and higher frequencies these gamma rays or X-rays or electron beams penetratethrough the food so rapidly that no heat is produced.Once the food has beenirradiated, it must be handled appropriately to preventrecontamination. When the radioisotopes i.e. cobalt-60 orcesium-137 are used for food irradiation purpose, theirradiation cell (source) consists of cobalt-60 orcesium-137 rods in stainless steel tubes. These tubes arestored in water and raised into a concrete irradiationchamber to dose the food. No radioactive waste is produced at a food irradiation facility.

35.4 Microbial inactivation by ionizing radiations

Mechanism of microbial inactivation:The reactive ions produced in the foods due to irradiation destroys the micro-organism immediately by several means viz. changing the structure of cell membranes, affecting metabolic enzyme activity, damaging DNA and RNA molecules in cell nucleus.

The sensitivity of microorganisms to irradiation processingvaries greatly from microorganism to microorganism and is also dependent on other extrinsic factors. Several factors viz. size of the organism (smaller organism are more resistant to ionizing radiation), type of organism (cell-wall characteristicsand gram positive or gram negative in nature), numberand relative ñageò of the cells in the food sample, and absenceor presence of oxygen affect the microbial destruction in irradiated food. The physical and chemical compositionof the food also affects microbial responses to irradiation.Vegetative cells are less resistant to irradiation than spores, whereas yeast and moulds have a susceptibility to irradiation similar to that of vegetative cells. Compared to bacteria, viruses generally require higher radiation doses for inactivation because of their smaller size. Irradiation dose of 5 kGy is sufficient to kill most of the spoilage bacteria present in the food. Irradiation dose of 10 kGy kills most of the pathogenic bacteria occur in foods. However, some spore forming microbial species (e.g. *Clostridium botulinum*) and some species capable of repairing damaged DNA rapidly (e.g. *Deinococcus radiodurans*) are more resistant to irradiation.

35.5Irradiation dose and its classification

The basic unit for measuring irradiation dose is gray (Gy), whichis the amount of irradiation energy that 1 kilogram offood receives. The irradiation dose applied to a food product isexpressed in terms of a kilogray (kGy) which is equivalent to 1,000 grays (Gy) or 0.1 megarad(Mrad) or 100,000 rads. The amount of radiation that a food product absorbs is measured by a dosimeter.In 1980 the Food and AgricultureOrganization of the United Nations, the International Atomic EnergyAgency and the World Health Organization (FAO/IAEA/WHO) stated that foods irradiated up to an overall averagedose of 1 Mrad (10 kGy) presents no toxicological hazard andintroduces no special nutritional or microbiological changes;hence they can be considered safe. Theirradiation dose applied to a food product will dependupon the composition of the food, the degree ofperishability, and the potential to harbor harmful microorganisms. Levels of irradiation permitted for use in various foods is expressed in Table 1.

Table 1. Irradiation levels permitted for food use

Dose level	Purpose	Product examples
Radurization - Low dose(up to 1 kGy)	Kill parasites Kill insects and larvae afterharvest Inhibit sprouting Slow ripening	Trichinae in pork Fruits, vegetables, wheat,flour Potatoes, garlic, onions Non-citrus fruits andVegetables
Radicidation - Medium dose (1ï 10 kGy)	Pasteurization to eliminatespoilage organisms Pasteurization to eliminatefood borne illness causingmicrobes	Strawberries, grapes Fresh or frozen seafood,poultry and meat

Radappertization - High dose (10ï 50 kGy)	Sterilize food forimmunocompromisedpeople,Eliminate someviruses Decontaminate some foodadditives and ingredients	Pathogen-free hospital foods Spices, enzymepreparations,gums,aromatic substances

(Source: Food safety and inspection service, 1999)

35.6Effect of ionizing radiations on food nutrients

The application of ionizing radiation results in the radiolysis of water, a basic component of foods. This triggers the development of species such as OH^{-}, hydrated electron and H^{+}, which can then induce several chemical reactions with food constituents. Food irradiation can induce several reactionsamong food components which include oxidation of metals and ions,oxidation/reduction of carbonyls tohydroxy derivatives,elimination of unsaturation (double bonds), decrease in aromaticity,hydroxylation of aromatic and heterocyclics, and generation offree radicals which can be oxidized to various peroxides. Thesereactions can initiate lipid oxidation, break down of protein components,damage vitamins and cause undesirable changes in colour, odour, and flavour of foods.Quantity of radiolysis products varies as a function of composition of food, as well as with the temperature during the irradiation process and the actual dose of radiation used.

