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Review Article

EFFECTS OF GAMMA IRRADIATION ON CEREALS AND PULSES- A REVIEW

Khalid Bashir* and Manjeet Aggarwal

National Institute of Food Technology Entrepreneurship and Management

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ABSTRACT

Many technologies have been studied and executed for the prevention of postharvest losses. Nevertheless, still a huge amount of losses to the extent of 20% still occur in many countries owing to insects and pests alone. According to the United Nations, about 30% of the mortality rate world-wide is caused by alimentary diseases due to some microorganisms, insects or pests through toxin formation in the food products. Gamma irradiation has emerged as an efficient and remarkable technique for the prevention of growth of microorganisms, insects and mites in order to have safe food as well as smooth trading across the borders. Irradiation can contribute to ensure food safety to healthy and compromised consumers (pregnant mothers, immune-compromised patients, people on medication and ageing persons), satisfying quarantine requirements and controlling severe losses during transportation and commercialization. The use of irradiation for decontamination of foods is a promising technology that could be applied to the end product. This technology also has the advantage that it can be applied to fresh, frozen or cooked products to enhance their shelf life. It is a physical, safe, environmentally clean and efficient technology. This paper reviews the application of gamma irradiation for inhibiting the growth of insects, pests and microorganisms.

INTRODUCTION

Food irradiation studies started shortly after World War II. The impetus for this research came largely from intensive investigations of nuclear energy, which led to developments in the economic production of radioactive isotopes and to evolution of high-energy accelerators. In 1963, the U.S. Food and Drug Administration approved irradiation-sterilized bacon, the first in a growing list of proposed products. The safety of irradiated foods has continued to receive attention since then, with several countries gradually adding various products to the list of approved irradiated foods. In 1983 the FDA approved irradiation as a means of controlling microorganisms on spices, and in 1985 the FDA widened the allowed uses of irradiation to additional foods such as strawberries, poultry, ground beef, and pork. In its early development, irradiation was thought of as a process to preserve foods for extended periods by sterilization, much as thermal processing does. However, this has proven to be impractical for many products because the amount of irradiation required to commercially sterilize foods causes its own form of deterioration. Freezing prior to irradiation can reduce the damage, but this makes the process excessively expensive. More recent developments have focused on the use of lower doses of irradiation which are less damaging to the food and have desirable effects. As currently practiced, irradiation is used for three purposes; first, it can be used as an alternative to chemical fumigation to control insects in foods such as cereals, legumes, spices, fruits and vegetables; the second use is to inhibit sprouting or other self-generating mechanisms of deterioration and the third use is to destroy vegetative cells of microorganisms including those that might cause human disease. This results in an increase in safety and shelf life (Becker, 1983; Al-Kaisey *et al*., 2002; Cieslaet *al*., 1991).

Food Irradiation

According to CAC, only three types of radiations are authorized to be used commercially for food irradiation viz X-rays (are the electromagnetic rays with maximum energy not exceeding 5MeV), accelerated electrons (are the beam of electrons produced in Van de Graaff generators, with maximum energy of 10MeV) and radiation from high energy gamma rays (rays produced from radioactive substances like cobolt-60, they have a high penetrating power) (Diehl 2002, Bhat *et al*., 2007). Depending upon the dosage level Irradiation has been classified into three categories viz, *Radappertization* (analogous to radiation sterilization), dosage level 30-40 kGy, used in Canning Industry; *Radurization*, used to enhance shelf life, dosage level is 0.75-2.5kGy, used for fresh meats, poultry, fruits, vegetables and cereals and *Radicidation* (analogous to pasteurization of milk), dosage level is 2.5-10 kGy. Irradiation has also been successfully used for the inhibition and removal of food allergens and anti-nutritional factors such as saponins,

Corresponding author:* ***Khalid Bashir*
National Institute of Food Technology Entrepreneurship and Management

tannins (Al-Kaisey *et al*., 2002, Byun *et al*., 2002, Diehl 2002, Bhat *et al*., 2007). The other advantages of irradiation treatment pertains to minimal sample preparation, no use of catalyst, high penetration, no increase in temperature during processing (1kGy of radiation increases the temperature of the product only by 0.36°C (Becker, 1983; Farkas, 1998; Diehl, 2002). As far as the safety of the irradiated food is concerned, Becker, (1983), reported that food cannot become radioactive through exposure to gamma rays from Cobolt-60, or accelerated electrons with energy levels below 10 MeV, as the rays are notstrong enough to disintegrate the nucleus of even one atom of a food molecule.

