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# Irradiation Preservation of Meat and Meat Products and its Effect –A Review

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## ABSTRACT

Radiation processing is one of the emerging technologies to ensure the safety of meat and meat products. Microbial contamination of meat is a serious concern for both meat products and consumers. Irradiation has emerged as an alternate technology to eliminate microbial contamination and several countries have approved it. Wide acceptability of radiation processed meat products will depend upon quality parameters such as oxidative changes and organoleptic attributes. Food irradiation can cause changes in both macro and micro nutrients, but these changes are small. Irradiation is not alone in its ability to produce nutritional changes. Many food processes, notably cooking and heating in general, also cause nutrient loss, often to a greater run. No significant effects on essential amino acids have been observed in beef, fish or many other food stuffs even at sterilizing doses. Irradiation affects flavour and texture of dairy products and eggs. On the whole irradiation of food does not cause nutrient losses to the extent that there could be an adverse effect on the nutritional status of the individuals consuming these foods. Development of shelf stable meat and meat products is a challenging task due to physico-chemical, microbiological and sensory alterations during storage. Lot of thrust is being given in the application of radiation processing in meat sector due to its microbial safety. Maintaining and delivering quality and safety products both in civilian and service sectors is the need of the hour. Even though irradiation can ensure complete microbial sterility it can lead to lipid and protein oxidation due to the formation of free radicals which can cause flavour changes. The adverse implications due to lipid and protein oxidation being observed in meat, poultry products can be suppressed by selecting proper natural antioxidant combinations. Irradiation can be employed as a critical control point in the meat, poultry chain and such an intervention is essential in ensuring the safety of products.

**Keywords:** *Meat, Irradiation, Protein, Lipid Oxidation, Preservation*

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## INTRODUCTION

Radiation processing of food is an emerging, promising, new food safety technology for improving hygiene and increasing storage and distribution life. Ionizing radiation can be used to bring about beneficial changes in food stuffs (Urbain, 1995) and it has been suggested as a method of ensuring the safety of meat products (Patterson and Stevenson, 1995). Ionizing radiation interacts with an irradiated material by transferring energy to electrons and ionizing molecules by creating positive and negativities (Moseley, 1989).

Despite substantial efforts in avoidance of contamination, an upward trend in the number of outbreaks of food-borne illnesses caused by non-spore forming pathogenic bacteria are reported in many countries. Good hygienic practices can reduce the level of contamination but the most important pathogens cannot presently be eliminated from most farms nor it is possible to eliminate them by primary processing, particularly from those foods which are sold raw. Though there are several decontamination methods in practice but the most versatile treatment among them is processing with ionizing radiation. Decontamination of food by ionizing radiation is a safe, efficient, environmentally clean and energy efficient process. Irradiation is particularly valuable as an end product decontamination procedure. Radiation treatment at doses of 2–7 kGy, depending on the condition of irradiation and the food can effectively eliminate potentially pathogenic non-spore forming bacteria including both long-time recognized pathogens such as *Salmonella* and *Staphylococcus aureus* as well as emerging or 'new' pathogens such as *Campylobacter, Listeria monocytogenes* or *Escherichia coli* O157:H7 from suspected food products without affecting sensory, nutritional and technical qualities.

Candidates of radiation decontamination are mainly poultry and red meat, egg products, and fishery products. It is a unique feature of radiation decontamination that it can also be performed when the food is in a frozen state. With today's demand for high-quality convenience foods, irradiation in combination with other processes holds a promise for enhancing the safety of many minimally processed foods. Radiation decontamination of dry ingredients, herbs and enzyme preparations with doses of 3–10 kGy proved to be a viable alternative to fumigation with microbicidal gases. Radiation treatment at doses of 0.15–0.7 kGy under specific conditions appears to be feasible also for control of many food borne parasites, thereby making infested foods safe for human consumption. Microorganisms surviving low and medium-dose radiation treatment are more sensitive to environmental stresses or subsequent food processing treatments than the microflora of unirradiated products. Radiation treatment is an emerging technology in an increasing number of countries and more-and-more clearances on radiation decontaminated foods are issued or expected to be granted in the near future.

The recent advancement in the applications of radioisotopes and radiation technologies in various areas like medicines, industry, agriculture and research have enhanced the peaceful uses of atomic energy and improved the quality of life in many spheres. Radiation sterilization of medical products and food preservation by irradiation are two most important application of nuclear energy. However, many people are still unaware of these developments and unfortunately, quite a number of people also have misconceptions

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and apprehensions regarding the use of radiation. It is absolutely necessary to create awareness among the general public about the beneficial application of the radioisotopes and radiation technology. Radiation processing has become a commercial activity in the health care sector. This technology is equally applicable to the processing of food and food products in a safe and wholesome manner. This radiation processing technology has been investigated and demonstrated for nearly five decades by the food scientists and technologists throughout the world. It is quite essential to clarify unambiguously that in no circumstances can radiation processing using Cobalt-60 radiation include radioactivity and naturally leave residual radioactivity in the material being processed. To this extent, the word irradiation, which might otherwise create some doubt because of the connotations, is replaced by the word radiation processing.

Radiation processing of food involves exposure of food to short wave energy to achieve a specific purpose such as extension of shelf-life, insect disinfestation and elimination of food borne pathogens and parasites. In comparison with heat or chemical treatment, irradiation is considered a more effective and appropriate technology to destroy food borne pathogens. It offers a number of advantages to producers, processors, retailers and consumers.

## PROCESS OF IRRADIATION

Ionization radiation interacts with an irradiated material by transferring energy to electrons and ionizing molecules by creating positive and negative ions (Moseley, 1989). The irradiation process involves exposing the food, either prepackaged or in bulk, to a predetermined level of ionizing radiation.

Radiation processing of meat is a controlled exposure of meat to ionizing radiation such as gamma rays, electrons and X-rays. Radioisotopes such as Cobalt-60 and Cesium-137 emit gamma rays while electrons and X-rays are generated by machines sources. Packaged meat is exposed to effective doses of ionizing radiation so that pathogens and spoilage organisms can be destroyed. Ionizing radiations inactivate microbes by damaging nucleic acids. This damage occurs directly as a result of electron and photon contact with DNA and RNA as well as indirectly through the action of charged ions further reacting with the nucleic acid. The radiation effects on biological materials are direct and indirect. Ionization radiation interacts with an irradiated material by transferring energy to electrons and ionizing molecules by creating positive and negative ions. The irradiation process involves exposing the food, either prepackaged or in bulk, to a predetermined level of ionizing radiation.

The radiation effects on biological materials are direct and indirect. In direct action, the chemical events occur as a result of energy deposition by the radiation in the target molecule, and the indirect effects occur as a consequence of reactive diffusible free radicals forms from the radiolysis of water, such as the hydroxyl radical (.$OH^-$), a hydrated electron (e-aq), a hydrogen atom, hydrogen peroxide ($H_2O_2$) and hydrogen (Moseley, 1989).

***Direct effect:*** In direct action the chemical events occur as a result of energy deposition by the radiation in the target molecule. Since atomic bonds are shared electron orbital, direct effect of ionising energy results in the fracture of bonds that hold the pathogen's DNA together resulting in DNA strand breaks (Fig.1). There could be single strand breaks that occur in the sugar phosphate backbone of the individual polynucleotide strand or double strand breaks in adjacent or near adjacent in both the polynucleotide strands. Base damage or intermolecular cross-links or intermolecular cross-links are also observed when isolated DNA is exposed to gamma radiation.

***Indirect effect:*** Indirect effect is caused by secondary electrons and free radicals formed due to interaction of radiation with water and other cell constituents. Radiolysis of water also plays an equally important role in the destruction of bacteria. Radiolysis of water results in a number of products such as hydroxyl radicals (.$OH^-$), hydrated electron (e-aq), hydrogen atoms, hydrogen molecule ($H_2$), Hydrogen peroxide ($H_2O_2$) and hydrated protons ($H_3O^+$). Hydrogen peroxide is a strong oxidizing agent and a poison to biological systems, while the hydroxyl radical is a strong oxidising agent and the hydrogen radical a strong reducing agent. These two radicals can cause several changes in the molecular structure of organic matter (Graham, 1980).

