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REVIEW PAPER

Radiation Processing: An Emerging Preservation Technique for Meat and Meat Products

K. Jayathilakan*, Khudsia Sultana, and M.C. Pandey

Freeze Drying & Animal Products Technology Division, Defence Food Research Laboratory, Mysore-570 011, India
**E-mail: drjayathilakan@dfrl.drdo.in*

ABSTRACT

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. Several studies on the usage of natural antioxidants which can arrest these changes have been reported. Irradiation can find excellent applications in the extension of shelf life of chilled and non chilled carcasses and birds in service sectors. There are several radiation processing plants in India commissioned in the private sector which can also be utilised by Armed forces for extending the shelf life of whole carcass and birds with an extension of shelf life. This will be of great significance to the defence forces.

Keywords: Radiation processing; Meat; Antioxidants; Spices; Safety; Quality

NOMENCLATURE

JECFI	Joint Expert Committee on Food Irradiation
IAEA	International Atomic Energy Agency
WHO	World Health Organisation
FAO	Food and Agriculture Organisation
kGy	kiloGray
NASA	National Aeronautics and Space Administration
γ	Gamma
DNA	Deoxyribonucleic acid
RNA	Ribonucleic acid
MoU	Memorandum of understanding
FSSAI	Food Safety and Standards Authority of India
CDC	Centres for Disease Control and Prevention
OH^-	hydroxyl radical
e^-_{aq}	hydrated electron
H_2O_2	hydrogen peroxide
$^{\circ}H$	Hydrogen radical
TVN	total volatile nitrogen
TBARS	Thiobarbituric acid reactive substances
FDA	Food and drug administration
mg	milligram
kg	kilogram
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
RTE	Ready-to-eat
per cent	Percentage
<	Less than

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1. INTRODUCTION

The usefulness and practicability of food irradiation has been used for more than three decades after extensive research and development on its technological aspects. Radiation processing of food is now recognised as an effective and safe process. Today nearly 50 different commodities are being radiation processed in more than 25 countries. Radiation processing of food is an upcoming and potential food safety technology for improving hygiene and increasing storage and distribution life. Ionising radiation is used to convey beneficial alterations in food stuffs and it has been recommended as a method of ensuring the safety of meat products[1].

The wholesomeness and acceptability of irradiated foods have been evaluated by various expert committees like Joint Expert Committee on Food Irradiation (JECFI), International Atomic Energy Agency (IAEA), World Health Organisation (WHO) and Food and Agriculture Organisation (FAO) and after reviewing all the data it was recommended that the irradiation of any food commodity up to an overall average dose of 10 kGy, presents no toxicological hazard as well as no nutritional or microbiological problem. Radiation doses greater than 10 kGy can lead to sterilised products, as is the case with meat products prepared for the NASA space flight programme. Sterilised foods are useful in hospitals for patients with severely impaired immune systems. The microbiological safety of irradiated foods is one of the major concerns. It is well identified that the macro nutrients are not significantly altered; however certain vitamins may be affected. Irradiation has differing effects on dairy foods and eggs by changing the flavour and texture. As a whole irradiation of food, does not lead to nutrient losses to the extent that there is an adverse effect on the nutritional status of the individuals consuming these foods.

2. IRRADIATION PROCESS

Radiation relates with material by transferring energy to electrons and ionising molecules by producing positive and negativities. Radiation processing of food is a controlled exposure of food to ionising radiation such as electrons, γ-rays and x-rays. Radioisotopes such as Cobalt-60 and Cesium-137 emit γ-rays while electrons and x-rays are produced by machines sources. Packaged food is exposed to effective doses of ionising radiation so that pathogens and spoilage organisms can be destroyed. Ionising radiations inactivate microbes by damaging nucleic acids directly as a consequence of electron and photon contact with DNA and RNA as well as indirectly through the action of charged ions. Cobalt 60 produces γ-rays during its transformation to a stable state of Nickel 60[2]. The profits of irradiation comprise its extremely effective inactivation of bacteria, negligible nutritional changes in the product and can be treated after packing[3].

3. COMMISSIONED RADIATION PROCESSING PLANTS IN INDIA

Presently 16 radiation processing plants have been commissioned in the private sector and several MoUs have been signed for setting up many more such facilities in the country. Table 1 provides a list of irradiation facilities throughout India. These plants are utilised for the quarantine treatment of fresh fruits and vegetables, disinfestations of cereals, pulses their products and spices. It also provides services for sterilisation of medical products by gamma irradiation. These facilities can also be utilised by Armed forces for extending the shelf-life of whole carcass and birds with an extension of shelf-life.

