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Food irradiation: A review

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Abstract
Consumers expect that the food they eat must be safe. In addition, consumers also wants the food to have high nutritional value with minimal preparation times, as evidenced by the growth in products such as convenience ready to eat and minimally processed fresh produce. In order to meet these demands, food manufacturer are looking for new method and technologies. One such technology is irradiation. Irradiation is non-thermal food preservation technique which is used to extend and enhance the shelf life of fresh or processed foods. Food irradiation is an energy-efficient, non-chemical method of food processing that can help reduce those huge losses occurring due to spoilage or contamination by harmful bacteria and other parasitic life forms. It involves exposure of foods to ionizing radiations either pre-packaged or in bulk to reduce the risk of foodborne illness, delaying or eliminating sprouting or ripening. Gamma rays, electron beams, and x-rays are used for irradiation of foods. Properly treated, irradiated foods retain their fresh appearance, flavour, and nutritional value, while most foods can be pre-packaged before irradiation, reducing the risk of re-contamination. The inactivation mechanism involves two processes either direct or indirect method. Ionizing radiations kills microbes directly by damaging biomolecules of cells. When incoming photons hit the microbes or food molecules, collisions occur, as a result, the microbes die**.** Irradiation doses can be generated using Cobalt-60 as an radiation source. Electron beams are propelled out of an electron gun with streams of high-energy electrons. Electron beam accelerators are used in X-ray facility to target electrons on metal plate.
Exposure time depends upon the characteristics of food and the doses of irradiation. Irradiation dose is measured as gray (Gy). This is a measure of the amount of energy transferred to food, microbe or other substance being irradiated. The most commonly products used for irradiation are fresh fruits and vegetables (strawberry, mangoes, guava, tomato, potato, garlic etc, cereals and cereal products (wheat, rice, barley, flour etc).

Keywords: Non-thermal technology, ionizing radiation, microbial inactivation, shelf-life

Introduction
Consumers are aware of the health benefits and risks associated with consumption of food. The food industry is devoting considerable resources and expertise to the production of wholesome and safe products in order to meet consumers expectations. Food contamination can be prevented by scrutinizing materials entering the food chain, storing the food at chilling temperature, and reduction or destruction of microbial load by processing and preventing post-processing contamination. Of primary importance to ascertain safety and stability of foods, the unit operation aiming at microbial destruction is of primary importance. Traditionally heat treatments are applied for pasteurization and sterilization of foods but at the expense of its sensory and nutritional qualities. Consumers consider fresh foods healthier than heat treated foods, food industry is seeking alternative technologies to maintain most of the fresh attributes, safety and storage stability of food (Ahvenainen, 1996) [2]. Which depends up on reliable estimation of its efficacy against pathogenic and spoilage food-borne microorganisms. However, success of these new technologies depends on progress in understanding microbial physiology and behavior of microbial cells during and after treatment (Beatrice & Ahmad, 2002) [5].
Food irradiation is one of the recent food preservation technologies which can be used to address some of these problems. It is a physical process which has been thoroughly researched and is as well-understood as other methods of food processing, or more so. The potential of food irradiation processing to reduce postharvest losses of foods, to meet quarantine requirements, to increase exports and to ensure the hygienic quality of foods has been increasingly recognized by many countries (Loaharanu & Ahmad, 1991) [23].

Irradiation is the process of applying low levels of radiant energy to a material to sterilize or preserve it. It is a physical means of food processing that involves exposing the prepackaged or bulk foodstuffs to gamma rays, x-rays, or electrons. Gamma radiations from radioisotope source, or electrons or x- rays generated using an electron accelerator are generally used for irradiation of foodstuffs (Mahapatra *et al.*, 2007) [24]. Only gamma-rays emitted from Cobalt-60 and Cesium-137, and X-rays generated from a machine operated at or below 5 MeV and electrons from a machine at or below 10 MeV can be used for food irradiation (FAO, 1984). The use of radiation in the prescribed energy levels does not induce radioactivity in food. Thus, food treated by irradiation is not radioactive regardless of the radiation dose absorbed. Food irradiation is carried out in a shielded room which does not permit radiation escaping during operation (Loaharanu & Ahmed, 1991) [23].

