SAND2007-5100P

Safety Aspects of Irradiated Food -

Chemical Effects On Major Food Components

Toxicological and Microbiological Effects

Nutritional, Wholesomeness, Labeling

CMC
COOPERATIVE MONITORING CENTER

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

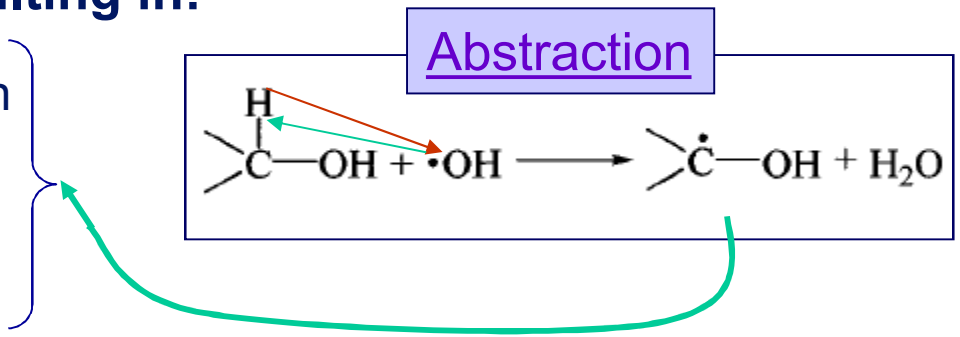
Effects On Major Food Components

- Major components of food are carbohydrates, proteins, and lipids,
  - Minor components include vitamins and minerals.
- All of these are of nutritional importance to the human body,
  - Their radiation chemistry has been studied extensively both in terms of the wholesomeness of irradiated food and from a toxicological point of view

Effects On Major Food Components

Carbohydrates

- **The radiation chemistry of carbohydrates is complex**
- **The hydroxyl radical (●OH) is of primary importance in the radiolysis of carbohydrates**
- **It acts by abstracting a hydrogen atom attached to a carbon atom, resulting in:**
  - Disproportionation
  - Dimerization
  - Dehydration



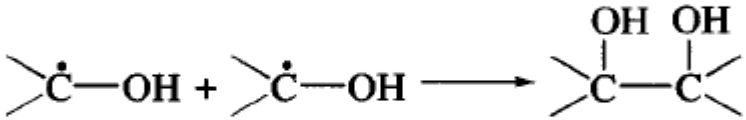
Effects On Major Food Components

Carbohydrates

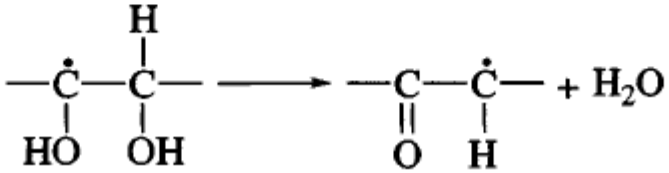
- Disproportionation, Dimerization, Dehydration

Disproportionation:

Dimerization:



Dehydration:



Effects On Major Food Components

Carbohydrates

- Presence of other food constituents has been shown to exert a protective effect on carbohydrates during irradiation
  - Presence of proteins in wheat flour curbs the formation of radiolytic products from carbohydrates,
- Effects observed when pure solutions of sugars are irradiated may not necessarily be noted when the sugars are contained within a foodstuff.

Effects On Major Food Components

- When sugars are irradiated in the solid state
  - Their melting point decreases
  - Their optical rotation is reduced
  - Browning can be observed with some sugars
    - Fructose, galactose, glucose, and xylose
  - Degradation can result
    - Formation of a mixture of gases consisting primarily of H_2 and CO_2
    - Together with traces of CH_4, CO, and H_2O
- Irradiation in aqueous solution changes the optical rotation and can generally cause browning.
  - The degree of degradation of sugars in solution is proportional to the dose.

Effects On Major Food Components

Proteins

- Considerable research has been undertaken to elucidate the chemical changes that occur in irradiated proteins
- An understanding of the changes occurring in amino acids and peptides on irradiation has been particularly important when studying the effects of ionizing radiation on the most complex proteins
- Taking into account the fact that there are about 20 amino acids, each with its own unique structure and composition, it is not difficult to comprehend why their radiation chemistry is complex, as it is that of the proteins they build

Effects On Major Food Components

Proteins

- Radiation-induced reactions in proteins are strongly influenced by their complex structure, that is, the folding of the peptide chains, disulfide linkages between the chains, secondary binding forces such as hydrogen bonds, hydrophobic bonds, ionic bonds, or those bonds holding several subunits together as a functional protein.