Storage of food products without affecting its quality attributes and safety aspects is a big concern due to infestation and other physico-chemical and microbiological quality changes. Irradiation of these products at low dosage levels may have positive effects in extending the shelf-life by maintaining the quality.

4. FSSAI REGULATIONS FOR RADIATION PROCESSING OF FOODS, 2016

According to the gazette notification dated 23 August 2016, FSSAI has made some changes to the regulations, 2011 relating to irradiation of foods. According to the new regulation, 'irradiation of foods' has now been termed as 'Radiation processing of food'. It states that only the foods given in the Tables 2 and 3 below will be permitted to be processed by radiation. Foods that are permitted for being radiation processed cannot receive excess dose of radiation than what has been stated in the regulations as mentioned in the two tables below. Earlier the permitted foods were named individually but in the new regulations foods permitted to be irradiated have been classified into groups.

5. ILLNESSES CAUSED BY FOOD-BORNE PATHOGENS

Centres for disease control and prevention (CDC) in the United States estimates that each year roughly 1 in 6 Americans (or 48 million people) gets sick, 128,000 are hospitalised, and 3,000 die of food-borne diseases. The illnesses are mainly caused due to the pathogens *Campylobacter, E.coli* STEC 015*, Staphylococcus aureus, Clostridium perfringens, Listeria monocytogenes, Salmonella, Staphylococci* and *Toxoplasma gondii.* Most of these illnesses were found to be domestically acquired and 90 per cent were foodborne. It also states that 59 per cent foodborne illnesses were caused by viruses, 39 per

Table 1. Commissioned radiation processing plants in India

Name	State	Products	Operational since
Radiation Processing Plant, Navi Mumbai	Maharashtra	Food & Allied products	2000
KRUSHAK, Nasik	Maharashtra	Food products	2002
Organic Green Foods Ltd., Kolkata	West Bengal	Food, packaging & medical products	2004
A.V. Processors Pvt. Ltd., Mumbai	Maharashtra	Food & Medical Products	2005
Universal Medicap Ltd., Vadodara	Gujarat	Food & Medical Products	2005
Microtrol, Bangalore	Karnataka	Food & Medical Products	2006
Agrosurg Irradiators, Mumbai	Maharashtra	Food & Packaging, Medical Products	2008
Gamma Agro Medical Processing, Hyderabad	Telangana	Food & Medical Products	2008
Jhunsons Chemicals Pvt Ltd., New Delhi	Delhi	Food & Medical Products	2010
Innova Agri Bio Park Ltd., Malur	Karnataka	Agro & Medical Products	2011
Hindustan Agro Co-operative Ltd., Rahuri	Maharashtra	Onion & Agri products	2012
NIPRO India Corporation Pvt. Ltd., Satara Road	Maharashtra	Medical Products	2012
Impartial Agro Tech (P) Ltd., Lucknow	Uttar Pradesh	Food & Medical Products	2014
Gujarat Agro Industries Corpn. Ltd, Bavla	Gujarat	Food & Medical Products	2014
Aligned Industries, Rewari	Haryana	Food Products	2015
Maharashtra State Agricultural Mktg. Board, Navi Mumbai	Maharashtra	Food Products	2015

Source: Department of Atomic Energy, 2016 [4]