Damage to DNA caused by the interaction of these species disables the organism to grow or multiply. Like other food preservation methods such as cooking and canning, the loss of electrons from atoms also creates charged ions or ''free radicals". These ions are highly reactive and although most combine harmlessly back into the same form as they were originally. It will react with the DNA

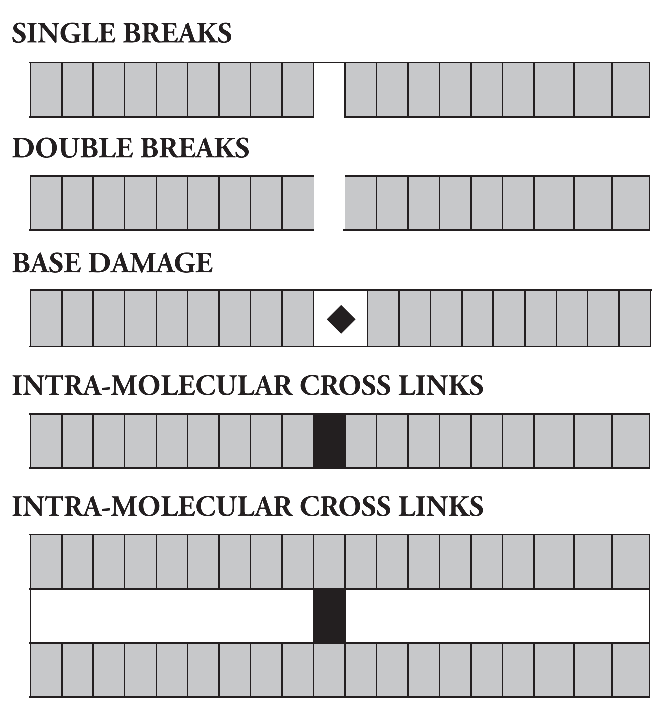


Fig-1: Diagrammatic representation of major types of damage to the isolated DNA after irradiation strands, thereby further damaging the nucleic acid and rendering the expression of complete DNA impossible. All of the free ions and electrons created by the process react with other atoms very quickly and so do not remain in the product. Free radicals also occur naturally during bread toasting, cooking, freeze-drying and from the normal oxidation process in food and living system. The sensitivity/ resistance of micro organisms to gamma radiation depend upon the environmental conditions. Oxygen enhances the radio sensitivity of bacterial cell. Radio sensitivity of bacteria also depends upon the dose rate, the water content, medium and temperature. It also depends upon the type of bacterium and its phase of growth.

## SOURCES OF IONIZING IRRADIATION

There are two classes of ionizing radiation: electromagnetic and particulate. They include γ-rays from radionuclides 60Co and 137Cs, X-rays generated from machine sources operated at or below 5 MeV, and electrons generated from machine sources operated at or below an energy level of 10 MeV (Loaharanu & Murrell, 1994). The characteristics of different irradiation sources are summarized in Table 1. Mitchell (1994) stated that although both isotopic and machine sources have identical impact on foods, consumers would react more favorably to machine sources than isotope sources because of the association of isotopes with the nuclear industry. All three sources require a large plant for economic viability. Much of the high cost of irradiation is associated with the need for heavy concrete shielding to protect the external environment when the source is in use. In addition, the plant must comply with hygiene and safety legislation relevant to such plants (Kilcast, 1995).

**Table 1: Characteristics of irradiation sources**

| Radiation Source | Characteristics |
|---|---|
| Cobalt-60 | 1. High penetrating power |
| | 2. Permanent radioactive source |
| | 3. High efficiency |
| | 4. Source replenishment needed |
| | 5. Low throughput |
| Electron breams | 1. Low penetrating power |
| | 2. Switch on-switch off capability |
| | 3. High efficiency |
| | 4. High throughput |
| | 5. Power and cooling needed |
| | 6. Technically complex |
| X-rays | 1. High penetrating power |
| | 2. Switch on-switch off capability |
| | 3. Low efficiency |
| | 4. High throughput |
| | 5. Power and cooling needed |
| | 6. Technically complex |

Source: Kilcast, 1995.

## EFFECTS OF IRRADIATION

***Effects on micro organisms:*** Ionization irradiation affects micro organisms, such as bacteria, yeasts and molds, by causing lesions in the genetic material of the cell, effectively preventing it from carrying out the biological processes necessary for its continued existence (Murano, 1995). The principal targets are nucleic acids and membrane lipids. Alteration in membrane lipids, particularly polyunsaturated lipids, leads to perturbation of membranes and to deleterious effects on various membrane functions, such as permeability. The activity of membrane-associated enzymes may be affected as a secondary effect of membrane lipid degradation (Willemoti *et al.,* 1996). Ionization radiation acts through changes induced in the DNA structure of the irradiated cells, which results in prevention of replication or function (Loaharanu and Murrel 1994). The energy levels used are sufficient to disrupt certain bonds in the molecules of DNA, thereby making cell reproduction impossible (Mitchell 1994). Nucleic acids, because of their large size, are the main targets of free radicals generated by irradiation (Willemoti *et al.*, 1996). Chromosomes of bacteria are intrinsically very sensitive, and lethal damage occurs as a result of exposure to irradiation. The ability of bacteria to repair a limited amount of such damage gives them considerably greater resistance to such radiation. The efficiency with which different bacteria repair the radiation induced damage to their DNA varies considerably. The most sensitive vegetative bacterium is Pseudomonas, and the most resistant one is Deinococcus by a factor of about 100 (Moseley 1989).

Murano (1995) reviewed the factors that affect the susceptibility of micro organisms to irradiation like dose level, temperature, atmosphere, medium and type of organism. In general, the higher dose applied, the lower the number of survivors and the lower the temperature and the rate of reactions such as the formation of radicals from water molecules. These radicals can affect cells indirectly by interfering with normal cellular functions such as membrane transport. If the product is frozen, radical formation is practically inhibited (Murano 1995). The D value increased from 0.16 kGy at 5°C to 0.32 kGy at -30°C when *Campylobacter jejuni* was inoculated into ground beef. In general, bacteria become more resistant to ionization radiation in the frozen state as well as in the dry state. In either state it is assumed that the contribution of indirect effects from the radiolysis of water is significantly reduced (Moseley, 1989). Off-flavour development in products irradiated in a dry state is less pronounced than that in moist products due to the low formation of free radicals at reduced moisture content (Graham, 1980). Irradiation may have an effect, but this may only occur under specific conditions (Murano, 1995). The composition of the irradiating medium will affect the survival of micro organisms. As a general rule, the simpler the life form, the more resistant it is to the effects of irradiation. For instance, viruses are more resistant than bacteria, which are more resistant than molds, which are more resistant than human beings. Also, some genera of bacteria are more resistant than others. Bacterial spores are more resistant than their corresponding vegetative cells by a factor of about 5-15.

Low dose irradiation (<1kGy) offers a unique opportunity for controlling the infectivity of food-borne parasites without changing the character of the food. Among the groups of food-borne parasites, trematodes appear to be the most sensitive to irradiation, followed by cestodes and protozoa (Loaharanu & Murrel, 1994).

Enzymes in foods must be inactivated prior to irradiation because they are more radiation resistant than micro organisms. Usually, enzyme inactivation is accomplished thermally. Generally, it may be said that complete inactivation of enzymes requires about 5-10 times the dose required for the destruction of micro organisms (Graham, 1980). The D-values of enzymes can be 50 kGy, and almost four D-values would be required for complete destruction. Thus, irradiated foods will be more susceptible to enzymatic attack than non-irradiated foods (Graham, 1980). High resistance of enzymes to irradiation has been demonstrated with milk phosphatase, which was not destroyed by irradiation doses sufficient to sterilize milk. Enzymes are affected by the indirect effects of the formation of free radicals in solvent phase, thus dilute solutions of enzymes are relatively more sensitive to irradiation than the concentrated solutes. Moreover, enzymes in their natural environments, as in foods, are relatively resistant (Graham, 1980). The activity of enzymes is unaffected at normal doses, and thus it limits the achievable shelf life extension of fruits and vegetables (Kilcast, 1995).

Contamination of foods, especially of those of animal origin, with micro organisms, particularly pathogenic non-spore forming bacteria, parasitic helminths and protozoa is an enormous public health problem and important cause of human suffering all over the world. Pathogenic micro organisms are frequently found also in some food ingredients.

In spite of all past efforts in avoidance of contamination, relatively high percentages of foods of animal origin are contaminated with potentially pathogenic bacteria, resulting in increasing food infections and food borne illness in many countries (Kaferstein 1992). Considering the tremendous importance of microbial and parasitic diseases related to foods, food safety should be guaranteed at the retail and possibly at the consumer level and preventive programmes should receive a high priority, including development and implementation of better food processing technologies. Elimination or reduction of food borne pathogens in foods is especially important to people with compromised immune systems, such as the elderly, AIDS patients and others. While thermal pasteurization of liquid foods is well established and satisfactory as a decontamination treatment of such commodities, it does not suit solid foods and dry ingredients well.