Sources of irradiation

Gamma rays

Gamma irradiation is produced from the radioisotopes cobalt-60 and caesium-137, which are derived by neutron bombardment of cobalt-59 and as a nuclear source by-product, respectively (Fellows, 2018) [17]. Cobalt-60 is normally used for food irradiation. It is a metal source doubly encapsulated in stainless steel. When the source is not in use, it is housed in a shielded container or in a pool of water which absorbs all radiation. It does not produce any waste, as the decayed source is returned to the supplier either for replenishing or retention. For food irradiation cobalt-60 is the most common source of gamma irradiation in foods in commercial scale facilities as it is water insoluble and hence has little risk of environmental contamination by leakage into the water systems (Fellows, 2018) [17]. In order to prevent the release of radiation and meet standards mentioned in the Regulations for Safe Transport of Radioactive Materials of the International Atomic Energy Act, it is necessary to transport Cobalt-60 in special trucks that must meet high safety standards and pass extensive tests to be approved to ship radiation sources. In comparison to cobalt-60, cesium-137 is water soluble and poses a risk of environmental contamination.

Electron beam

It is created as a result of high energy electrons in an accelerator that generates electrons accelerated to 99% the speed of light and can be powered on and off. Electron beam has higher throughput and low cost but have disadvantage of low dose uniformity and a penetration depth of centimeters. Therefore, it is used for treating the foods of less thickness (Fellows, 2018) [17].

X-rays

X-rays are produced by bombardment of dense target material with high energy accelerated electrons (this process is known as bremsstrahlung-conversion), giving rise to a continuous energy spectrum (Fellows, 2018) [17]. Tantalum and tungsten (heavy metals) are used because of their high atomic numbers and high melting temperatures while the former one is preferred for industrial, large-area, high-power targets and has higher threshold energy for induced reactions and is more workable than tungsten (Marshall & Stilchelbaut, 2009) [26]. Like electron beams, x-rays do not require the use of radioactive source and can be turned off when not in use. X-rays have high penetration depth and high dose uniformity but they are a very expensive source of irradiation as only 8% of the incident energy is converted into X-rays (Fellows, 2018) [17].

Mechanism of ionizing radiations

The DNA in the chromosomes is the most critical target of ionizing radiation. Effects on the cytoplasmic membrane appear to play an additional important role in radiation-induced damage of cells. Although changes caused by radiation at the cellular level, the consequences of these changes vary with the microorganism (Mahapatra *et al.*, 2006). Damage to the cells by irradiation can be caused directly or indirectly on the DNA molecules. When irradiation hits the DNA molecule directly, it results in the disruption of molecular structure of DNA, leading to the cell damage or cell death. Carcinogenesis or other abnormalities may be induced later if damaged ells survive. The radiation hits indirectly the water molecules, the major constituent of the cell, and other organic molecules in the cell, whereby free radicals such as hydroxyl (HO) and alkoxy (RO2) are produced, which are characterized by an unpaired electron in the structure, which is very reactive, and therefore reacts with DNA molecules to cause a molecular structural damage. Hydrogen peroxide, H2O2, is also considered toxic to the DNA molecule. The effect of free radicles on DNA molecules is the impairment of function or death of the cell. Their production depends upon the total dose. It has been found that the majority of radiation induced damage results from the indirect action because water constitutes nearly 70% of the composition of the cell (Desouky *et al.*, 2015) [10]. In addition to the damage caused by water radiolysis products, cellular damage may also involve reactive nitrogen species (RNS) and other species and can occur also due to the ionization of atoms on constitutive key molecules as in DNA (Wardman, 2009) [37]. The ultimate result, of direct and indirect effects, is the development of biological and physiological, as well as genetic and epigenetic alterations that may manifest themselves seconds or decades later (Desouky *et al.*, 2015) [10]. The principal lesions induced by ionizing radiation in intracellular DNA are chemical damage to the purine and pyrimidine bases and to de-oxyribose sugar and physic-chemical damage resulting in a break in the phosphor di-ester backbone in one strand of the molecule (single-strand break) or in both strands at the same place (double-strand break). Double-strand breaks are produced by ionizing radiation at about 5 to 10% of the rate for single-strand breaks. Most microorganisms can repair single-strand breaks. The more sensitive microorganisms, such as *Escherichia coli*, cannot repair double-strand breaks, but highly resistant species (e.g., *Deinococcus* sp.) are able to repair both single- and double-strand breaks (Farkas, 2007) [16]. The potential application of ionizing radiation to food products is based mainly on the fact that ionizing radiation very effectively damages DNA so that cell division is impaired. Given the right doses, this impairment is obtained without serious effects on the food itself. Irradiation offers a broad scope also as a quarantine treatment for fresh produce (Farkas, 2007) [16]. In those parts of the world where the transport of food is difficult and where refrigerated storage of food is scarce and extremely expensive, the use of ionizing radiation may facilitate wider distribution of some food than would otherwise be feasible. In this way, a more varied and possibly nutritionally superior diet may become available to the residents.