Table 2. Classes of food products and their irradiation dosage limits

Class	Food	Purpose	Dose limit kGy (kilo Gray)	
			Minimum	Maximum
Class 1	Bulbs, rhizomes, stem and root tubers	Inhibit sprouting	0.02	0.2
Class 2	Fresh fruits and vegetables (other than Class 1)	Delay ripening	0.2	1.0
		Insect disinfestation	0.2	1.0
		Shelf life extension	1.0	2.5
		Quarantine application	0.1	1.0
Class 3	Cereals and their milled products, pulses and their milled products, nuts, oil seeds, dried fruits and their products	Insect disinfestation	0.25	1.0
		Decrease in microbial load	1.5	5.0
Class 4	Fish, aquaculture, seafood and their products (fresh or frozen) and crustaceans	Elimination of pathogenic micro organisms	1.0	7.0
		Shelf -life extension	1.0	3.0
		Control of human parasites	0.3	2.0
Class 5	Meat and meat products including poultry (fresh and frozen) and eggs	Elimination of pathogenic microorganisms	1.0	7.0
		Shelf -life extension	1.0	3.0
		Control of human parasites	0.3	2.0
Class 6	Dry vegetables, seasonings, spices, condiments, dry herbs and their products, tea, coffee, cocoa and plant product	Microbial decontamination	6.0	14.0
		Insect disinfestation	0.3	1.0
Class 7	Dried foods of animal origin and their products	Insect disinfestation	0.3	1.0
		Control of molds	1.0	3.0
		Elimination of pathogenic micro organisms	2.0	7.0
Class 8	Ethnic foods, military rations, space foods, ready to-eat, ready-to-cook/ minimally processed foods.	Quarantine application	0.25	1.0
		Reduction of microbial load	2.0	10.0
		Sterilisation	5.0	25.0

Table 3. Dose limits for radiation processing of allied products

Allied Product	Purpose	Dose limit kGy (kiloGray)	
		Minimum	Maximum
Packaging materials for food or allied product	Microbial decontamination	5.0	10.0
	Sterilisation	10.0	25.0
Food additives	Insect disinfestation	0.25	1.0
	Microbial decontamination	5.0	10.0
	Sterilisation	10.0	25.0
Health foods, dietary supplements and nutraceuticals	Insect disinfestation	0.25	1.0
	Microbial decontamination	5.0	10.0
	Sterilisation	10.0	25.0

cent by bacteria and 2 per cent by parasites. The pathogens that caused the most illnesses were norovirus (58 per cent), non-typhoidal *Salmonella* spp. (11 per cent), *Cl. perfringens* (10 per cent), and *Campylobacter* spp. (9 per cent). The potential benefit of the irradiation would be a 25 per cent reduction in the morbidity and mortality rate caused by these infections. The approximate advantage would be significant, as the measure could prevent nearly 900,000 cases of infection, 8,500 hospitalisations, over 6,000 catastrophic illnesses, and 350 deaths each year[5].

6. MECHANISM OF ACTION BY IRRADIATION

The radiation effects on biological substances are direct and indirect. In direct action, the chemical events occur as a result of energy given by the radiation in the target molecule, and the indirect effects occur as a result 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.

Irradiation causes disruption of internal metabolism of cells by destruction of chemical bonds. DNA cleavage results in loss of cells ability to reproduce. The free radicals are formed upon contact with water containing foods and react with cellular DNA causing radiation damage. Irradiation can indirectly form radiolytic products/free radicals from water (°H, °OH) °OH are responsible for 90 per cent of DNA damage.

7. EFFECTS OF IRRADIATION ON LIVING BEINGS

The rays of energy emitted during irradiation directly damages the DNA of living organisms and brings about cross-linkages and other changes that make an organism unable to grow or reproduce. When these rays combine with water

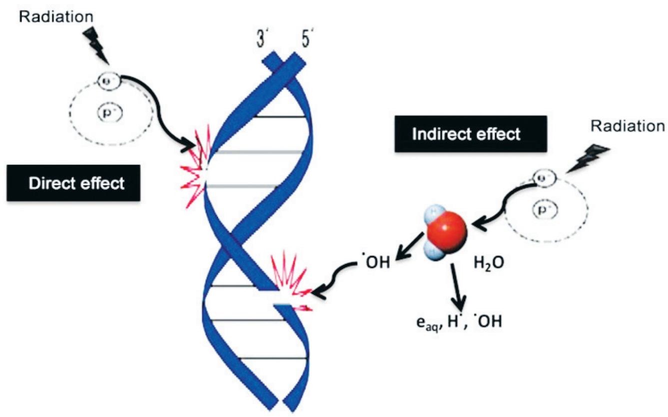

Figure 1. Radiation damage to DNA.

molecules in an organism, they produce short-lived free radicals that can cause further indirect damage to DNA.

The radiation dose (level of treatment) is defined as the quantity of energy absorbed during exposure. Traditionally the dose of ionising radiation absorbed by irradiated material has been measured in rads, which recently has been superseded by the gray (Gy), which is equal to 100 rad. One gray represents one joule of energy absorbed per kilogram of irradiated product, and the energy absorbed depends on the mass, density and thickness of the food.