Effects On Major Food Components

Proteins

- The fact that irradiation can alter proteins does not create a significant problem from a nutritional point of view
  - Because amino acids, protected within the complex structure of the protein, generally survive the process.
- It has even been shown that doses as high as 50 kGy do not significantly alter protein quality
- It should, however, be noted that the degradation and aggregation of proteins on irradiation may alter the viscosity of proteins
  - For example, irradiation can impair the whipping quality of egg white

Effects On Major Food Components

Lipids

- The lipid or fat portion of food consists primarily of triglycerides that consist of fatty acids esterified with glycerol
- As for proteins, an understanding of the basic mechanisms involved in the chemical changes occurring in lipids on irradiation has been obtained using model systems
- Changes in lipids due to ionizing radiation can be brought about in two ways
  - By catalyzing their reaction with molecular oxygen, that is, autoxidation; or
  - By the action of high-energy radiation (direct or indirect) on lipid molecules.

Effects On Major Food Components

Lipids – Final thought

- It is worth noting that the nature of the compounds produced from fats by heat treatment is similar to that obtained by irradiation
- Certain qualitative and quantitative differences exist, and significantly more decomposition products have been identified from heated or thermally oxidized fats than from irradiated fats.

Effects On Major Food Components

Vitamins

- Irradiation of vitamins in solution or in model systems results in a considerable reduction of these micronutrients, but in irradiated foods the effects observed are rarely as marked
- As for other major food components, vitamin losses are affected by the irradiation dose applied, but they can be minimized by treating the food at freezing temperatures or by packaging the product in an inert atmosphere

Effects On Major Food Components

Vitamins

- Other food preservation methods, such as those involving heat, also destroy vitamins, so the effect of ionizing radiation on these minor components is not unique to the irradiation process
- Vitamins can be subdivided into two main groups:
  - Water-soluble,
    - Composed of C, choline, the B vitamins, and folic acid
  - Fat-soluble
    - Include A, D, E, and K

Effects On Major Food Components

Vitamins

Sensitivity of Fat- and Water-Soluble Vitamins to Ionizing Radiation

Most sensitive ⟶ least sensitive

Fat-Soluble Vitamins

Vitamin E ⟶ carotene ⟶ vitamin A ⟶ vitamin D ⟶ vitamin K

Water-Soluble Vitamins

Vitamin B_1 ⟶ vitamin C ⟶ vitamin B_6 ⟶ vitamin B_2 ⟶ folate, niacin ⟶ vitamin B_{12}

Source: Diehl and Josephson (1994).

Toxicological Effects

- Extensive studies have been performed on the potential Toxicological Effects of Irradiation on Foods
- No evidence showing that irradiation of food will generate any measurable toxins have been found
- There are no indications that any food irradiated and stored under conditions prevailing in practice would be at risk of increased formation of mycotoxins
- Effects of irradiation on toxin production in certain bacteria have also been studied and no alarming results were found
- Several attempts to produce toxic strains from nontoxic strains of C. botulinum by means of irradiation have not been successful

Microbiological Effects

- When foods are treated with a nonsterilizing dose of radiation, some microorganisms will survive
- Different species or strains of microorganisms differ in their radiation resistance
- The surviving microflora will therefore differ in composition from the flora present before the radiation treatment

Microbiological Effects

- **Most food poisoning pathogens are quite sensitive to radiation**
  - **A dose of 5 kGy will reduce a population of typical bacteria by a factor of 10^6 (to one millionth of its pre-irradiation level)**

Mutation

- **It is well known that exposure to ionizing radiation can increase the rate of mutation in bacteria and other organisms.**

Microbiological Effects

Mutation

- It is ***conceivable*** that , mutations could spontaneously convert nonpathogenic organisms into pathogenic ones or less virulent strains into more virulent ones, and irradiation could increase the chance of this occurring; HOWEVER,
  - Not only no indication of such an event has ever been observed
  - On the contrary, there has been some reports of loss of virulence and infectivity as a result of radiation treatment - and this has been amply confirmed by more recent studies.

Microbiological Effects

In Summary:

- Irradiation pasteurisation produces definite and large improvements in the microbiological status of foods and feeds, by eliminating most pathogens and extending storage life
- The associated risks seem relatively small and are still not demonstrated
- The balance of advantage to public health seems heavily in favor of such a process, as in heat pasteurization or cooking of food

Example

Effects of Irradiation on Harmful Bacteria In Poultry and Meat Products

- Irradiation doses of 3 kGy were found to eliminate more than 99 percent of food poisoning bacteria such as *Salmonella* spp., *Staphylococcus aureus*, *Listeria monocytogenes*, *Campylobacter jejuni*, and *Escherichia coli* O157:H7 in poultry and fresh meats.

Example

Effects of Irradiation on Harmful Bacteria In Poultry and Meat Products

- Irradiation destroys food poisoning bacteria and other microorganisms by altering the genetic material needed for their growth and reproduction.

Example

Effects of Irradiation on Harmful Bacteria In Poultry and Meat Products

- Irradiation of quality food coupled with good food handling practices would reduce the incidence of foodborne disease.