Mechanism of gamma irradiation

Gamma rays destroy the micro-organism by damaging the structure of cell membrane or injuring the critical element in the cell (affects the metabolic enzyme activity or most often is damage to deoxyribonucleic acid (DNA) and ribonucleic acids which are required by microorganism for growth and replication. The effect of radiation become apparent after a period of time, DNA helix fails to unwind and the micro-organism cannot reproduce by replication (Diehl, 1995; Yeh and Yeh, 1993; Ciesla *et al*., 1991). Damage to the genetic material occurs as a result of a direct collision between the radiation energy and the genetic material, or as a result of the radiation ionizing an adjacent molecule, which in turn reacts with the genetic material. In most cells, the adjacent molecule is usually water. In the first instance, the effects are straightforward. An electron randomly strikes the genetic material of the cell and causes a lesion in the DNA. The lesion can be a break in a single strand of the DNA or, if the orientation of the DNA is appropriate, the energy or electron can break both strands on the DNA. However, large numbers of single-strand lesions may exceed the bacterium's repair capability, which ultimately results in the death of the cell. Foods when subjected to irradiation treatment, the rays collide with the food ingredients, causing the breakdown of the chemical bonds and formation of the (short lived) free radicals like hydroxyl, hydrogen atom (·OH and ·H), hydrogen peroxide and high energy electrons. The free radicals so produced, react with nucleic acids and the chemical bonds that bind one nucleic acid to another, thereby ultimately seizing the growth of microbes and insects (Rayas-Duarte and Rupnow, 1994; Yeh and Yeh, 1993; Ciesla *et al*., 1991).

Factors influencing the effects of irradiation on food

Irradiation Dose

Irradiation dose affects the rate of physicochemical changes that occur in the food product. At lower doses there is a linear relationship between the products formed and the dose. However, at higher doses, there occur secondary reactions between the compounds resulting in the formation of completely new products. I order to achieve the desired effect due to irradiation, the doses need to be optimized. In every application of food irradiation, the basic mechanism involves chemical changes which ultimately decides the amount (dose) of ionizing radiation to be received by the product (Diehl 2002, Bhat *et al*., 2007).

Moisture content

Moisture plays a key role in food irradiation. Water acts as a medium for the free radicals to move and interact with other food components. Free water is thus important in promoting the secondary effects of irradiation. This fact has been proven when food are irradiated in frozen state with the production of limited secondary effects. Secondary effects are also very limited if the moisture content is less than 12% (Hasselman and Marchioni, 1991; Kempner and Haigker, 1982; Rayas-Duarte and Rupnow, 1994).

Temperature

The primary effects of irradiation are independent of the temperature during irradiation. However, the secondary effects are highly temperature dependent. The role of temperature is very critical when irradiation is aimed at sterilization of foods like animal products, protein concentrates etc. Such foods are generally frozen prior to irradiation to minimize the free radical mobility and production of off flavor (Olson, 1998).

Atmosphere during irradiation

Free oxygen in the air behaves like a free radical and combines readily with the reactive compounds in the food matrix (Davis *et al*., 1987; Rayas-Duarte and Rupnow, 1994). In absence of oxygen, irradiation leads to decarboxylation, dehydration and polymerization. The commonly produced radiolytic products include carbon dioxide, carbon monoxide and aldehydes (Giroux and Lacroix, 1998).