Complex life forms with large DNA molecules are affected by relatively low doses. Simpler organisms with smaller DNA can take progressively higher doses. Thus, a low dose of less than 0.1 kGy is sufficient to destroy insects and parasites and reduce sprouting. A medium dose, between 1.5 kGy and 4.5 kGy, eliminates most bacterial pathogens other than spores, and a higher dose of 10 kGy - 45 kGy will inactivate bacterial spores and some viruses. Prions, which do not contain nucleic acid, are difficult to inactivate by irradiation. For humans, the lethal dose is 4 Gy. The lethal doses of irradiation to living beings are depicted in Table 4.

Table 4. Approximate lethal doses of irradiation

Organisms	Dose (kGy)
Higher animals	0.005 to 0.1
Insects	0.01 to 1
Non-spore forming bacteria	0.5 to 10
Bacterial spores	10 to 50
Viruses	10 to 200

Source: Yadav & Tyagi [6]

8. AREAS OF APPLICATION

Irradiation (1 kGy - 10 kGy) is a successful method of reducing the microbial load of food. *Salmonella, Listeria* and other harmful microorganisms may contaminate foods such as chicken, meat, eggs, shrimps, cheese made from raw milk. Some of these foods may be eaten without further heat treatment to destroy these harmful microorganisms. Irradiation improves the shelf-life of meat, chicken and fish products since spoilage organisms are reduced and as with heat treatment, this process may also inactivate enzymes that would otherwise assist meat spoilage. It is also being used for inhibition of sprouting in potatoes, onion and garlic and in delaying ripening of fresh fruits and vegetables. It is also used as a preventive measure in the disinfestation of insects and parasites in cereals, pulses, dried fruits and pork. It also reduces the microbial load of products like spices and flesh foods.

9. 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[7]. From past several years radiation processed meat and meat products are marketed in countries like France, Indonesia, Belgium, China, South Africa, Netherlands, and Thailand[8]. 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, 2006.

There are numerous studies on the radiation processing of meat products like bacon, ham, sausages[9] and beef burgers[10]. In addition to spoilage bacteria, irradiation also eliminates pathogenic bacteria and parasites in meat and meat products. The irradiation doses of about 1 kGy - 4 kGy essential in order to inactivate 90 per cent spoilage micro organisms[11].

Badr[12] 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 kGy, 1.5 kGy, 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[13,14].

9.1 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 ionising radiation is based on their respective D_{10} values (which is the dose required to reduce the population by 90 per cent). Lower D_{10} 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[15].

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, D_{10} increases as the water in the product freezes, thereby decreasing the rate of migration of the ionisation products, including free radicals, and requiring greater energy to cause the collisions necessary to destroy the microbes[17]. The knowledge of D_{10} value and the quantity of organisms will establish the dosage required. The D_{10} values for fresh and frozen meat are depicted in Table 5.

Table 5. D10-values of pathogens in fresh and frozen meat

Organism	D-values (kGy)	
	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[16]

9.2 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[6]. 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[18]. Radiation processing of muscle foods generates free radicals and hastens lipid and protein oxidation resulting to detrimental changes[19]. Ionising radiation generates free radicals which encourage lipid peroxidation and other changes as well as influencing sensory quality of meat[20]. 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[21]. As lipids oxidise, they form hydroperoxides, aldehydes, ketones and various other products that adversely affect taste, flavour, nutritional profile and acceptability.

It is of greatest significance to supply good quality, safe meat and meat products to Armed Forces. As on date, the only meat products included in the service rations are the canned ones. Over the time a disliking has developed for these products among the consumer due to certain physico-chemical changes during processing and storage of canned meat products. 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[22]. Ahn[23], *et al.* 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[24]. Effect of natural antioxidants like chitosan[21], mint[25] 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.

9.3 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[26].

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[27]. He demonstrated that rosemary extract (400 mg/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[8], *et al.* reported a synergistic effect of antioxidants and irradiation on the stability of minced beef. The addition of water soluble rosemary powder (0.25 per cent) resulted in stabilising colour and inhibited lipid peroxidation at 1 kGy, 2 kGy, 3 kGy, and even 4 kGy dosage in aerobically packed minced beef.