The chemical sanitizing procedures have inherent problems concerning residues and environmental pollution. This is where food irradiation among the other intervention alternatives (Corry *et al.,* 1995) comes into the picture. By irradiation, the use of ionizing radiations - either gamma rays from radionuclides such as Co or Cs, or high energy electrons and X-rays produced by machine sources is meant. In conjunction with good manufacturing practices, its well established safety and freedom from residues create a solid scientific background for implementation of radiation processing of specific food products as an effective means to improve safety of our food supply (WHO 1994, Diehl 1995, Wilkinson & Gould 1996). The simultaneous reduction in number of the non-pathogenic spoilage microflora by the same radiation treatment results in the concomitant extension of non-frozen (fresh or defrosted) edible / marketable life of radiation decontaminated high-moisture foods (Urbain, 1986). The benefits of irradiation also include the fact that products can be processed in the package, as a terminal treatment, eliminating the possibility of contamination until it is removed from it and ready to be used. Radiation can inactivate organisms in foods that are in the frozen state, without thawing them up.

## Effects on Food Components

***Changes in Lipids:*** Ground beef has high lipid content. Regulation states that regular type meat should contain a maximum of 30% fat, lean type 23% and extra-lean type 17% (Lefevre, 1994). Animal fats predominantly contain neutral lipids (triglycerides), phospholipids, sterols and sterol esters, with other lipids in small quantities when detectable. Typical composition of ground beef is about 18% lipids and its fatty acid content is divided into 46% saturated, 51% mono-unsaturated and 3% poly-unsaturated (Johnson *et al.,* 1994). Dugan (1987) showed that the usual fatty acids found in beef, in order of importance, are oleic acid (18:1), palmitic acid (16:0), stearic acid (18:0), palmitoleic acid (16:1), linoleic acid (18:2), linolenic acid (18:3) and arachidonic acid (20:4). Saturated and mono-saturated fatty acids represent the essential content of neutral lipids in meat. These neutral lipids contain approximately 14% linoleic acid (18:2) which is an essential, polyunsaturated fatty-acid. Phospholipids represent 0.5 to 1% of the total lipids in meat. They contain a great amount of unsaturated fatty acids and some of them are polyunsaturated. Polyunsaturated fatty acids of the phospholipid fraction were the major contributors to the development of rancidity during meat storage (Igene and Pearson, 1979). The only sterol found in meat is cholesterol (Schweigert, 1987).

Some of the fatty acids found in meat play important roles in metabolism. Polyunsaturated fatty acids such as linoleic and arachidonic acids are of great nutritional importance being essential to the human diet as they cannot be synthesized within the body. Phospholipids and cholesterol also are of nutritional consideration being critical components of cell walls. Unsaturated fatty acids are also well known to carry fat-soluble vitamins, e.g. vitamin A, D, E and K (Schweigert, 1987).

Since polyunsaturated fatty acids are oxidized rapidly, precautions must be taken during the irradiation treatment. Oxidative and non-oxidative changes in lipids can be observed. Ionizing radiation causes the radiolysis of water which is present in a great extent in meat. This generates free radicals such as $.OH^-$, hydrated electron and $H^+$. Chemical reactions with food constituents are then brought out by these free radicals. Studies show that the amount of radiolysis products vary as a function of fat content and fat composition as well as a function of the temperature during irradiation and the irradiation dose (Merritt *et al.,* 1978).

The most susceptible site for free radical attack in a lipid molecule is at a double bond. The most affected lipids during irradiation are thus the polyunsaturated fatty acids that bear two or more double bonds available for reaction. It has been concluded that each additional double bond in a fatty acid increases its rate of oxidation by a factor of two (Singh *et al.,* 1991). Love and Pearson (1971) along with Hassan and Shams El-Din (1986) showed that unsaturated fatty acids in the phospholipid fraction oxidized more rapidly than the ones in the neutral lipid fraction. Hassan et al., (1988) also observed a decrease in unsaturated fatty acids with an increase in the irradiation dose and prolongation of the storage period. Hassan and Shams El-Din (1986) reported that the loss of unsaturated fatty acids after an irradiation treatment was mainly due to oxidative decay.

In the presence of oxygen, polyunsaturated fatty acids undergo autoxidation. Autoxidation is a chain process that can be initiated by various free radicals from different sources including ionizing radiation. This process occurs in two steps with phospholipids being oxidized first followed by the neutral lipids (Pearson *et al.,* 1983). The general reaction occurs in three phases which are initiation or formation of free radicals, propagation or free radical chain reaction and termination or formation of non-radical products. The free radicals can react with oxygen over an extended period causing the formation of hydroperoxides which will yield a great variety of compounds like alcohols, aldehydes, aldehyde esters, hydrocarbons, hydroxy and keto acids, ketones, lactones, oxoacids and dimeric compounds (Pearson *et al.,* 1983).

Lipid peroxidation in muscle foods is one of the major degradative processes responsible for loss of meat quality. It leads to the formation of warmed over flavors, destruction of essential fatty acids and some of the fat soluble vitamins (Singh *et al.,* 1991). It would be good to note that the path of by-product formation from lipids followed by ionizing radiation induced autoxidation is the same that as natural autoxidation (Francis and Wood, 1982). Normally, lipid oxidation should be greater in air. Experiments on chicken packaged under air or vacuum showed little difference upon irradiation of samples (Singh *et al.,* 1991). This suggests that at low radiation dose, the lipids in presence of their natural protectors are not particularly sensitive to radiation induced peroxidation (Singh *et al.,* 1991). The literature also shows that the nature of radiolysis of lipids is basically the same and the products formed are similar regardless of the dose or the source of energy (Hammer & Wills, 1979).

Changes in lipids caused by irradiation in the absence of oxygen are decarboxylation, dehydration and polymerization. Radiolytic products in that case include $CO_2$, CO, $H_2$, hydrocarbons and aldehydes. Hydrogenation of unsaturated fat is the process which leads to dimer formation. The general mechanism for the non-oxidative radiolysis of triglycerides involves cleavage at preferential locations in the lipid molecule and randomly at the remaining carbon to carbon bonds. This scission of the fatty acid molecules gives rise to free radicals which mainly add hydrogen to other molecules or to a lesser extent loose hydrogen or combine with other free radicals. Stable radiolytic products are thus formed with their composition being related to the composition of the initial lipid molecule. The possible radiolytic products of triglycerides included $C_n$ fatty acid, propanediol diesters, propenediol diesters, $C_n$ aldehyde, diglycerides, oxo-propanediol diesters, 2-alkylcyclobutanones, $C_{(n-1,\ n-2)}$ alkane, $C_{(n-1,\ n-2)}$ 1-alkene, formyl diglycerides, acetyl diglycerides, Cn fatty acid methyl ester, ethanediol diester, $C_{n-x(x\ ^3\ 3)}$ hydro-carbons (Delincee, 1983, p.89). The amount of product generated depends on the irradiation dose and is generally small (Singh *et al.,* 1991).

The volatile compounds isolated from the radiolysis of beef fat are alkenes and alkanes with acetone and methyl acetate as carbonyl compounds (Merritt *et al.,* 1978). Alkanes and alkenes are the most abundant representing 95% of the volatile substances formed by lipid radiolysis. Carbonyl compounds will also be recovered after irradiation. It is generally recognized that free fatty acids result from the cleavage of neutral lipids or phospholipids. Free fatty acids are not harmful to animals and do not lower the quality of fats except for a slight reduction in absorbability of long-chain free fatty acids like palmitic and stearic acids (Fuller, 1982). It would be good to note that the hydrocarbons are formed by the cleavage of neutral lipids (Merritt, 1972). However, low dose irradiation (3 kGy) generates relatively low quantities of hydrocarbons (Lacroix *et al.,* 1997).

Different studies on meat irradiation and its effect on lipids have been done in the past years. Studies done on chicken by Rady *et al.,* (1987) showed no significant difference in total saturated and unsaturated fatty acids between irradiated (1, 3, 6 kGy) and unirradiated frozen (-20$^{o}$C) chicken muscle. Therefore, within the levels of detectability by flame ionization-gas chromatography, no fatty acids formed by radiolysis could be detected at the doses used, and the radiolytic alteration to the composition of the natural fatty acids was virtually undetectable. A feeding experiment conducted on humans by Plough *et al.,* in 1957 showed that overall digestibility of pork fat, whether it was irradiated or not, was unaffected. This indicates that lipolysis and absorption of end products is not seriously disrupted (Josephson *et al.,* 1978). Rady and Schwartz (unpubl.report) showed that the free unsaturated fatty acid and saturated fatty acid content of meat was increased after treatment with a dose of 1 kGy irrespective of the presence or absence of air. Only minor changes were noted when increasing the dose up to 10 kGy.