Gamma irradiation of Cereals and Pulses

Currently, the legume industry relies on fumigation with methyl bromide (MeBr) for postharvest insect control (Carpenter *et al*., 2000). Since, MeBr leaves residues it possess some harmful health effects which include: abdominal pain, convulsions, dizziness, headache, vomiting, weakness, hallucinations, loss of speech and incoordination. In 2004, India imposed a non-tariff barrier requiring all imported legumes to be fumigated with MeBr and certified free of bruchids. However, most phytosanitary uses of MeBr were phased out in 2005 by the U.S. Environmental Protection Agency (EPA) under the Federal Clean Air Act and the Montreal Protocol. In addition, MeBr fumigation is only practical at treatment temperatures ≥5°C. Therefore, there is a need to develop a practical alternative to MeBr for control of insect pests in both cereals and pulses. At the same time, it is important that alternative must also have a minimum impact on product quality and environment.

Thermal treatment methods using hot air have also been investigated extensively as an alternative to Me Brfor disinfesting stored commodities (Fields, 1992; Dowdy, 1999; Dosland *et al*., 2006). Although heat treatment for the purpose of disinfestation is relatively easy to use, leaves no chemical residues, and may offer some anti-fungi activity, but, unfortunately, it is difficult to accomplish disinfestation using conventional hot air heating methods which may produce certain deleterious effects to product quality (Armstrong, 1994). It has also been observed that using certain appropriate temperature and time combinations required to killing the target insects may reduce the crop nutrients, germination or shelf life of the products (Evans *et al*., 1983). Another common difficulty with hot air heating methods is the slow rate of heat transfer due to a high resistance of conduction within bulk materials, resulting in hours of treatment times. On the other hand low heating rates may increase the thermo-tolerance of the targeted insects (Neven, 1998; Thomas and Shellie, 2000; Beckett and Morton, 2003; Yin *et al*., 2006).

Irradiation of cereals and legumes has emerged as a new technology for combatting the problems created by the insects and pests. The main advantage of the gamma irradiation technique is that it can be given after the product has been packed, thereby restricting the chances of cross contamination. The nutritive value, sensory acceptability and other related quality parameters of the cereals and related products can be retained if the doses are optimized and the product is irradiated at the optimized doses. Codex Alimentarius Commission and the World Health Organization (WHO) have adopted the standards for Irradiation of foods, which are practiced by more than 42 countries. Literature studies conducted for the effects of gamma irradiation on different cereals and grains are summarized below and highlighted in Table 1.

approximately 23% protein, 35% starch, 2% fat, and 4% ash (Hamid *et al*., 2016)

The prevention of insect infestation in cowpea seeds has been reported by Diop *et al*., (1997) by using low doses of gamma irradiation. The changes in the nutritive value of proteins and amino acid profiles by gamma irradiation up to 10kGy have been reported to be very small. The functional properties of the gamma irradiated (2, 10, 50 kGy) cowpea flours and pastes were studied by Abu *et al*., (2006) and they found that most of the functional properties related to proteins remained unaffected at low dosage levels, however, at higher dosage levels above 10kGy the functional properties, nitrogen solubility index, swelling and pasting properties significantly changed, which could be attributed to the structural changes in starch brought about by higher irradiation doses.

Buckwheat (*Fagopyrumesculentum)*, it belongs to Kingdom: Plantae, Order: Caryophyllales and Family: Polygonaceae

Buckwheat, a short-season crop, grows on low-fertility or acidic soils, with excellent drainage.

Table 1 Effects of gamma irradiation on cereals and pulses: A brief as reported under various studies conducted

