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Nutritional adequacy of irradiated meat—a review

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Gamma irradiation is well known to assure food innocuity. The use of this treatment on fresh meat could extend shelf life and protect the host against pathogenic bacteria. On the other hand, irradiation treatment brings about biochemical changes that could affect the nutritional adequacy of food. The following text is a review of the biochemical changes caused by irradiation related to their nutritional significance. The changes in lipids, proteins and vitamins are discussed. © 1999 Canadian Institute of Food Science and Technology. Published by Elsevier Science Ltd. All rights reserved.

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INTRODUCTION

Different treatments can be used in order to extend the shelf-life of meat and eliminate pathogenic bacteria it may contain. Common methods used are salting, canning, freezing and modified atmosphere packaging (Stevenson, 1994). In 1981, the use of irradiation treatment for food preservation was approved by the FAO/IAEA/WHO joint committee on the wholesomeness of irradiated food. The committee stated that irradiation of food at doses up to 10 kGy introduced no special nutritional problem. Currently, 26 countries are using the process on a commercial scale (Stevenson, 1994).

Most of the work on meat irradiation as been done at sterilization doses (20–40 kGy). On the other hand, experiments done at radappertization doses ($\leq$10 kGy)—the doses envisioned for commercial application—demonstrate that the nutritional effects are not that different from those obtained with other preservation methods (Josephson *et al.*, 1978). Although there is high sensitivity when lipids, proteins or vitamins are exposed to irradiation in solution, the inherent protective quality of food will render the effects of radiation negligible in most cases.

CHANGES IN LIPIDS

Ground beef has a 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, 1990). 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 aproximately 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. Poly-unsaturated 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).

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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 most 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 $\cdot OH^-$, 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. Its 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 and 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 nonoxidative 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 an 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, $C_{(n\text{-}1,\,n\text{-}2)}$ alkane, $C_{(n\text{-}1,\,n\text{-}2)}$ 1-alkene, formyl diglycerides, acetyl diglycerides, C_n fatty acid methyl ester, ethanediol diester, $C_{n\text{-}x(x\geq 3)}$ hydrocarbons (Delincée, 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°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 nonirradiated 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 ($\leq$7 kGy), it does not result in significant loss of nutritional value (Thomas, 1988).

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. Nonessential 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 and 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 (Delincée, 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 crosslinks 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 and Delsignore, 1987).

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 a

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 wich 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 (Delincée, 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 nonexistant 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 $\cdot$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 $\cdot$OH$^-$ in the presence of oxygen generally produce 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 $\cdot$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 $\cdot$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 aggregation are routes well separated by the presence or absence of oxygen, both processes are preceeded by the denaturation of the protein. The $\cdot$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 $\cdot$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 and Metta, 1956). Long-term feeding studies with rats have also shown that the use of irradiation for the sterilization and preservation of meat, does noy have a significant effect upon the nutritional quality of the meat protein (Schweigert, 1987). Reviews by the De Groot *et al.* (1972), Josephson *et al.* (1978), Murray (1983), 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 occured, 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 protein 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^{-1}), 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.

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 as 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 is 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 $\cdot OH^-$ 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).

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 μg 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 μg (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. 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).

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 1.86 µg of riboflavin per g at 28 and 56 kGy showed that the amounts of riboflavin remaining after treatment were 1.76 and 1.79 µg, 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 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 µg, 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°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 ≥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 ≥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.

CONCLUSION

The review discussed the effect of irradiation on meat components. Most of the data included showed the effect of gamma radiation on lipids, proteins or vitamins when whole food was irradiated. Studies on meat irradiation showed much less significant alteration in its nutrients than when the different nutrients were irradiated individually.

The data also indicated that no essential fatty acids or amino acids are lost in an extent great enough to be of nutritional concern. The only significant loss due to irradiation of beef is the reduction of thiamin content. However, cooking the meat will result in a greater loss of thiamin as compared to irradiation. Combination treatments, like refrigeration, are currently being studied as they seem to reduce the losses during irradiation treatment.

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