Analysis of free fatty acids in irradiated ground beef during storage indicated that the irradiation treatment did not affect their production (Lefevre *et al.,* 1994). In fact, the lipolytic enzymes involved in the endogenous hydrolysis of neutral lipids and phospholipids are not fully inactivated by an irradiation dose of 50 kGy (Urbain, 1986). Monty (1960), Moore (1961) and Nassett (1957) reported that 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. From the literature, we can conclude that when lipids are irradiated under conditions anticipated for commercial food processing (£7 kGy), it does not result in significant loss of nutritional value (Thomas, 1988).

Irradiation initiates the normal process of auto-oxidation of fats which gives rise to rancid off-flavors. Highly unsaturated fats are more readily oxidized than less unsaturated fats. This process can be slowed by elimination of oxygen by vacuum or modified atmosphere. In lipids, particularly unsaturated fatty acids, radiolytic decomposition occurs via a preferential break at the level of the carbonyl function of the double bond. This decomposition induces the formation of some volatile compounds responsible for off-odors. The formation of peroxides and volatile compounds and the development of rancidity and off-flavors have been reported. The peroxide formed can also affect certain labile vitamins, such as vitamins E and K.

Lipids in cereals degraded only high doses of irradiation, and no significant effects on iodine value, acidity, or color intensity of wheat flour lipids was observed. At 10 kGy, a 20% increase in total free lipids and a 46% decrease in bound lipids were observed. Lipid-protein complexes, which are critical in baking, were not noticeably affected at low doses upto 2 kGy.

The volatile oil content of spices has a dose-dependent reduction effect in black pepper and ginger above 6kGy. Similar reduction was also observed in Ashanti pepper berries when 47 essential oil compounds were analyzed individually at a dose of 10kGy.

On irradiation of lipids, the primary effect of incident energy leads to the formation of cation radicals and excited molecules.

$$H_2\text{-O-CO-}(CH_2)_nCH_3 \longrightarrow (RCH_2\text{-O - CO - }(CH_2)_nCH_3)^{\cdot +} + e^- \quad \textbf{ionisation}$$

$$H_2\text{-O-CO-}(CH_2)_nCH_3 \longrightarrow (RCH_2 - O - CO - (CH_2)_nCH_3)^* \quad \textbf{excitation}$$

The general mechanism of radiolysis of lipids is thought to involve primary ionization, followed by migration of the positive charge either towards the carboxyl group or double bonds. Some sixteen free radicals have been postulated to be preferentially produced by cleavage of bonds in the vicinity of the carbonyl group (Stewart, 2001). These may then engage in a number of reactions involving abstraction, dissociation, recombination, disproportionate and radical molecule interactions leading to the formation of stable products (Delincee, 1983). Products formed include hydrocarbons, aldehydes and ketones and these are considered important volatiles related to the off-odour production in irradiated meat. If oxygen is present during or after irradiation normal autoxidation is accelerated (Katusin-Razem *et al.,* 1992). The formation of peroxides and volatile compounds and the development of rancidity and off-flavours have been reported by Merritt *et al.,* (1975). The peroxide formed can also affect certain labile vitamins, such as vitamins E and K (Graham, 1980). Irradiation induced oxidative chemical changes are dose dependent.

Irradiation treatment is not effective in stopping the changes in meat that diversely affect consumer acceptance, such as oxidation of pigment to yield brown or grey discolouration, drip loss from the cut surface of lean tissue, and oxidation of meat lipids which causes off-flavours, by atmospheric oxygen (Mitchell, 1994). Prevention of oxidative rancidity in irradiated meat.

Oxidative rancidity in irradiated meat can be minimised / retarded by various means. The most obvious precaution to take against oxidative deterioration is removal of air. Vacuum packaging and modified atmosphere packaging (MAP) of meat is very effective in controlling oxidative rancidity (Lambert *et al.,* 1992, Stapelfeldt *et al.,* 1993). However, the usefulness of vacuum packing is limited by the product characteristics. Also meat packed in modified atmosphere increases the pack volume and different gas formulations are required for each product (Gould, 1995). Freezing of meat can considerably slow down the rate of oxidative rancidity. However freeze thawing, temperature abuse in handling and distribution and/or prolonged storage can accelerate lipid oxidation. Antioxidants are one of the principal ingredients that protect meat quality by preventing oxidative deterioration of lipids (Shahidi & Wanasundara 1992; Pokorny *et al.,* 2000). They can interfere with the oxidation process by reacting with free radicals, chelating catalytic metals and also by acting as oxygen scavengers. There is an increasing demand for naturally occurring antioxidants because they are presumed to be safe since they occur naturally in food.

***Changes in Proteins:*** Proteins are built with amino acids which are the essential nutrients although many think that the proteins are. Of the 20 amino acids, nine are essential and must be provided in the diet since they are not synthesized in sufficient amount by the human body. The nutritional quality of a protein directly refers to its ability to provide the nine essential amino acids in quantity required to the health of man. The amount of essential amino acids in the crude protein of beef is approximately as follows: 8.4% leucine, 8.4% lysine, 5.7% valine, 5.1% isoleucine, 4.0% phenylalanine, 4.0% threonine, 2.9% histidine, 2.3% methionine and 1.1% tryptophan. Non essential amino acid content in order of importance is glutamic acid, aspartic acid, glycine, arginine, alanine, proline, serine, tyrosine and cystine (Schweigert and Payne, 1956). It should also be pointed out that meat containing a large amount of connective tissue is rich in collagen. The amino acid content of collagen is principally proline, hydroxyproline, glycine, tryptophan, tyrosine and a small amount of sulfur-containing amino acids (Bowes & Moss, 1962).

Because of the importance of proteins to human health, the effect of irradiation on this food constituent is of interest. Similar to lipids, protein damage due to irradiation is catalyzed by free radicals formed by the radiolysis of water. 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) (Diehl, 1990), reduction of disulfide linkages, oxidation of sulfydryl groups, breakage of peptide bonds and changes of valency states of the coordinated metal ions in enzymes (Delincee 1983, pp. 129-146). The prevalence of ammonia and pyruvic acid production indicates that deamination plays a greater role than decarboxylation (Diehl, 1990). That range of possible chemical and physical changes is similar to that seen with other treatments of food material (Singh *et al.,* 1991).

Major products formed by the interaction of radiation with protein material are carbonyl groups, ammonia, free amino acids, hydrogen peroxide, organic peroxides and more. At high doses, some cross links can occur leading to the formation of new proteins by the bonding of free amino acids to proteins and protein to protein aggregation (Singh *et al.,* 1991, Brault *et al.,* 1997, Lacroix et al., 1998, Mezgheni *et al.,* 1998, Ressouany *et al.,* 1998). Protein to lipid cross-linking can also be seen (Singh *et al.,* 1991). These chemical changes are all affected by the structure and state of the protein and by the conditions of irradiation such as the dose, dose rate, temperature and presence of oxygen. Changes stated here mostly affect the primary structure of the protein but many studies indicate that irradiation is a major process by which the secondary and tertiary structures are affected. The folding pattern changes are brought about by aggregation due to cross-linking among peptide chains or denaturation through the breaking of hydrogen bonds and other linkages involved in the mentioned foldings. To some extent, the particular effect of radiation is related to the 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 (Davies 1987; Davies & Delsignore,

***Oxidation of amino acids by irradiation:*** Amino acids inside a protein are less labile to irradiation than free amino acids. The effect of irradiation on aliphatic and aromatic amino acids differs. For aliphatic amino acids, irradiation in the presence of oxygen will lead to the formation of ammonia and alpha-ketoacids, or to the formation of ammonia, carbon dioxide and an aldehyde or a carboxylic acid. The yield of expected oxidation products decreases linearly as a function of the number of carbon atoms present in the aliphatic side chains. This is explained by the fact that the more carbon atoms are present, the more sites for attack by an $OH^-$ radical are available. If oxygen is not present, this may suppress the generation of peroxy radicals and thus favor deamination or combination interactions forming some amino dicarboxylic acid derivatives (Stadtman, 1993).

Sulfur containing amino acids 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. Oxidation of phenylalanine produces tyrosine and hydroxy derivatives. Oxidation of tyrosine produces 3,4-dihydroxyphenylalanine (dopa). Tryptophan produces formylnurenine. Alpha-hydrogen abstraction and deamiation are minor events (Stadtman, 1993). It has been noted that further oxidation of dopa produces cross-linking reactions which provoke melanin type pigment formation (Ley *et al.,* 1969).