Application of ionizing radiation to foods is limited to the use of high-energy electromagnetic radiation (gamma rays of

60Co or X rays) with energies up to 5 MeV or electrons from electron accelerators with energies up to 10 MeV. These types of radiation are chosen because (i) they produce the desired effects in foods, (ii) they do not induce radioactivity in foods or packaging materials, and (iii) they are available in quantities and at costs that allow commercial use of the process. The penetration depths of electron beams and X or gamma rays into matter are different. The practical usable depth limit for 10-MeV electrons in water-equivalent material is 3.9 cm, and the so-called half-thickness value for 5-MeV X rays is 23.0 cm. Except for different depths of penetration, electromagnetic radiation and electrons are equivalent in food irradiation and can be used interchangeably (Farkas, 2007) [16]. Radiation sensitivity is roughly inversely proportional to the size and complexity of an organism.

Factors affecting the Food irradiation process

Medium

The composition of the medium surrounding the microorganisms plays an important role in the dose requirement necessary to achieve a given effect. In general, the more complex the medium, the greater the competition of the medium components for the free radicals formed from water and the activated molecules produced by the radiation, thus protecting the microorganisms. Buchanan *et al.*, 1999 [8], reported that prior growth at acidic conditions increased the resistance of *E. coli* O157:H7 to ionizing radiation at acidic pH. It is impossible to predict the foods in which particular bacterial cells will be more radiation sensitive or radiation resistant.

Water activity

As in heat treatment, a reduction in the moisture content (reduction of aw) of the food protects microorganisms against the lethal effect of ionizing radiation. Under drier conditions, the yield of free radicals produced from water by radiation is lower, and thus the indirect DNA damage that the free radicals may cause is decreased.

Temperature

Temperature at which a product is treated may influence the radiation resistance of microorganisms. For vegetative cells, elevated-temperature treatments, generally those with temperatures in the sub-lethal range above 45ºC, synergistically enhance the lethal effect of radiation. This enhancement is thought to occur because the repair systems, which normally operate at ambient and slightly above ambient temperatures, are damaged at higher temperatures.

Freezing

Freezing causes a striking increase in the radiation resistance of vegetative cells. Microbial radiation resistance in frozen foods is about two or threefold higher than that at ambient temperature. This increase is due to the immobilization of the free radicals and prevention of their diffusion when the medium is frozen. Thus, in the frozen state, the indirect DNA damage by OH radicals is nearly prevented. The change in resistance with temperature demonstrates the importance of the indirect action in high-moisture foods.

Oxygen

The lethal effect of ionizing radiation on microbial cells increases in the presence of oxygen (Thayer & Boyd, 1999) [33]. In the total absence of oxygen, and in wet conditions, radiation resistance usually increases by a factor of 2 to 4. In dry conditions, the radiation resistance might increase by a factor of 8 to 17 (Farkas, 2007) [16].

Gamma irradiation facilities

Cobalt-60 emits the gamma rays with the energies of 1.17 and 1.33 MeV while as cesium-137 emits gamma rays with the energy of 0.66 MEV. The Cobalt-60 is a radioactive metal that decays with a half-life of around 5.3 years. Although Cesium-137 has a longer half-life of around 30.1 years, few commercial gamma facilities use Cesium-137 as a gamma ray source because, of low energy of emitted radiations that are approximately half the energy than those emitted by cobalt-60 (Suresh *et al.*, 2005) [31]. Gamma rays are suitable for treating large bulk packages of food than electron beams due to their high penetration depth. But the gamma radiations cannot be switched off. So, when they are not in use, they must be stored in a water pool to absorb the radiation energy and protect workers from exposure if they must enter the irradiation room (Hvizdzak *et al*., 2010) [20].