Jung[29], *et al*. showed that addition of 1 per cent *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 per cent *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 per cent, 2 per cent, and 3 per cent) have demonstrated antioxidant potential in products such as irradiated turkey[30]. Addition of plum extract at 3 per cent in vacuum-packaged, ready-to-eat turkey breast rolls irradiated at 3 kGy helped in controlling lipid oxidation and improving the sensory properties of ready-to-eat turkey breast rolls.

Nunez[31], *et al.*, 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 per cent plum powder increased the cooking losses by 17.7 per cent 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 per cent and 0.1 per cent 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)[25]. 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 per cent) extended the shelf-life of minced lamb meat and pork cocktail salami by more than one week during chilled storage (0 °C - 3 °C) as compared to the control ones which spoiled in less than two weeks[32].

Jayathilakan[33], *et al*. assessed the positive effects of lactic acid (1 and 2 per cent) in hurdle processed chicken legs irradiated at 1 kGy and 2 kGy. Incorporation of lactic acid at 2 per cent 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 per cent lactic acid could extend the shelf-life to 6-7 months at 5 °C.

The antioxidant effect of carrot juice (35 per cent and 60 per cent concentrate) was evaluated in gamma irradiated beef sausage (0 kGy, 3 kGy, and 4.5 kGy) during refrigerated and frozen storage[34]. According to this study, 60 per cent 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.

9.4 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 utilised for several hundred years in the preservation of flavour, colour 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 utilised for the benefit of developing shelf stable meat products. Many studies have been undertaken to establish the antioxidant characteristics of herbs and spices like rosemary[35-39], oregano[38,39] and extracts of thyme, basil, rosemary, chamomile, lavender, and cinnamon[40-42].

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[43]. 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[44]. In another study, addition of clove oil in combination with lactic acid or vitamin C decreased lipid oxidation, maintained high colour a* value, and improved the sensory color in buffalo meat during retail display[45]. In addition, the effect of clove oil on the oxidative stability of rapeseed oil was studied[46].

Sallam[47], *et al*. 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[27], *et al*. 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 per cent), clove extract (1 per cent) and their combinations (0.5+0.5 per cent) were evaluated for their antioxidant and antimicrobial effects in raw chicken meat fillets during refrigerated storage[48]. 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 per cent level in raw chicken meat were evaluated during storage for 15 days at 4 °C[49]. 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[50], *et al*. Application of rice bran oil in improving the quality characteristics of irradiated mutton kheema were studied by Jalarama Reddy[51], *et al*. 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.

10. 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 optimising 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 w.r.t 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 utilised by removing the myth and stigma associated with the use of irradiation in the masses. The commercial radiation facilities already installed at various centres in India clearly demonstrated the upcoming usage of irradiation for ensuring safety and quality and these facilities can be employed for the benefit of Armed forces especially in the case of meat and poultry food chain sector.

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CONTRIBUTORS

Dr K. Jayathilakan obtained his MSc (Chemistry) from University of Calicut and PhD (Chemistry) from University of Mysuru. Presently working as Scientist 'E' in DFRL, Mysuru. His area of specialisation is in meat science and technology, food chemistry, freeze drying, radiation processing and development of meat and poultry products using innovative processing technologies. He has published more than 45 research articles in journals, four book chapters and six patents to his credit. He is a recipient of various prestigious awards of DRDO.
He contributed towards the planning, execution, technical advice and writing of the manuscript.

Mrs Khudsia Sultana is working as Technical Officer 'A' in DFRL, Mysuru. Her current research interests include : Development of light weight meat products and freeze dried probiotic juice powders. She has contributed significantly towards the development and evaluation of convenient meat and poultry products and beverage powders with functional attributes by various processing techniques like irradiation, freeze dehydration, compression technology and freezing.
She contributed towards the collection of literature, formatting and writing of the manuscript.

Dr M.C. Pandey obtained his BTech (Agricultural Engineering), MTech (Process Engineering), and PhD (Process and Food Engineering) from GB Pant University. Currently working as Scientist 'G' and heading Freeze Drying and Animal Products Technology Division at Defence Food Research Laboratory, Mysuru. He has experience in food R&D and process engineering with distinguished background in Statistical design and optimisation of food processing parameters, frying kinetics of optimally processed foods, freeze drying of functional foods for high altitudes, optimisation and standardisation of ready-to-eat frozen foods, and development of convenient strip based testing kits.
He contributed towards the execution, technical advice and writing of the manuscript.