Flour	Effects	Reference
Pearl millet	Decrease in leucine, glutamic acid and phenylalanine content	Elshazali *et al*., (2010)
	Decrease in tannin and phytate content	ElShazali *et al*., (2011)
	Increase in water absorption capacity and colour intensity while reduction in viscosity.	Falade and Kolawole (2013)
Tunisian millet	Increase in peroxide value, D_{10} values for total plate count and yeasts and molds was reported as 1.5 and 3.7k Gy respectively.	Mustapha *et al*., (2014)
Legumes	Reduced concentration of anti-nutritional factors, increase in phenolics, antioxidants and total free amino acids content.	Singh *et al*., (2014)
	Increase in water and oil absorption capacity and antioxidant properties.	Jabeen *et al*., (2015)
Sorghum	Decrease in hemicellulose content and increase in digestibility coefficient	Mekkawy, (1996)
	Alpha and beta amylase activity was decreased by 22% and 32% respectively; decrease in microbial load.	Mukisa *et al*., (2011)
Rice	Reduction in ageing time; improvement in processing stability and quality of the products made from the irradiated flours.	Sung, (2005)
	Disinfestation of grains and decreased pasting properties	Zanao *et al*., (2009)
Buckwheat	Increase in peroxide value; decreased viscosity. Oxygen absorbers decreased peroxide value.	Muramatu *et al*., (1991)
Cowpea	Disinfestation, decrease in amino acid content at higher doses	Diop *et al*., (1997)
	Above 10k Gy the functional properties, nitrogen solubility index, swelling and pasting properties decreased.	Abu *et al*., (2006)
Wheat	Increase in water soluble protein and total sugar content and more darker colour with irradiation.	El-Nashaby (1996),
	Combined gamma radiation (1.5 kGy) and infrared radiations for 180 seconds resulted in 96.0% adult mortalities	Mohamed and Mikhaiel (2013)
	Decrease in carotenoid content and reduced viscosity of the starch pastes,increase in the reducing sugar content	Deschreider (1996)
	Reduction in total plate count and cysteine content; increased whiteness in noodles	ManLi *et al*., (2012)

Cowpea (*Vigna unguiculata*), it belongs to Kingdom: Plantae, Order: Fabales and Family: Fabaceae.

Cowpea is one of the most ancient human food sources and has been reported to be used as a crop plant since Neolithic times. Cowpea is now grown throughout the tropics and subtropics and has become a part of the diet of about 110 million people. Its production has spread to East and Central Africa, India, Asia, South and Central America.Cowpea is a rich source of protein for people who cannot afford proteins from animal sources such as meat and fish and are often referred to as poor man's meat. It has been estimated that worldwide area of production of cowpeas is approximately 10.1 million hectares with annual global grain production being approximately 4.99 million tons. In India cowpea is grown on an area of 3.9 million hectares with a production of 2.21 million tonnes with the national productivity of 683 kg per ha. It contains

Too much fertilizers, especially nitrogen, reduces the yield. In hot climates it can only be grown by sowing late during the season, so that the onset of blooming occur during the cold weather. Russia is the major producer of buckwheat followed by China. The major composition of buckwheat consists of 3% fat, 3% ash, 75% starch (25% amylose and 75% amylopectin), 17% protein and approximately 0.1% polyphenols.

Muramatu *et al*., (1989) studied the effects of gamma irradiation (3, 4, 5, 6 and 7 kGy) and electron beam (2 MeV) on the microbial load of buckwheat flour and the products prepared from the irradiated flour. They found that the peroxide value of lipid in buckwheat flour increased with absorbed dose of both gamma-rays and electron beams. However, oxygen absorbers reduced the production of peroxide value. Irradiation also resulted in the decrease of viscosity of dough. The usage of oxygen absorber was found to have resulted in a high sensory score of noodles prepared from irradiated buckwheat flour with minimal changes in color, flavor and texture.

Wheat (*Triticum* sp.), it belongs to Kingdom: Plantae, Order: Poales, Family: Poaceae and Subfamily: Pooideae.

Wheat is an important cereal crop and ranks third in production after maize and rice around the globe. It is the second most important winter cereal in India after rice contributing substantially to the national food security by providing more than 50% of the total calories to the people who mainly depend on it. The annual global wheat production during the year 2014–15 was 717 million metric tonnes and is estimated to reach 720 million metric tonnes during 2015–16, among which India is expected to produce 95 million metric tonnes. It contains approximately 72% carbohydrates, 2% fat, 12% protein and 3% ash (State of Indian Agriculture, 2014-15; Bashir *et al*., 2017; International Grains Council, 2014)

El-Nasha by (1996), studied the effects of different doses of gamma irradiation (2.5, 5 and 10 kGy) on physiochemical, rheological and bread quality of the Egyptian wheat flour. They observed that gamma irradiation does not cause any change in the proximate composition of wheat. However, water soluble proteins and total sugar content increased with storage time for both non-irradiated and irradiated samples. The rheological properties of the dough were found to have modified. Irradiation resulted in darker colour of the crumb while the taste and freshness were retained. A significant enhancement in the loaf weight and volume was obtained with increase in the irradiation dosage.