Conclusions on Chemical Effects, Toxicological, and Microbiological Effects

- Irradiated foods have been found to be safe while maintaining flavor, aroma, and texture (mouthfeel).
- More than 40 years of scientific research has shown that irradiated foods do not cause cancer, genetic mutations, or tumors.
- Irradiation of foods does not result in production of any unknown or unsafe by products.
- According to the International Consultative Group on Food Irradiation (ICGFI), the by-products produced in foods treated with irradiation are naturally present in foods and formed by heat processing.

Conclusions on Chemical Effects, Toxicological, and Microbiological Effects

- The Joint Expert Committee on Food Irradiation (JECFI) of the World Health Organization (WHO), Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA) concluded that irradiated foods were safe and wholesome at irradiation levels up to 10 kGy.
- The BFIFC concluded that a diet consisting of food irradiated at 1 kGy (the approved level for fruits, vegetables, pork, and grains in the United States) would not contain a significant amount of these compounds.
- The irradiation process produces very small changes in the chemical composition of foods. These changes have not been found to be harmful or dangerous.

Next Segment

- Nutritional Aspects
- Wholesomeness
- Labeling

Nutritional, Wholesomeness, and Labeling

Nutritional Quality

- Food proteins, carbohydrates, and fats have been found to be relatively stable to irradiation up to 10 kGy.
- Minerals have also been reported to be stable to irradiation.
- Low-dose irradiation does not cause a significant decrease in the nutritional quality of foods.

Nutritional, Wholesomeness, and Labeling

Nutritional Quality

- Vitamins A, C, E, and B1 (thiamin) tend to be susceptible to irradiation at doses of 1 kGy or above
  - These vitamins are also sensitive to heat processing
  - The reduction of these vitamins in foods is minimal and would not create a risk of deficiency in the diet
  - A joint committee of the FAO, WHO, and IAEA claim that losses of vitamins in foods treated with irradiation doses of 1 kGy or less are minimal and compatible with losses of vitamins in foods heat treated and stored for extended periods of time

Nutritional, Wholesomeness, and Labeling

Nutritional Quality

- The percent of vitamins lost in a food product will depend upon the irradiation dose, the food's composition, temperature of the food being irradiated, and the presence or absence of oxygen.
- Vitamins tend to be more susceptible to irradiation in the presence of oxygen and at temperatures above freezing.
- Therefore, frozen foods are normally vacuum-packed in oxygen-permeable film to minimize loss of vitamins and preserve product quality.

Nutritional, Wholesomeness, and Labeling

Wholesomeness

- **Irradiated foods have been found to be safe and wholesome, while maintaining flavor, aroma, and texture (mouthfeel).**
- **Prior to and during the 1960s, the U.S. Army conducted research on high-dose sterilization of meat products such as ham, corned beef, cooked salami, and turkey.**
  - The army found that these products could be held for many years without refrigeration.
  - After a 10-year safety testing program, including a feeding study with human volunteers consuming 32 to 100 percent of the diet as irradiated food for seven 15-day periods within a year, the army concluded that irradiated foods are **safe and wholesome**.

Nutritional, Wholesomeness, and Labeling

Wholesomeness

- At low and medium doses, it is well established that the nutritional value of proteins, carbohydrates, and fats as macro nutrients are not significantly impaired by irradiation, and neither the mineral bioavailability is impacted.

- The Joint Food and Agriculture Organization (FAO)/International Atomic Energy Agency (IAEA); World Health Organization (WHO) Expert Committee on Food Irradiation (JECFI) has evaluated the very extensive literature on wholesomeness of irradiated food and concluded already in 1980 that "...the irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard, hence, toxicological testing of foods so treated is no longer required," and ". ..irradiation of foods up to an overall average dose of 10 kGy introduces no special nutritional or microbiological problems."

Nutritional, Wholesomeness, and Labeling

Conclusion: Wholesomeness

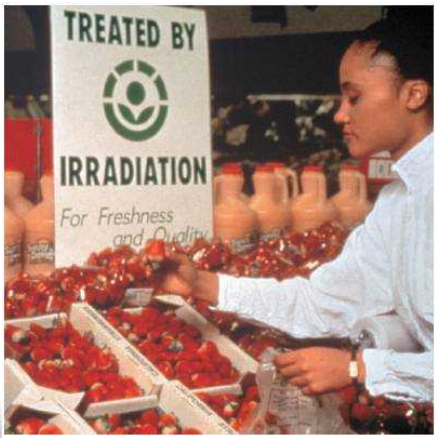
- Wholesomeness (toxicological innocuity, nutritional adequacy, and microbiological safety) of irradiated food has been carefully evaluated by an unprecedented width of research and testing over more than 50 years.

- All scientifically acceptable evidence resulted from these studies supports the safety of irradiated foods for consumption.

Nutritional, Wholesomeness, and Labeling

Labeling

- Legislatory authorities require that irradiated food products be labeled.
- In general, the international food irradiation symbol, the so-called Radura logo is required with a statement that the product has been intentionally subjected to radiation.



- The standard Nutritional Label, as used on Non-Irradiated Food, is placed on the Irradiated Food as well.

CMC Cooperative Monitoring Center

Sandia National Laboratories