Electron beam facility

Machines are used to produce electron beams, generated by accelerating a stream of electrons, which are focused into a narrow beam-spot. As food is perpendicular to the beam direction, this spot of incident electrons is scanned across food (Suresh *et al.*, 2005) [31]. In comparison to gamma rays, e-beam offer three distinctive advantages: firstly, use of radioactive element is eliminated. Secondly when not in use can be turned off; and last one is that they are characterized by low penetration depth and high dosage rates. Therefore, it can effectively be used to inactivate foodborne pathogens on the surface of the slices, with the least negative effect (Hvizdzak *et al.*, 2010) [20].

X-ray facility

X-rays are generated by machines and can be switched off. Machine generated electrons are accelerated at a metallic target (*e.g.*, tungsten or gold) to generate a stream of X-rays. In this process energy is lost as heat; however the X-ray efficiency can be increased with atomic number of the target material and also with increasing E-beam energy. X-ray facilities can be used to process large bulk produce without using any radioactive material; but very few products are irradiated by using X-rays nowadays (Follett, 2004) [18]. Advancement in X-ray technology will diversify its use in future. But, it seems that, the commercial food irradiation facilities will continue use of gamma rays for a long period (Kume *et al.*, 2009) [22].

Irradiation of fruits and vegetables

Irradiation is applied to fruits and vegetables to extend their shelf life and enhance their quality. During storage, fruits and vegetables undergo postharvest quality losses due to inappropriate storage conditions, pathogenic attacks, mechanical injuries and environmental stresses which are global horticulture problems resulting every year in substantial losses of fresh produce (Zhang *et al*., 2011) [39]. To minimize such loses during storage, fumigation and synthetic chemicals are used to extend the shelf life of fruits and vegetables, but because of potential health risks and environmental problems they are vigilantly accepted by consumers (Majeed *et al.*, 2014) [25].

Sau *et al.*, 2018 [30] studied the impact of low doses of gamma irradiation on off- season guava at ambient storage condition. Bio- chemical and physical parameters like shelf life,

unmarketable fruit percent, weight loss, TSS, Sugar content etc. and even in all the sensory observed parameters of off-season guava, stored at ambient storage condition were improved. Majeed *et al*., 2014 [25], reported that shelf life of strawberry can be extended by gamma irradiation doses of 1 and 1.5 kGy. Same irradiation doses retarded the decay and weight loss to significant extent without causing any apparent damage to fruits. He, concluded that the irradiation dose of 1.0 and 1.5 kGy can be effectively used for extension of shelf life and for minimizing postharvest decay and weight loss of strawberry without causing drastic changes in its pH, TSS ad TA. Desai and joshi, 2018 [9] studied the effect of gamma irradiation on physic-chemical properties and shelf life of tomatoes. They irradiated the breaker stage (BS) and light red stage (LS) tomatoes and stored them at 28±1^{0}C and 14±1^{0}C temperatures. Increase in irradiation dose from 1.0 KGy to 4.0 KGy resulted in lower physiological loss in weight, higher firmness, higher skin resistance, lower "a" value of color, lower spoilage, higher titratable acidity and lower lycopene content in BS during storage while as higher physiological loss in weight, lower titratable acidity and higher lycopene content during storage was observed in LS tomatoes stored at 14±1^{0}C as compared to LS irradiated tomatoes stored at 28±1^{0}C. Sugars are the only component to undergo significant modification, which account for nearly 99% of the reactions in the irradiated mangoes. Starch (0.2%), protein (0.2%), phenol (0.4%), and ascorbic acid (0.2%) are other components which are slightly reactive when mangoes were irradiated. As reported by, Basson *et al.*, 1979 [4], only carbohydrate degradation needs to be considered, as its eactivity tends to protect other components from degradation. Susheela *et al.*, 1996 irradiated the pine apple (*Ananas comosus*) and reported that no significant loss of sugar and ascorbic contents was found in three quarter ripe and fully ripe pineapples. The fully ripen pine apples which were stored at 25-29 ºC with 90-97% RH after irradiated with 0.05, 0.1 and 0.15 kGy maintained their texture better than control. Irradiation of grape fruits was carried out by vanamala *et al.*, 2007 [34], at different doses 0, 0.15, and 0.3 kGy followed by their storage for 36 days at 10 ^{0}C, followed by additional storage for 20 days at 20^{0}C. During their storage period, irradiation doses not result in the considerable changes in total soluble solids, but acid content of grape fruit declined during storage. Higher acidity was observed in samples irradiated with 0.3 kGy. Moreover, their results suggest that low-dose irradiation at 0.3 kGy enhanced or at least maintained the flavonoid content. Irradiation of gala apples at 0.60 kGy and above reduce the titratable acidity while as no, loss of titratable acidity was evident for granny smith apples as reported by Drake *et al*., 1999 [13]. Electron beam were used to irradiate the fresh Tristar strawberries at irradiation dose of 0, 1, and 2 kGy. With increase in irradiation dose, firmness of strawberries decreased and was correlated to oxalate soluble pectin content that decreased at 0 and 1 day after 1 and 2 kGy. However, increase in water soluble pectin was observed. Firmness and oxalate- soluble pectin increased slightly in beginning of 2 ^{0}C and then decreased with storage period. Total pectin content was not effected during storage. These results were reported by Yu *et al.*, 1996 [38].