Amer *et al*., (2007) found that gamma irradiation of the wheat flour up to doses of 7.5 kGy showed improvement in baking and rheological properties but be yond that farino graph, amylo graph and extensor graph properties were found to be changed, which can be attributed to the irradiation induced changes in starch and gluten network.

Mohamed and Mikhaiel (2013) studied the effects of infrared and gamma irradiation (1.5 kGy) on insects in stored wheat grains. They reported that the infrared radiations for 180 seconds (in order to achieve 64.8^{o}C) gave about 60% adult mortality. However, the combined gamma radiation (1.5 kGy) with the equivalent doses of infrared gave 96.0% adult mortalities for the same insects.

Deschreider (1996) studied the effects of gamma irradiation on the carotenoids of the oily fraction of the wheat and reported that the carotenoid content on irradiation gets reduced and further at higher doses (4 Mrad) were undetected. However, they reported that the chemical composition remained unchanged at all doses. They also reported an increase in the reducing sugar content as the irradiation dose was increased. Gamma irradiation was also found to have reduced the viscosity of starch pastes besides increasing the solubility of amylopectin. Areduction in the proteolytic activity of flour was also observed in the case of high doses, which could be attributed not only to the partial denaturation of the proteins but also their polymerization and/or condensation. The polymerization was explained by the reaction of free radicals with the gluten proteins having -SH groups and by the interaction of primary radicals in the protein macromolecules during irradiation. At low gamma radiation doses (0.2 to 1.5 kGy) improvement in the baking properties of the products was observed.

Manupriya *et al*., (2015) studied the changes in total carbohydrate and total antioxidant activity induced by gamma irradiation in wheat flour. They observed that an increase in the antioxidant content of the wheat flour when subjected to the gamma irradiation. Christian *et al*., (2012) reported that falling number of the wheat flour decreased with gamma irradiation (0, 1, 3 and 9 kGy) and took it as a positive effect for bread making process. They also reported an increase in the weight of Pan breads prepared from irradiated wheat flour. Texture analysis displayed a decrease in maximum deformation force for the bread. The disinfestation of the stored wheat grain and flour by gamma rays and microwave heating was studied by El-Naggar and Mikhaiel, (2011), they reported that all the insects were killed within 24 h when gamma irradiation (0.5, 1, 2 and 4 kGy) and microwave were used in the combination for only 30s. They also reported no detectable change in the quality parameters of the wheat grain and wheat flour. However, the germination of the wheat grain was reduced when subjected to microwave but no effect was observed in case of gamma irradiation up to dosage level of 1kGy.

ManLi *et al*., (2012) evaluated the quality parameters of the wheat flour and shelf life of fresh noodles when treated with ozone treatment. Their study revealed that the TPC can be greatly reduced in the wheat flour when treated with ozone. They also found an increased trend in the whiteness of the noodles and flour, dough stability, while the cysteine content was reduced. The noodles showed an increased firmness, springiness and chewiness but the adhesiveness was reduced.

Rice (*Oryza sativa*), it belongs to Kingdom: Plantae, Order:

Poales and Family: Poaceae.

Rice is the most widely consumed staple food by large part of the world's population. It ranks third in terms of production after sugarcane and maize. Rice is an important staple food crop for more than 60% of the world people. Rice is a semiaquatic, annual grass plant and is cultivated in wide range of soil types. It contains approximately 75% carbohydrates, 1% fat, 10% protein and 2% ash.