The products formed from sulfur-containing amino acids in proteins include methyl or ethyl mercaptan, dimethyl disulfide, carbonyl sulfide or hydrogen sulfide. 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 (Delincee 1983, pp. 129-146). The typical odor of irradiated meat is related to the formation of sulfuric compounds. The most radiation sensitive amino acids are in fact the ones bearing sulfur notably cystine, methionine and tryptophan. Desulfuration must thus be considered as one of the principal effect of ionizing radiation on amino acids and proteins (Singh *et al.,* 1991).
According to Rhodes (1966), when the amino acid content of beef protein was tested before and after irradiation at 0±1°C, no significant destruction of meat amino acids was observed up to a dose of 200 kGy. Partmann and Keskin (1979) showed that the majority of amino acids in minced lean beef or pork and chicken breast muscle are stable up to a dose of 5 kGy. Josephson et al., (1978) indicated that there was no significant destruction of cystine, methionine and tryptophan up to a dose of 71 kGy. It would be good to note that the loss of lysine by irradiation at 70 kGy is negligible and that an increase is even detected (Ley et al., 1969). In comparison, cooking can generate up to 40% loss in lysine which is an essential amino acid (Harris 1987).

***Oxidation of proteins by irradiation:*** In the case of proteins, the presence or absence of oxygen has a large effect on the products recovered. The major player in irradiation damage to proteins is $.OH^-$. In the presence of oxygen, little or no aggregation occurs but fragmentation of the polypeptide chain is basically the rule. When gamma irradiation is conducted under ambient conditions, proteins are seen to fragment with increasing dose showing that even 20% oxygen is enough to produce fragmentation reactions. Exposure to $OH^-$ in the presence of oxygen generally produces a dispersed pattern of lower molecular weight protein fragmentation products. Fragmentation appears to occur predominantly at the alpha carbon rather than at the peptide bond (Davies, 1987). Fragmentation is again the result of the action of oxygen free radicals and of secondary reactions leading to the formation of alkyl peroxides or hydroxy derivatives. Oxidation-mediated cleavage of the polypeptide is believed to occur by alpha-amidation mechanism. This reaction is catalyzed by decomposed peroxy intermediates. The N-terminal amino acid of proteins may be submitted to deamination releasing ammonia (Stadtman, 1993).

When oxygen is absent during irradiation, there is almost no fragmentation of the proteins but larger amounts of high molecular weight aggregates are formed. Exposure to $.OH^-$ without $O_2$ induces aggregation of proteins to higher molecular weight forms like dimers, trimers and even tetramers. This aggregation reaction seems to involve intermolecular bityrosine formation. Analyses indicate that 90% of the protein aggregates induced by $.OH^-$ can be attributed to new intermolecular covalent bonds (not S-S bonds). Less than 10% of the aggregation products can be considered as non covalent interactions or disulfide bonds (Davies *et al.,* 1987). Although fragmentation or aggregations are routes well separated by the presence or absence of oxygen, both processes are preceded by the denaturation of the protein. The $.OH^-$ induced alteration of the primary structure lead to the modification of the secondary and tertiary structure and the protein now unfolded in a random conformation is more susceptible to a secondary attack by the $.OH^-$ radical leading to fragmentation or aggregation (Davies, 1987, Davies and Delsignore, 1987).

Since proteins are not destroyed but only transformed by radiolysis, the total amino acid content of meat is not changed (Anon, 1973). A study done on the digestibility of raw beef sterilized by irradiation (20-40 kGy) shows that the true digestibility of proteins remains 100% and that the apparent digestibility is even enhance by 0.5% (91.8-92.3%) (Johnson & Metta 1956). Long-term feeding studies with rats have also shown that the use of irradiation for the sterilization and preservation of meat does not have a significant effect upon the nutritional quality of the meat protein (Schweigert, 1987). Reviews by the Gallien *et al.,*. (1985) and Thayer (1987) indicate that irradiation of meat at typical commercial doses (2-7 kGy), has no significant effect on the nutritional value of proteins or amino acids. No distinct decrease of the biological value of proteins was observed (Anon, 1973). Frumkin *et al.,* (1973) also concluded that irradiation of raw and prepared meat, to prolong shelf-life, does not lead to a reduction of its protein nutritional value.

Meat contains connective tissue and the effect of gamma irradiation on collagen is thus of concern. Properties of irradiated collagen were studied under low and high moisture conditions. Irradiation at doses of 50 and 500 kGy resulted in loss of crystallinity, increase in solubility and other changes in physical properties, indicative of extensive loss of molecular structure and breakdown to smaller units. Little hydrolytic scission of peptide bonds occurred, but increase in amide nitrogen and carbonyl groups indicated that N-C bonds were broken. At the 500 kGy dose, some loss in nitrogen, and an overall loss of 10 to 20% amino acids was noted (Bowes and Moss, 1962).

Myosin is one of the most important proteins in muscles. Taub (1981, 1983) showed that at sterilization doses and low temperature, there was only a minor effect on myosin. Zabielsky *et al.,* (1984) suggest that myosin solubility goes down with increasing irradiation dose up to 10 kGy, resulting in reduced water holding capacity. Latreille *et al.,* (1993) observed that a study of the electrophoretic pattern of irradiated meat proteins indicated a decrease of myosin band with dose and dose rate of gamma irradiation done at 4°C. Lacroix *et al.,* (1992) demonstrated that meat irradiated at 6 kGy, under vacuum and at low dose rate (2 kGy/ h), seemed less affected by the treatment and remained more stable during storage. The emulsifying capacity of the irradiated proteins was higher than the control product. The hydrolysis of proteins in smaller fractions of lower molecular weights could be at the origin of this emulsifying capacity increase.

The effects of irradiation on the nutritional qualities of foods are reviewed by Graham (1980). Low doses of irradiation may cause molecular uncoiling, coagulation, unfolding, even molecular cleavage and splitting of amino acids. Apparently peptide linkages were not attacked, and the main effects were concentrated around sulfur linkages and hydrogen bonds (Graham, 1980). The sequence of protein bonds attacked by ionizing radiation is as follows: $-S-CH_3-SH$, imidazol, indol, alpha-amino, peptide, and proline. At 10 kGy radiation, overall increase in total free amino acids was observed mainly due to a rise in the levels of glycine, valine, methionine, lysine, isoleucine, leucine, tyrosine and phenylalanine. Irradiation is thought to bring about unfolding of the protein molecule, leading to the availability of more reaction sites.

Irradiation also affects the functional properties of proteins. In eggs, the doses required for effective Salmonella reduction have undesirable side effects, such as loss of viscosity in the white and off-flavors in the yolk (Kilcast, 1995). Eggs irradiated with 6kGy become thin and watery, possibly due to the destruction of alteration of ovomucin, the main thickening compound of egg albumin. Irradiation of milk resulted in an increase in rennet coagulation time and reduced heat stability (Graham, 1980).

Off-flavor development at high radiation doses is due to the presence of benzene, phenols, and sulfur compounds formed from phenylalanine, tyrosine and methionine respectively. Flavor changes and off-flavor resembling a burnt flavor were observed in irradiated milk (Graham, 1980). Irradiation of cheese usually produces smoky off-flavors. Irradiation of soft cheeses at doses of 1-2kGy is sufficient to reduce food pathogens and does not impair flavor quality, thus dose regulation is certainly the key for preventing off-flavour development (Kilcast, 1995).

***Changes in Carbohydrates:*** Irradiation can break high molecular weight carbohydrates into smaller units, leading to depolymerization. This process is responsible for the softening of fruits and vegetables through breakdown of cell wall materials, such as pectin. Softening may be desirable, e.g., in reducing juice yield and in reducing the drying and cooking times of dehydrated products (Kilcast, 1995). Sugars may be hydrolyzed or oxidized when subjected to gamma irradiation (Willemoti et al., 1996).

The irradiation of wheat at 0.2-10kGy increased the initial levels of water-soluble reducing sugars by 5-92% compared to untreated samples (Rao *et al.,* 1978). Such overall increase in initial total reducing sugars resulted from the stepwise and random degradation of starch. These changes are highly advantageous in the generation of bread flavor and aroma by reducing sugar-amino acid reactions (Graham, 1980). Irradiation of pure carbohydrates produced degradation products that have mutagenic and cytotoxic effects. However, these undesirable effects were produced using very high doses of irradiation (Graham, 1980).