Irradiation can be used as a quarantine treatment in fruits like cherries, apricots or peaches, resulting in less quality loss. Small differences in stem conditions and bruising were more evident in irradiated cherries than cherries treated with methylbromide. Loss of firmness was also seen in irradiated cherries than MeBr treated cherries. However no loss of fruit and stem color were observed in irradiated cherries than MeBr treated cherries. Little loss of quality was seen in apricots and peaches (regina) at irradiation dose of 0.3 kGY. At dose level of 0.6 kGy, firmness, color changes and increased internal breakdown were apparent in both apricots and peaches. These results were reported by Drake *et al.*, 1998. Buchanan *et al*., 1998 [7], reported that the low irradiation doses can be used to eliminate pathogenic bacteria from apple juices and other fruit juices. *E. coli* O157: H7 could be readily eliminated from fresh apple juice by using low doses irradiation while maintain the product at refrigerated conditions. Juice of Golden Empress cantaloupe that was irradiated with cobalt-60 were analyzed for enzymatic activity. Wang *et al.*, 2006 [36] reported that lipoxygenase was easiest one to be inactivated, followed by polyphenoloxidase and peroxidase. However, at irradiation dose of 5 kGy, all the three enzymes were active. Plaque assays of HAV virus following exposure to various doses of gamma irradiation indicated a gradual and linear log10 reduction pattern of inactivation in virus titre (PFU) was observed as the irradiation dose was increased. For 1 log reduction (90 %) in HAV population irradiation doses of 2.72 and 2.97 were required. No noticeable deterioration was observed in texture and appearance of either lettuce or the strawberries, even at the highest dose of 10 kGy (Bidawid *et al*., 2000) [6]. Effects of irradiation on dehydration characteristics and quality of apples (Fuji Aples) were studied by wang and chao, 2003 [35]. Higher dehydration rate, less vitamin C content and lower rehydration ratio was shown with increase in irradiation dose (1.5, 4.5, 5, and 6 kGy).

Irradiation of cereals and pulses

Gamma irradiation plays an important role in preventing the insect infestation. Various cereals and cereal products have been subjected to irradiation to prevent them from spoilage. Diop *et al.*, 1997 [11], reported that the Low doses of gamma irradiation have been used to prevent the insect infestation of cowpea seeds. Very small changes in amino acid profile and nutritive value of proteins have been reported. Abu *et al.*, 2006 [1] studied the effect of gamma irradiation (2,10, 50 kGy) on functional properties (nitrogen solubility index, swelling and pasting properties) of cowpea flours and pastes. They reported that functional properties remained unaffected at low dosage levels, but have changing effect at high doses (above 10 kGy), which could be attributed to structural changes in starch brought about by higher irradiation doses. Increase in peroxide value of buckwheat flour was observed with the increased irradiation doses (3, 4, 5, 6 and 7 kGy) and x-ray (2 MeV). However, production of peroxide value decreased by using oxygen absorbers which resulted in high sensory scores of noodles prepared from irradiated buckwheat flour with minimal changes in color, flavor and texture (Muramatu *et al*., 1991) [28]. El-Nasha (1996) [15], 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. No change was observed in proximate composition of irradiated wheat flour. Modifications was observed in rheological properties of dough. However, with storage time, water soluble proteins and total sugar content increased for both irradiated and non-irradiated samples. Freshness and taste was retained while as dark color was observed in crumbs of irradiated samples. With the increase in irradiation dose, enhancement in the loaf weight and volume was obtained. Gamma irradiated Egyptian wheat flour (upto 25 kGy) was used to prepared the bread and Physical,