Sung, (2005) studied the effects of different doses of gamma irradiation (0, 0.01, 0.1, and 1.0 kGy) on the physicochemical properties of the two rice varieties and the products prepared from them. The results revealed that the gamma irradiation reduced the ageing time and improved the processing stability and quality of the products made from the irradiated flours. Zanao *et al*., (2009) studied the effect of gamma irradiation (0.5, 1, 3 and 5 kGy) on physicochemical (grain breakage, longevity composition, apparent amylose content, starch paste properties and colour) and sensory characteristics of raw and cooked rice. They observed that gamma irradiation did not change the percentage of grain breakage during the enrichment process and that irradiation caused a negative effect on the development of insects. The irradiation did not change significantly the percentage composition and the apparent amylase content. Pasting properties decreased with irradiation dose.

Sorghum (*Sorghum*sps), it belongs to Kingdom: Plantae, Order: Poales, Family: Poaceae, and Subfamily: Panicoideae

Sorghum is widely cultivated in Australia and seventeen of the twenty-five species are native to Australia with the range of some extending to Africa, Asia, and certain islands in the Indian and the Pacific Oceans. Sorghum is mainly composed of about 72% carbohydrates, 3 % fat, 9% protein and 2% ash.

Mekkawy, (1996) irradiated sorghum grains with different doses of gamma irradiation (10, 50, 100, 150 and 200 KGy). He found that gamma irradiation had no effect on total protein, fat and ash contents of sorghum grains. Irradiation treatments of sorghum did not cause a pronounced effect on tannic acid content even the ones which received the highest irradiation dose (200 kGy). Tannic acid is a polyphenol, that has found wide applications in food industry (beer, wine clarification, aroma compound and colour stabilizer in soft drinks and juices). Hemicellulose content was found to have decreased with the increase of irradiation dose levels. Also, it was noticed that feeding rats on basal diets enriched with irradiated sorghum grains had a beneficial effects on digestibility coefficient. Mukisa *et al*., (2011) studied the effects of gamma irradiation (10 and 10+25 kGy) on microbial inactivation, amylase activity and other properties of sorghum flour. They found that the gamma irradiation reduced the activity of amylases (alpha and beta) by 22% and 32% respectively. Irradiation had resulted into more dense porridge products, which they attributed to depolymerisation of starch by gamma irradiation. They also observeda decrease in the microbial load with increase in irradiation doses.

Millets (*Pennisetum* sps), they belong to Kingdom: Plantae, Order: Poales, Family: Poaceae, Subfamily: Panicoideae.

Millets are a group of small-seeded grasses, widely grown around the world for fodder and human food. Millets are important crops in the semiarid tropics of Asia and Africa (especially in India, Mali, Nigeria, and Niger), with 97% of millet production in developing countries. The crop is favoured due to its productivity and short growing season under dry, high-temperature conditions. The most widely grown millet is pearl millet, which is an important crop in India and parts of Africa. Africa is the major producer of millets, followed by India and China. Millets are mainly composed of about 73% carbohydrates, 4 % fat, 11% protein and 3% ash.

Elshazali *et al*., (2010) studied the effects of gamma irradiation (2 kGy) process on total protein and amino acids composition of raw and processed pearl millet flour during storage. They found that except the amino acids leucine, glutamic acid and phenylalanine, most of the other amino acids were stable against all treatments. ElShazali *et al*., (2011) studied protein digestibility, anti-nutrients and sensory quality of pearl millet flour when treated with gamma irradiation (2 kGy). According to the studies conducted by them, gamma irradiation alone has no effect on the tannin and phytate content, but when followed by cooking the amount was found to have significantly reduced. They also reported that the quality attributes of the flour were improved. The color, functional and physiochemical properties of pearl millet at irradiation doses of 2, 4, 6 and 8 kGy was also studied by Falade and Kolawole (2013). In their study they reported that the color intensity was increased by irradiation. Irradiation also resulted in increased water absorption capacity while viscosity was found to have decreased.