35.6.1 Changes in lipids

Lipids are less stable food components and hence very sensitive toionizing radiation. Lipids undergo both oxidative and non-oxidative changes during exposure to ionizing radiation. Exposure of fats to ionizing radiation may induce many auto-oxidizing andhydrolytic reactions leading to undesired organoleptic changes and losses ofessential fatty acids.The range and thenature of changes caused by ionizing radiation depend on the type of fat and its content of unsaturated fatty acids. Moreover, irradiated animal fat is more resistant against auto-oxidizing processes compared to plant fats.

The strong oxidizer ozone is produced from oxygen during food irradiation and can promote the oxidization of lipids and myoglobin.Moreover,the peroxo-compounds produced during fat oxidation may negatively affect othersensitive food components, for example, vitamins.The most susceptible site for free radical attack in a lipid molecule is at a double bond. Poly unsaturated fatty acids that bear two or more double bonds are the most affected lipids during irradiation. Each additional double bond in a fatty acid increases its rate of oxidation by a factor of two. With an increase in the irradiation dose unsaturated fatty acids will be decreased due to oxidative decay.

In the absence of oxygen, decarboxylation, dehydration and polymerization are the main changes observed in lipids subjected to irradiation. Radiolytic products obtained in this case include CO_2, CO, H_2, hydrocarbons and aldehydes. Fatty acids undergo preferential cleavage in the ester-carbonyl region giving rise to certain radiolytic compounds that are specific for each fatty acid. Alkanes and alkenes are the most abundant representing 95% of the volatile substances formed by lipid radiolysis. The amount of radiolytic products generated depends on the irradiation dose and are generally small quantity. Free fatty acids also will be released from the cleavage of neutral lipids or phospholipids after radiation treatment. Free fatty acids are not harmful but they cause a slight reduction in absorbability of long-chain free fatty acids like palmitic and stearic acids. Irradiated fatty acids are digested and absorbed at a slower rate than non-irradiated fatty acids, but there is no alteration in their nutritive value. However, after several extensive studies it can be concluded that when lipids are irradiated under conditions anticipated for commercial food processing (Ò7 kGy), it does not result in significant loss of nutritional value.

35.6.2 Changes in proteins

Free radicals formed by the irradiation of water catalyze the changes in proteins. Damage caused to protein by ionizing radiation include deamination (resulting in a production pyruvic and propionic acid), decarboxylation (resulting in a production of ethylamine and acetaldehyde), reduction of disulfide linkages, oxidation of sulfydryl groups, breakage of peptide bonds and changes of valency states of the coordinated metal ions in enzymes. The products formed after irradiation of protein include carbonyl groups, ammonia, free amino acids, hydrogen peroxide, organic peroxides, etc.

At high doses of irradiation, cross linking can occur between free amino acids and protein or proteins and proteins leading to the formation of new proteins. Radiation splitting ofhydrogen and -S-S- bridges is the main cause for this cross linking between proteins. Cross linking between protein and lipid can also occur. Changes brought about by irradiation affect the primary, secondary and tertiary structures of proteins. These changes in the structure of protein is ascribed to the reduction of the -S-S- bond or the oxidation of the ï SHgroup caused by irradiation.

Amino acids inside a protein are less labile to irradiation than free amino acids. Sulfur containing amino acids (cystine, methionine and tryptophan) along with aromatic amino acids are the most susceptible to irradiation damage. For aromatic amino acids, the indole ring of the aromatic group is the primary target of oxygen radicals. When sulfur compounds are submitted to radiation in the absence of oxygen, hydrogen sulfide and sulfide are formed in large amounts. In the presence of oxygen, the amount of ammonia and sulfuric acid produced increases. The typical odor of irradiated foods is related to the formation of these sulfuric compounds.

These chemical changes are all affected irradiation dose rate, temperature and presence of oxygen, protein structure, composition, whether native or denatured, whether dry or in solution, whether liquid or frozen, and to the presence or absence of other substances. However, data obtained from the literature indicate that irradiation at commercial doses (2ï 7 kGy) has no significant effect on the nutritional value of proteins or amino acids.