rheological and baking properties of bread and acceptability of bread by sensory tests was studied by Amer *et al*., 2007 [3]. With the increase in irradiation doses, pH, amylograph, farinograph and extensograph characteristics showed significant decrease. Decrease in such characteristics resulted in the loss of unique elastic and cohesive properties of wheat gluten and starch damage upon increment of radiation dose. However, the bread irradiated with 7.5 kGy showed the improvement in the properties of bread but lower values of acceptance because of because of physico-chemical changes in both starch and gluten. Mohamed and Mikhaiel 2013 [27], applied infrared and gamma irradiation dose to newly emerging adults of T. granarium, T. castaneum, S. granaries and R. dominica in wheat flour. Infrared dose of 180 seconds gave the mortality of about 60.00% and 44.67 % for T. granarium, 58.67 % and 39.33 % mortality for T. castaneum on distance of 4 cm in 50 and 100 gram wheat flour respectively. Infrared dose in combination with gamma irradiation dose of 1500 Gy gave mortality of 96% and 86% for T. granarium and 90 % and 78 % mortality for T. castaneum in 50 gram and 100 gram flour respectively. El-Naggar & Mikhaiel, 2011 [14], reported that irradiation in combination with microwave heating for 30 seconds resulted in the death of insects within 24 hours. He stated at irradiation doses of 1 and 2 kGy, larva of T. confusam and C. cephalinica required 7 days to die and the same larva died in 1 day at dose of 4 kGy. They also reported no change in the quality parameters of the wheat grain and wheat flour. However, on subjecting the wheat grain to microwave heating, its germination was reduced while no effect was seen in case of gamma irradiated (1kGy) wheat grain. Changes in the chemical characteristics were induced in the gamma irradiated wheat grains and flour at dose level of 1kGy. Decrease in crude protein, crude fibre, ash levels and total carbohydrate levels were observed in gamma irradiated flour and grains. The combination of gamma radiation and microwave heating produced little decrease of crude protein, total carbohydrates or ash in both wheat flour and grains relative to the control. On the other hand crude fat and fiber levels were slightly increased. Effect of gamma irradiation on nutritional quality and functional properties of soy flour and sprouted soy flour was studied by Jabeen *et al.,* 2014. They stated that no organoleptic changes or any chemical change was brought by irradiation or sprouting in soy flour. Both the process improved the shelf life. At irradiation dose of 1 kGy, increase in protein content, oil absorption capacity, total antioxidant activity was observed. Also, a decrease in anti-nutritional factors was seen. Hassan *et al.,* 2017 [19] carried out the study on effects of gamma irradiation (0.5, 1.0, 1.5 and 2 kGy) on the protein characteristics and functional properties of sesame (*Sesamum indicum*) seeds. They reported increase in IVPD of sesame seeds with the increase in irradiation doses. Gamma irradiation doses higher than 0.5 kGy can possibly unfold the proteins by deamination and partial denaturation that increased the protein solubility. Due to denaturation and aggression of sesame protein at doses higher than 1 kGy, resulted in reduced emulsifying capacity. The increase in ES in irradiated sesame seeds could be attributed to increased solubility and hydrophobicity characteristics, which are desired for good emulsifiers. At higher irradiation doses, foaming capacity was reduced due to the denaturation of proteins. Gamma Irradiation dose of 5 kGy reduced the total aerobic plate count and total yeast and mold count to 54.62% and 63 % respectively than non-irradiated Tunisian millets. Gamma irradiation dose at 1 kGy and 3 kGy reduced ochratoxin concentration to 13 and 44 % respectively as reported by Mustapha *et al.,* 2014. At dose level of 5 kGy pH remained unaffected. Increase in peroxide value was observed from initial concentration of 26.16 meq O2/ kg to 34.43 O2/ kg from the non-irradiated sample to irradiated (3 kGy) sample respectively, but with increase in irradiation dose (5kGy), peroxide value decreased. In their study, they reported a decrease on phenylalanine concentration from 32 to 23 mg/g concentrations in a dose-dependent manner in millet flour irradiated with 5 kGy. A non-significant decrease in total phenolic content was observed.