***Changes in Vitamins:*** Meat is a great source of water-soluble B complex vitamins. The amount of these vitamins is largely influenced by the fatness of the meat, being principally found in lean portions due to their lipid insolubility. Age of the animal also has an effect on the water-soluble vitamin content. The B vitamins include thiamin (B1), riboflavin (B2), niacin (B5), pyridoxine (B6), biotin (B10), cobalamin (B12), choline, folic acid and pantothenic acid. There are little fat-soluble vitamins in meat. Beef contains around 1 microgram of vitamin A per gram of fat, some ascorbic acid and negligible amounts of vitamins D, E and K (Schweigert 1987).

In the case of vitamin radiolysis, the types of possible free radical reactions are determined by the medium in which the vitamins are present. The fat-soluble vitamins would thus be exposed to radicals produced by the direct action of radiation on lipids and the water-soluble vitamins to 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. For water-soluble vitamins, some may react with hydrated electrons directly or acquire an electron from the other radicals produced in the aqueous medium. The fate of the reaction is determined by the electron reduction potential of the vitamin and the weakness of its H bonds (Singh *et al.,* 1991). Since vitamins are in quite low amounts in most foods, the $.OH^-$ 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 (Kilcast 1994). The effect of irradiation on nutritional content of cooked chicken is shown in Table 2.

**Table 2: Effect of irradiation on nutritional content of cooked chicken**

| Vitamin | Non-irradiated | Irradiated |
|---|---|---|
| A (IU) | 2200 | 2150 |
| E (mg) | 3.30 | 2.15 |
| Thiamin (mg) | 0.58 | 0.42 |
| Riboflavin(mg) | 2.10 | 2.05 |
| Niacin (mg) | 58.0 | 56.5 |
| Vit.B6 (mg) | 1.22 | 1.15 |

Source: Stevenson MH. (1994).

***Irradiation and the fat-soluble vitamins:*** Since these vitamins are not readily present in meat but more in dairy, fruit and vegetable products, they are of minor concern. Vitamin E (α-tocopherol) is the most irradiation sensitive fat-soluble vitamin. Vitamin A is lost to some extent in liver (Janave and Thomas 1979). Vitamin D is mostly found in fish and has a general high stability to irradiation. Finally, vitamin K being synthesized by bacteria in the human gut is of no concern although the vitamin K originating from meat is sensitive to high irradiation doses (Kilcast, 1994).

***The water soluble B vitamins:*** This group of vitamins is of greater importance in meat. We should note that the sensitivity of many B vitamins seems to vary between meat cuts and also from meat to meat (Schweigert, 1987).

***Thiamin:*** Meat can be a significant source of thiamin. It has been shown that thiamin is the most irradiation labile water-soluble vitamin. However, this vitamin is even more labile to heat (Stevenson, 1994). When a beef sample containing 0.24 mg of thiamin per g was submitted to irradiation doses of 28 and 56 kGy, the thiamin content decreased, respectively, to 0.057 and 0.037 mg (Ziporin *et al.,* 1957). These results are consistent with those of Wilson (1959) who showed that the destruction of thiamin by irradiation correlates with the dose of irradiation received.

Table 3 shows the comparison of thiamine retention in irradiated and canned samples. It as also been shown that the temperature of the beef sample during irradiation as a major effect on the rate of thiamin loss. The colder the meat during the treatment, the lower the thiamin destruction in the sample (Wilson, 1959). Similar results have been obtained by Hanis*et al.,* (1989). Gallien *et al.,*(1985) found that thiamin content was not significantly affected by irradiation. Oxidative damage to thiamin is responsible for its loss. When thiamin is irradiated, a decrease in spectrophotometric absorbency indicates the destruction of its pyrimidine ring. Loss of the amino group is observed and this reaction generates ammonia in function of the irradiation dose. The source of ammonia is believed to be the 6-amino group of the pyrimidine portion of thiamin and is less likely to be from the thiazole and pyrimidine ring nitrogen (Groninger and Tappel 1957).

**Table 3: Comparison of thiamine retention in irradiated and canned samples**

| Meat | Percent in irradiated sample | Percent in canned sample |
|---|---|---|
| Beef | 36 | 44 |
| Chicken | 44 | 61 |
| Pork | 29 | 42 |

Source: Graham 1980.

***Riboflavin:*** This vitamin is relatively stable to irradiation. No loss was found in pork chops and chicken breasts irradiated at temperatures between-20 and 20°C at doses up to 6.6 kGy. Some irradiated samples even showed an increased in riboflavin concentration of up to 25% (Kilcast, 1994). Irradiation of a beef sample containing 1.86mg of riboflavin per g at 28 and 56 kGy showed that the amounts of riboflavin remaining after treatment were 1.76 and 1.79 mg, respectively (Ziporin *et al.,* 1957). This is a very small loss and an increase is even noted when the dose is increased. Fox *et al.,* (1989) demonstrated that riboflavin content was stable during irradiation.

***Niacin:*** Niacin is the most abundant B complex vitamin in beef. A sample of meat containing 30 micrograms of niacin per gram irradiated at 28 and 56 kGy was analyzed for its content after treatment. Niacin contents after irradiation were 28.90 and 29.29 mg, respectively (Ziporin *et al.,* 1957). These data shows that there is no major difference in niacin content after beef irradiation. Pork chops irradiated at different temperatures with doses up to 5 kGy showed no loss in niacin. A loss of 15% was observed with a dose of 7 kGy when irradiation was done at 0°C (Fox *et al.,* 1989). No significant effect was seen with chicken breasts under the same conditions (Fox *et al.,* 1989).

***Pyridoxine, biotin and cobalamin:*** Sensitivity of pyridoxine to gamma irradiation is less than that of thiamin. The sensitivity of pyridoxine is closer to that of riboflavin at doses higher than 10 kGy (Richardson *et al.,* 1961). Kennedy (1965) stated that losses appeared to be low at doses <10 kGy. Gallien *et al.,* (1985) found that it was not significantly affected at these doses (<10 kGy). Work at sterilization doses (20-40 kGy), showed no significant losses in biotin. No loss in cobalamin was observed when pork was irradiated at 7 kGy, 0$^{o}$C (Fox *et al.,* 1989).

***Choline, folic acid and pantothenic acid:*** No losses due to irradiation have been reported for choline (Diehl *et al.,* 1991). There are indications that some components of folic acid are sensitive at a dose of 25 kGy while others not (Kilcast, 1994). In the case of pantothenic acid, studies showed that there is no loss in many foods irradiated at doses of $^{3}$ 10 kGy (Thayer *et al.,* 1991). A study done by the Office of the Army Surgeon General shows the effect of different processing treatments upon the thiamin, riboflavin, niacin and pyridoxine content of enzyme-inactivated beef (Josephson *et al.,* 1978). It can be concluded that heat sterilization reduces the vitamin content of beef more than any other method including gamma irradiation, electron treatment and frozen storage. De Groot *et al.,* (1972) concluded that, with the possible exception of a slight decrease in vitamin E and thiamin contents after irradiation at a dose $^{3}$ 6 kGy, there was no indication that irradiation caused any vitamin destruction. Fox *et al.,* (1989) demonstrated that only thiamin loss due to irradiation process is relevant.

The extent of vitamin C, E and K destruction by radiation depends on the dosage used. Thiamine is very labile to irradiation. Ascorbic acid in solution is quite labile to irradiation but in fruits and vegetables seems quite stable at low-dose treatment (Graham 1980). Vitamins, particularly those with antioxidant activity, such as A, B12, C, E, K, and thiamine, are degraded when irradiation is carried out in the presence of oxygen.

Irradiation can also partially damage vitamins C and B1. Kilcast (1994) stated that the literature referring to vitamin loss is misleading in many cases. Vitamin losses are often described at unrealistically high irradiation doses or under unrealistic conditions. In particular, vitamin C loss is often equated with ascorbic acid loss; ignoring the fact that irradiation converts ascorbic acid into dehydroascorbic acid, which is also active as a vitamin.

## APPLICATION OF IRRADIATION

### Meat Irradiation

Radiation processing of meat is a novel alternative to traditional preservation methods such as salting, curing, smoking, drying, canning, cooking, refrigeration, freezing, modified atmosphere packaging and high-pressure. Some of the advantages of this technology are that it is a physical, cold and non-additive process that causes minimal changes in food. It is also an ecofriendly process. It can be applied to pre-packaged food and is highly effective compared to chemicals and fumigants. It does not leave harmful residues in food. It is one of the best emerging technologies to ensure the microbiological safety of meat. In developed as well as developing countries an increase in the incidence of food -borne diseases especially of animal origin has been noticed (Kanatt *et al.,* 2006). In the USA, the US FDA approved radiation processing of meat in 1997 and the USDA in 1999 (USDA 1999). Radiation processed ground beef and poultry have appeared since on the market shelves of several states in the US. Meat and meat products pasteurised by radiation have been successfully marketed in Belgium, France, China, Indonesia, Netherlands, South Africa and Thailand for a number of years (Diehl, 1995). In India, the Ministry of Health and Family Welfare approved meat and meat products including chicken for radiation preservation under prevention of Food Adulteration Rules in 1998.