The microbiological, antioxidant and physiochemical properties of the Tunisian millet treated with gamma irradiation (1, 2, 3 and 5 kGy) were studied by Mustapha *et al*., (2014), they reported the D_{10} (logarithmic reduction dose) values for total plate count, yeasts and molds as 1.5 and 3.7 kGy respectively. Likewise, gamma irradiation did not alter the fatty acid composition significantly, but the peroxide value increased from the reference value of 26.16 to 34.43 meq O_2/Kg.

Pulses

Pulses are an excellent source of protein, dietary fibre, essential vitamins and minerals. These grains complement proteins from other plant sources, such as, cereal grains, contributing essential amino acids in many parts of world, to the predominantly vegetarian diets. Protein content varries between 15 to 40% depending on the legume, variety and growing conditions. Bioactive components, such as isoflavones and peptides are beneficial for the prevention of cancer and cardiovascular diseases. Legumes mixed with an equal proportion of water, can be used as an egg-replacer in vegan cooking because of its high protein content (Bashir *et al*., 2012; Singh *et al*., 2014; Bashir and Aggarwal, 2016)

Jabeen *et al*., (2015) studied the impact of irradiation (1 kGy) on nutritional quality and functional properties of soy flour and sprouted soy flour. They found that the functional properties (water and oil absorption capacity) of the flour were improved with increased dosage. They also reported that there was an increase inthe antioxidant properties with dosage for both normal and sprouted flour.

Singh *et al*., (2014) studied the effects of gamma irradiation processing (1, 2, 3, 4 and 5 K Gy) on the nutritional quality of legumes (green mung, masur, brown chickpea and kabuli chickpea. They observed that radiation significantly reduces the concentration of anti-nutritional factors in legumes in a dose dependent manner. However, antioxidant and total free amino acid content increased with dosage.

Khattak and Klopfenstein (1989) studied the effects of gamma irradiation (0.5, 1, 2.5 and 5 kGy) on the nutritional quality of grains and legumes with respect to the amino acid profile and available lysine. They reported losses of certain amino acids in the irradiated samples but the available lysine content in the irradiated samples was higher.

Regulatory status on the use of gamma irradiation for cereals and pulses

More than 100 countries have adopted irradiation technology and about 60 different irradiated food products are available in the market, the major ones include potato, onion, meat etc. According to the American Council on Science and Health, in 2003, about 7,000 supermarkets and other retail stores in the US were selling irradiated ground beef. Food irradiation of foods has been approved by the CODEX, Food Safety and Standards Authority of India (FSSAI), Food Standards Australia New Zealand, American Medical Association, the Institute of Food Technologists, International Atomic Energy Agency (IAEA), Food and Agriculture Organisation (FAO), World Health Organisation (WHO). As per the CODEX, the foods having moisture content of less than 12% can be re-irradiated if the objective was not achieved. The CODEX and FAO recommends the use of gamma irradiation for cereals and pulses as maximum of 1 kGy for disinfestation and maximum of 5 kGy for reduction of microbial load.

CONCLUSION

Application of gamma irradiation has shown promising results in extending the shelf life of cereals and pulses by disinfestation and preventing microbial growth. Irradiation has also resulted in increased antioxidant properties besides decreasing the anti-nutritional content of the grains. Food irradiation has been approved by the CODEX, Food Safety and Standards Authority of India (FSSAI), Food Standards Australia New Zealand, American Medical Association, the Institute of Food Technologists, International Atomic Energy Agency (IAEA), Food and Agriculture Organisation (FAO), World Health Organisation (WHO). In spite of the importance of communicating information about food irradiation to consumers, it is also important for regulators and producers to know the consumers general attitude to the technology. This includes trust in regulators and producers and risk perception associated with the use of ionizing radiation in food processing. However, more research is needed to evaluate the mechanism of action of different doses of gamma irradiation on the most important pathogens found in different foods and to optimize the doses. Gamma irradiation seems to be one of the promising techniques of future to be used to meet the ever growing consumer demands for safe food, food security and enhanced food shelf life so as to feed the huge population and to approach the distant markets while maintaining high quality of the food.

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