Conclusion

In order to prevent the fruits, vegetables, cereals and pulses from insect infestation and microbial spoilage during storage, application of gamma irradiation has promising results in extending their shelf life. In general, the irradiation advantages were: shelf life prolongation and no change in physical and organoleptic properties in conjunction with its lower cost (almost 50% lower costs) compared to other widely employed conventional methods. Gamma irradiation is emerging as an alternative technology for pathogen inactivation in foods. With the increasing demand for high quality ready-to-eat foods including fresh fruits and vegetables, irradiation may provide a suitable means of enhancing product safety.

References

1. Abu JO, Duodu KG, Minnaar A. Effect of gamma irradiation on some physicochemical and thermal properties of cow pea starch. Food Chemistry. 2006; 95:386-393.
2. Ahvenainen R. New approaches in improving the shelf life of minimally processed fruit and vegetables. Trends Food Science and Technology. 1996; 7:179-187.
3. Amer HH, Attia AA, Elsayed AA, Ali MA. Characterization of gamma irradiated Egyptian wheat flour. The Second All African IRPA Regional Radiation Protection Congress 22-26 April 2007, Ismailia Egypt.
4. Basson RA, Beyers M, Thomas AC. A radiation-chemical approach to the evaluation of the possibly toxicity of irradiated fruits: Part 1-The effect of protection by carbohydrates. Food Chemistry. 1979; 4(2):131-142.
5. Beatrice HL, Ahmed EY. Alternative food-preservation technologies: efficacy and mechanisms. Microbes and Infection. 2002; 4(4):433-440.
6. Bidawid S, Farber S, Sttar A. Inactivation of hepatitis A virus (HAV) in fruits and vegetables by gamma irradiation. International Journal of Food Microbiology. 2000; 57:91-97.
7. Buchanan RL, Edelson SG, Snipes K, Boyd G. Inactivation of Escherichia coli O157: H7 in apple juice by irradiation. Applied and environmental Microbiology. 1998; 64(11):4533-4535.
8. Buchanan RL, Edelson SG, Boyd G. Effects of pH and acid resistance on the radiation resistance of enterohemorrhagic Escherichia coli. Journal of Food Protection. 1999; 62:219-228.
9. Desai D, Joshi DC. Effect of gamma irradiation on physico-chemical properties and shelf life of tomato (Solanum lycopersicum cv. Anand tomato-3). International Journal of Chemical Studies. 2018; 6(4):63-71.