There are several reports on the radiation processing of meat products like bacon, ham (Weirbicki and Heilgman, 1980) sausages (Kiss *et al.,* 1990) and beef burgers (Dempster *et al.,* 1995). In addition to spoilage bacteria, meat products may contain parasites and pathogenic bacteria, which could be eliminated by irradiation. The radiation doses required to inactivate 90% of the colony forming unit of the common food borne pathogens associated with meat and meat products are in the range of 1-4 kGy (Thayer *et al.,* 1993).

### Poultry Irradiation

The presence of pathogenic bacteria such as Salmonella and Campylobacter in poultry is a world-wide phenomenon. The contamination problem is aggravated by modern mass rearing practices. Poultry borne Salmonellosis and Campylobacteriosis occur mainly as a result of under-cooking, time-temperature abuse leading to survival and growth of the pathogens, or recontamination after cooking due to contact with surfaces, hands or utensils which have been previously contaminated with raw chicken (Molins *et al.,* 2001). Poultry-borne Salmonellosis or Campylobacteriosis account for a heavy toll in human disease and associated suffering, including death (Roberts and Unnehever 1994). Economic losses associated with these problems were estimated by Buzby and Roberts (1997) to be in the thousands of millions of US dollars. The US, for example, reports some 30,000 cases of Salmonellosis annually, including a high proportion of the total 1800 deaths attributed by the Centers for Disease Control and Prevention (1998) to food borne disease in 1997. An important proportion of these cases may be due to consumption of poultry. Whether the causes are cross-contamination or under-cooking of poultry, it is clear that if the pathogens were prevented from reaching the homes or institutional kitchens, poultry-borne Salmonellosis also would be effectively prevented (Scott, 1996).

At the present time, irradiation is the only physical process for rendering contaminated poultry safe other than by heat treatment. A total of 11 countries has so far recognized the importance of this technology for ensuring the safety of poultry products and has approved irradiation of poultry.

### Beneficial effects of meat irradiation

Since the meat industry deals with a highly perishable commodity, its distribution lines are limited to areas, which have freezing/

refrigeration facilities. Irradiation can help expand the available market to include a much wider clientele. It can also cut down losses incurred as a result of spoilage. Irradiation also offers as effective method to control pathogenic microorganisms in meat. Meat and meat products are irradiated at different doses for the following purposes.

**Radiation processing of meat and meat products**

Meat irradiation is a novel alternative to traditional preservation methods such as smoking, salting, curing, cooking, canning, drying, freezing, refrigeration, modified atmosphere packaging and High pressure processing. The advantages of this technology are that it is a physical, cold and non-additive process that causes minimal variations in food. It can be applied to pre-packaged food and is highly effective compared to chemicals and fumigants. In developed as well as developing countries an increase in the incidence of food borne diseases particularly of animal origin has been observed. From past several years radiation processed meat and meat products are marketed in countries like France, Indonesia, Belgium, China, South Africa, Netherlands, and Thailand. In India, FSSAI Ministry of Health & Family Welfare, Government of India, approved meat and meat products including chicken for radiation preservation under the food safety and standards act,

There are numerous studies on the radiation processing of meat products like bacon, ham, sausages and beef burgers. In addition to spoilage bacteria, irradiation also eliminates pathogenic bacteria and parasites in meat and meat products. The irradiation doses of about 1-4 kGy essential in order to inactivate 90% spoilage micro organisms.

Badr (2004) evaluated the microbiological status of rabbit meat and the option of employing irradiation to control food borne pathogenic bacteria and lengthen the refrigerated storage life of meat. Rabbit meat samples were irradiated (0, 1.5 and 3 kGy) and stored at refrigeration temperature. Results exhibited that irradiation of samples significantly increased their amounts of Thiobarbituric acid reactive substances (TBARS) but had no significant affects on their total volatile nitrogen (TVN) contents, while storage significantly increased the TBARS and TVN for irradiated and non-irradiated samples. Irradiation showed no substantial effects on the raw meat sensory attributes. Further, burgers developed with irradiation rabbit meat exhibited great sensory acceptability. Several studies revealed that irradiation accelerated lipid oxidation when meat and meat products were aerobically packed and resulted in development of objectionable color and odour (Ahn *et al.,* 2000, 2001)

**Effect of irradiation on microbial growth in meat and meat products**

Chicken and mutton meat is a nutritious food and consumed all over the world, however, it is extremely perishable with a quite less shelf life. Irradiation has been used in combination with packaging to increase the safety and improve the shelf-life extension of meat. The safety and effectiveness of irradiation in preservation has been comprehensively established. The relative sensitivity of different microorganisms to ionizing radiation is based on their respective D10 values (which is the dose required to reduce the population by 90%). Lower D10 values indicate greater sensitivity of the organism in question. Bacteria are more resistant to irradiation during latency and more sensitive as they enter the logarithmic growth phase and reach the lowest resistance at its end (Jay 2000). Gram-negative bacteria are generally more sensitive than the Gram-positive vegetative cells. The physical and chemical composition of the food also affects microbial responses to irradiation. For example, as the temperature of fresh and frozen meat is decreased from 30°C to –30°C, D10 increases as the water in the product freezes, thereby decreasing the rate of migration of the ionization products, including free radicals, and requiring greater energy to cause the collisions necessary to destroy the microbes. The knowledge of D10 value and the quantity of organisms will establish the dosage required. The D10 values for fresh and frozen meat are depicted in Table 4.

**Table 4: D10-values of pathogens in fresh and frozen meat**

| | D-values (kGy) | |
|---|---|---|
| Organism | Fresh (refrigerated) | Frozen |
| *Campylobacter jejuni* | 0.08 – 0.20 | 0.21 – 0.32 |
| *E. coli O157:H7* | 0.24 – 0.27 | 0.31 – 0.44 |
| *Staphlococcus aureus* | 0.26 – 0.60 | 0.30 – 0.45 |
| *Salmonella* spp. | 0.30 – 0.80 | 0.40 – 1.30 |
| *Listeria monocytogenes* | 0.27 – 1.00 | 0.52 – 1.30 |

Source: Molins et al., (2001).

## EFFECTS OF IRRADIATION ON MEAT QUALITY

Meat irradiation is considered as a safe and effective method to extend the shelf life of fresh meat and meat products. Food and Drug Administration (FDA) approved the poultry and red meat irradiation for controlling food borne pathogens and extending shelf life. Irradiation is a promising preservation technology; however, its application in meat and its products lead to physico-chemical and biochemical changes, affecting its nutritional and sensory properties (Grolichova *et al.,* 2004). Radiation processing of muscle foods generates free radicals and hastens lipid and protein oxidation resulting to detrimental changes (Alfaia et al., 2007). Ionizing radiation generates free radicals which encourage lipid peroxidation and other changes as well as influencing sensory quality of meat (Wong *et al.,* 1996). The factors that influence the oxidation of meat products due to irradiation are mainly fatty acid composition, storage, packaging and proportion of poly unsaturated fatty acids (Kanatt *et al.,* 2004). As lipids oxidize, they form hydroperoxides, aldehydes, ketones and various other products that adversely affect taste, flavour, nutritional profile and acceptability.

A combination preservation technique involving irradiation as one of them is expected to improve the quality of such processed ready-to-eat meat products. The feasibility of using irradiation along with natural antioxidants to develop products of good chemical and microbiological stability has been investigated extensively. Addition of conjugated linoleic acid to cooked and ground beef showed reduction in TBARS values of irradiated ground beef patties (Chae, *et al.,* 2009). Ahn *et al.,* (2004) compared natural antioxidant effectiveness in preserving red color of fresh beef. Addition of ascorbic acid, tocopherols and sesamol prior to irradiation preserved the redness of irradiated ground beef during storage (Ismail *et al.,* 2009). Effect of natural antioxidants like chitosan (Kanatt *et al.,* 2004), mint (Kanatt *et al.,* 2007), and tocopherol in combination with sesamol were evaluated on lamb and pork meats during radiation processing and storage to determine its antioxidant potential. Studies showed encouraging results in coping with the problem of lipid oxidation.

**Control of oxidation in irradiated meat and meat products with natural antioxidants**

Natural and synthetic antioxidants are generally employed to inhibit the oxidative reactions developed during processing of meat and meat products. Antioxidants comprising metal chelators, free radicals scavengers and intrinsic antioxidants are reported to lower the off odor formation in meat and meat products subjected to irradiation (Nam and Ahn, 2003).