35.6.3 Changes in saccharides

Ionizing radiation effect saccharides when they are either solid stateor in a solution. Saccharides are extremely sensitive toradiation in the crystalline state and the radiolyticproducts obtained will depend on crystalline form of saccharides as well as the content of water present in it. When saccharides in solid state are irradiated their melting point may be reduced and also their optical rotation changes. When saccharides in aqueous solution are exposed to irradiation both the optical rotation and the index ofrefraction may be reduced. The irradiation of aqueous monosaccharide solutions gives rise toH_2, CO, CO_2, formaldehyde, malonaldehyde, glyoxal, aldonic acid, uronic acid, sugarpolymers and deoxy-compounds. Some of these substancesif produced in higher concentrations couldpresent a certain carcinogenic risk. The content of carboxyl acids may increases if oxygen is presentduring irradiation. The fission of the glycosidic bond may also occur. Irradiation ofpolysaccharides for example starch leads to reduction in viscosity of solution and at higher doses the gel doesnot form. Starch grains become fragile and disintegrate, and starch exhibits an increasedreactivity to Ŭ-amylase after irradiation treatment. During irradiation of saccharide-rich foods, a small amount of potentially hazardous substances (e.g., formaldehyde, malomaldehyde anddeoxysaccharides)to human health may be formed.

35.6.4 Changes in vitamins

Effect of ionizing radiation on vitamins is influenced by the medium in which the vitamins are present. Fat-soluble vitamins are affected by radicals produced during fat irradiation. Similarly water-soluble vitamins are affected by radicals formed by water irradiation. In the case of fat-soluble vitamins, the free radical-mediated reactions are negligible since they will mostly recombine with positive lipid ions. Since vitamins are in quite low amounts in most foods, the primary ·OHī radicals will mostly react with other major food components like lipids, proteins and carbohydrates, before reacting with vitamins. The vitamins are thus more affected by the secondary radicals formed by the interactions with the major components which are mostly hydroperoxides.

Among the fat soluble vitamins, vitamin E is the most irradiation sensitive while vitamin D and it K are highly stable. At high irradiation doses vitamin K may be lost significantly.

Among the water soluble vitamins, thiamin is the most irradiation labile vitamin. With increase in temperature during the irradiation processing, thiamine destruction will be increased. Oxidative damage to thiamin is responsible for its loss.Sensitivity of pyridoxine to gamma irradiation is less than that of thiamin.Folic acid is sensitive to irradiation at a dose of Ó25 kGy.Riboflavin, niacin, biotin, cobalamin, choline and pantothenic acid are relatively stable to irradiation. Relative radiation sensitivity of vitamins is presented in Table 2.

Table 2. Relative radiation sensitivity of vitamins(Mahindru, 2005)

Most sensitive	**Least sensitive**
Fat soluble vitamins	
Vit E → Carotene → Vit A → Vit D → Vit K	
Water soluble vitamins	
Vit B_1 → Vit C → Vit B_6 → Vit B_2 → Folate → Niacin → Vit B_{12}	

35.6.5 Changes in minerals/trace elements

Irradiation did not significantly affect the bioavailability of the minerals/trace elements.

35.6.6 Changes in organoleptic characteristics

Textural alterations and development of off-flavors are not significant when food irradiated at doses lower than 2 kGy. The changes in foods at lower doses of irradiation are similar to those occur during heat treatment equal to pasteurization. At higher doses i.e. more than 5 kGy, irradiation leads to off-flavours and textural alterations. Several methods namely exclusion of oxygen from the package, replacement of oxygen with inert gas, addition of antioxidants etc. can be employed to decrease the detrimental effects of irradiation on foods.

35.6 Labelling of foods treated with ionizing radiations

The FDA established regulationsfor labelling of irradiated foods. Labels must contain the words"Treated with Radiation" or "Treated by Irradiation" and displaythe irradiation logo, the Radura (Fig. 1). However, no label is required for food products that contain irradiated ingredients, such as spices, as longas the entire product has not been irradiated.

Fig. 1 Radura symbol developed to denote the irradiated food

35.7 Suggested readings

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