10. Desouky O, Ding N, Zhou G. Targeted and non-targeted effect of ionizing radiations. Journal of Radiation Research and Applied Sciences. 2015; 8:247-254.
11. Diop YM, Marchioni E, Doudou BA, Hasselmann C. Radiation disinfestation of cowpea seeds contaminated by Callosobruchus maculatus. Journal of Food Processing and Preservation. 1997; 21:69-81.
12. Drake SR, Neven LG, Sanderson PG. Carbohydrate concentrations of apples and pears as influenced by irradiation as a quarantine treatment. Journal of Food Processing and Preservation. 2003; 27(3):165-172.
13. Drake SR, Sanderson PG, Neven LG. Response of apple and winter pear fruit quality to irradiation as a quarantine treatment. Journal of Food Processing and Preservation. 1999; 23(3):203-216.
14. El-Naggar SM, Mikhaiel AA. Disinfection of stored wheat grain and flour using gamma rays and microwave heating. Journal of Stored Products Research. 2011; 47:191-196.
15. El-Nashaby FM. The technological evaluation of irradiated wheat flour. Arab Journal of Nuclear Sciences and Applications. 1996; 29(2):145-159.
16. Farkas J. Physical methods of food preservation. Food microbiology: Fundamentals and frontiers 2007; 685-712
17. Fellows PJ. Food Processing Technology: Principles and Practices, 2018, 279-280.
18. Follett PA. Irradiation to control insects in fruits and vegetables for export from Hawaii, Radiation Physics and Chemistry. 2004; 71:161-164.
19. Hassan AB, Mahmood NS, Elmamoun K, Adiamo Q, Isam A, Ahmed M. Effects of gamma irradiation on the protein characteristics and functional properties of sesame (Sesamum indicum L.) seeds. Radiation Physics and Chemistry. 2017, 144.
20. Hvizdzak AL, Beamer S, Jaczynski J, Matak KE. Use of electron beam radiations international review of food science and technology (winter 2004/2005) an international union of food science and technology (IUFOST), 2010.
21. Jabeen NM, Kola M, Reddy JK. Impact of irradiation on nutritional quality and functional parameters of soy flour and sprouted soy flour. International Journal of Advanced Research. 2015; 3(3):1120-1129.
22. Kume T, Furuta M, Todoriki S, Uenoyama N, Kobayashi Y. Status of food irradiation in the world. Radiation Physics and Chemistry. 2009; 78(3):222-226.
23. Loaharanu P, Ahmed M. Advantages and disadvantages of the use of irradiation for Food Preservation. Journal of Agricultural and Environmental Ethics. 1991; 4(1):14-30.
24. Mahapatra Ak, Muthukumarappan K, Julson IJ. Applications of ozone, bacteriosins and irradiation in Food processing: a review. Critical Reviews in Food Science and Technology. 2007; 45:447-461
25. Majeed A, Muhammad Z, Majid A, Shah AH, Hussain M. Impact of low doses of gamma irradiation on shelf life and chemical quality of strawberry (*Fragaria Ananassa*) CV. 'Corona'. The journal of Plant and Animal Sciences. 2014; 24(5):1531-1536.
26. Marshall R, Stilchelbaut F. Radiation processing with high energy X-rays. Association of Brasileria De Energia Nuclear. 2009; 84:91-99.
27. Mohamed SA, Mikhaiel AA. Combined effect of infrared and gamma irradiation on certain insects in stored wheat grains and wheat flour. Isotope and Radiation Research. 2013; 45(2):375-384.
28. Muramatu N, Ohinata H, Karasawa H, Oike T, Ito H, Ishigaki I. Use of gamma irradiation for microbial inactivation of buckwheat flour and products. Shokuhin Shosha. 1991; 26:30-39.
29. Mustapha MB, Bousselmi M, Jerbi T, Bettaleb NB, Fattouch S. Gamma radiation effects on microbiological, physico-chemical and antioxidant properties of Tunisian millet (Pennisetum Glaucum L.R.Br.). Food Chemistry. 2014; 154:230-237.
30. Sau S, Datta P, Sarkar T, Sarkar S. Impact of low doses of gamma irradiation on off- season guava at ambient storage conditions. International Journal of Current Microbiology and Applied Sciences. 2018; 1:295-307.
31. Suresh P, Leslie A, Braby L. Introduction to electron-beam food irradiation. Chemical Engineering Progress. 2005; 112(11):36-44.
32. Susheela K, Damayanti M, Sharma GJ. Irradiation of Ananas comosus: Shelf life improvement, nutritional quality and assessment of genotoxicity. Biomedical Letters. 1997; 56(223):135-144.
33. Thayer DW, Boyd G. Irradiation and modified atmosphere packaging for the control of Listeria monocytogenes on turkey meat. Journal of Food Protection. 1999; 62:1136-1142.
34. Vanamala J, Cobb G, Loaiza J, Yoo K, Pike LM, Patil BS. Ionizing radiation and marketing simulation on bioactive compounds and quality of grapefruit (Citrus paradisi c.v. Rio Red). Food Chemistry. 2007; 105:1404-1411.
35. Wang J, Chao Y. Effect of ^{60}Co irradiation on drying characteristics of apple. Journal of Food Engineering. 2003; 56:347-351.
36. Wang Z, Ma Y, Zhao G, Liao X, Chen F, Wu J, Chenand J *et al*. Influence of gamma irradiation on enzyme, microorganism, and flavor of cantaloupe (Cucumis melo L.) juice. Journal of Food Science. 2006; 71(6):215-220.
37. Wardman P. The importance of radiation chemistry to radiation and free radical biology (The 2008 Silvanus Thompson memorial lecture). British Journal of Radiology. 2009; 82(974):89-104
38. Yu L, Reitmeir CA, Love MH. Strawberry texture and pectin content as affected by electron beam irradiation. Journal of Food Science. 1996; 61(4):844-850.
39. Zhang H, Li R, Liu W. Effects of chitin and its derivative chitosan on postharvest decay of fruits: A Review. International Journal of molecular Science. 2011; 12 (2):917-934.