Incorporation of antioxidants with free radical scavenging activities helped in protecting from lipid peroxidation in irradiated meat and meat products. Rosemary and oregano extracts possess antioxidant capacity on irradiated frozen beef burgers (Trinidade *et al.,* 2010). He demonstrated that rosemary extract (400mg/kg) proved to be effective in inhibiting lipid oxidation in comparison with oregano extract and in combination with either Butylated hydroxyanisole /Butylated hydroxytoluene (BHA/BHT). It also helped in maintaining the TBARS values below 2.0 in irradiated beef burgers up to 90 days during frozen storage at -18 °C.

Formanek, *et al.,* (2003) reported a synergistic effect of antioxidants and irradiation on the stability of minced beef. The addition of water soluble rosemary powder (0.25%) resulted in stabilising colour and inhibited lipid peroxidation at 1, 2, 3 and even 4kGy dosage in aerobically packed minced beef.

*et al.,* (2012) showed that addition of 1% radix puerariae extracts lowered the cooking losses and had more moisture and lesser fat content than the control. A reduction in Thiobarbituric acid-reactive substance (TBARS) values was also observed in the sausages with radix puerariae extracts. Results indicated that 1% radix puerariae extracts were as effective as BHA/BHT in controlling lipid oxidation in pre cooked pork sausages during storage at 4°C.

The effect of plum extracts (1%, 2% and 3%) have demonstrated antioxidant potential in products such as irradiated turkey (Lee & Ahn, 2005). Addition of plum extract at 3% in vacuum-packaged, ready-to-eat turkey breast rolls irradiated at 3kGy helped in controlling lipid oxidation and improving the sensory properties of Ready-to-eat (RTE) turkey breast rolls.

Nunez *et al.,* (2008) studied the effect of fresh and dried plum concentrates in vacuum packaged boneless hams and evaluated its cooking loss, texture, TBARS and sensory attributes. Studies revealed that addition of 5% plum powder increased the cooking losses by 17.7% and no significant differences ($p > 0.05$) in lipid oxidation were observed among treatments as determined by TBARS and sensory evaluation.

Radiation processed lamb meat treated with mint leaf extract at 0.05% and 0.1% showed better antioxidant activity in contrast with control and decreased lipid oxidation during chilled storage. The antioxidant activity of mint leaf extract was found to be equivalent to the synthetic antioxidant butylated hydroxytoluene (BHT) (Kanatt *et al.,* 2007). In another study, the researchers found the synergistic effect of Chitosan and mint extract in the shelf life extension of meat and meat products. Incorporation of Chitosan and mint extract (0.1%) extended the shelf life of minced lamb meat and pork cocktail salami by more than one week during chilled storage (0-3°C) as compared to the control ones which spoiled in less than two weeks (Kanatt *et al.,* 2008).

Jayathilakan *et al.,* (2009) assessed the positive effects of lactic acid (1 and 2%) in hurdle processed chicken legs irradiated at 1 and 2kGy. Incorporation of lactic acid at 2% levels showed significant reduction in TBARS, total carbonyls and non-heme iron values of irradiated chicken legs. Irradiation of the hurdle processed chicken samples at 2 kGy with 2% lactic acid could extend the shelf-life to 6-7 months at 5°C.

The antioxidant effect of carrot juice (35% and 60% concentrate) was evaluated in gamma irradiated beef sausage (0, 3 & 4.5kGy) during refrigerated and frozen storage (Badr and Mahmoud, 2011). According to this study, 60% carrot juice concentrate incorporation inhibited the lipid and protein oxidation in irradiated beef sausage and showed good sensory attributes in comparison with their control counterparts.

**Effect of spices in controlling lipid oxidation in meat products**

Spices and herbs are known to be one of the richest sources of antioxidants. They have been utilized for several hundred years in the preservation of flavor, color and aroma of foods. Spices and herbs possess excellent antioxidant activity as they contain flavonoids, terpenoids, lignans, sulfides, polyphenolics, carotenoids, coumarins, saponins, plant sterols, curcumins, and phthalides. They are used as antioxidants in the form of ground spices/herbs, extracts, essential oils, oleoresins, emulsions or encapsulated form. Spices and herbs are known to have several functional attributes which can be utilized for the benefit of developing shelf stable meat products. Many studies have been undertaken to establish the antioxidant characteristics of herbs and spices like oregano (Rojas & Brewer 2007, 2008), rosemary (Sebranek *et al.,* 2005) and extracts of thyme, basil, rosemary, chamomile, lavender, and cinnamon (Lee and Shibamoto, 2002, Murcia *et al.,* 2004, Du & Li, 2008).

Clove was able to prevent discoloration of raw pork during storage at room temperature and was the strongest antioxidant in retarding lipid oxidation among spice and herb extracts including cinnamon, oregano, pomegranate peel and grape seed (Shan *et al.,* 2009). The ethanolic extract of clove was used effectively used to improve the keeping quality of fresh mutton up to 4 days at 25±2°C (Kumudavally *et al.,* 2011). In another study, addition of clove oil in combination with lactic acid or vitamin C decreased lipid oxidation, maintained high color a* value, and improved the sensory color in buffalo meat during retail display (Naveena *et al.,*2006). In addition, the effect of clove oil on the oxidative stability of rapeseed oil was studied (Nguyen *et al.,* 2000).

Sallam *et al.,* (2004) assessed the antioxidant and antimicrobial activity of garlic in raw chicken sausage during refrigerated storage. Garlic showed antioxidant effect equivalent to the commercial synthetic antioxidant butylated hydroxyanisole (BHA). The authors concluded that fresh garlic and garlic powder through their combined antioxidant and antimicrobial effects could be used as potential natural antioxidant in preserving meat products.

Trinidade *et al.,*(2010) demonstrated that addition of rosemary (400 mg/kg) and oregano (400 mg/kg) extracts independently or by blending (200 mg rosemary+200 mg oregano) and with either BHA/BHT (200 mg/kg) or their blend (100 mg/kg BHA/BHT plus 200 mg/kg rosemary/oregano) in irradiated beef burgers decreased TBARS in meat samples stored at −20°C for 90 days. Further rosemary singly or in blend with either BHA/BHT or oregano showed the highest inhibitory effect among all the formulations.

Rosemary extract (1%), clove extract (1%) and their combinations (0.5+0.5%) were evaluated for their antioxidant and antimicrobial effects in raw chicken meat fillets during refrigerated storage (Zhang *et al.,* 2016). Studies revealed the effectiveness of clove and rosemary extracts in reducing lipid oxidation, inhibiting microbial growth, preserving or enhancing sensory attributes and extending the shelf-life of raw chicken meat during storage at 4°C for 15 days.

The antioxidant effect of 4 different spice extracts Syzygium aromaticum, Cinnamomum cassia, Origanum vulgare, and Brassica nigra at 1% level in raw chicken meat were evaluated during storage for 15 days at 4°C (Radha Krishnan *et al.,* 2014). The samples treated with a combination of spice extracts significantly ($p<0.05$) increases the sensory characteristics with higher colour and odour values and retarded lipid oxidation as well as microbial growth. The results demonstrated the effectiveness of these antioxidants and its applicability in meat industry.
The effectiveness of radiation processing in extending the shelf life of fluidised bed dried mutton was reported by Jayathilakan *et al.,* (2012). Application of rice bran oil in improving the quality characteristics of irradiated mutton kheema were studied by Jalarama Reddy *et al.,*(2015). Overall, radiation processing can be employed as a safe preservation technique in the development of meat and poultry products by optimising the natural antioxidants and threshold radiation dosages.

## CONCLUSION

Radiation processing is emerging as an important preservation technique which can ensure safety and shelf life of meat, poultry and other products. The threat due to food-borne pathogens can be effectively eliminated by optimizing the irradiation protocols in terms of radiation dosages. The present scenario of production methods lacks microbial safety standards which can be effectively overcome by the application of this technology especially for meat and poultry products. The adverse implications due to lipid and protein oxidation being observed in meat, poultry products can be suppressed by selecting proper natural antioxidant combinations. Irradiation can be employed as a critical control point in the meat, poultry chain and such an intervention is essential in ensuring the safety of products. Several research works clearly indicated the efficacy and acceptability of the process which has to be clearly utilized by removing the myth and stigma associated with the use of irradiation in the masses. The commercial radiation facilities installed at various centres in India clearly demonstrate the upcoming usage of irradiation for ensuring safety and quality and these facilities can be employed for the benefit of public especially in the case of meat and poultry food sector.

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