Emerging Applications of E-beam irradiation and Soft X-rays treatments on fresh produce and ready-to-eat foods

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List of Abbreviations

EBI- Electron Beam Irradiation

kGy- Kilo grays

Gy- Grays

g- Grams

MeV- Mega Electron Volts

KeV- Kilo Electron Volts

CFU- Colony Forming Unit

TAC- Total Aerobic Count

TVC- Total Viable Count

NaCl- Sodium Chloride

DPPH- 2,2 Diphenyl-1-Picrylhydrazyl

TBARS- 2-ThioBarbituric Acid Reactive Substance

RTE- Ready to Eat

TBA - ThioBarbituric Acid

TPC – Total Plate Count

Abstract

Increasing population worldwide makes cultivation of wide variety of crops, efficient agriculture practices, and preservation of food commodities a basic need. On the other hand, microbial contamination in foods & crops is found to be a significant problem for food losses. For every three parts of total food production, one factor is lost or reduced during production in the food supply chain. To overcome this problem, different preservation technologies & methods come all over across. Unlike traditional food technologies, novel technologies work efficiently & effectively without compromising on food quality, safety and consumer acceptance. Food irradiation is a promising technology that is non-chemical, non-thermal, and applicable to all products without any negative impact on macro and micronutrients. Familiar irradiation sources are Gamma rays, X-rays, and E-Beam. X-rays and E-beam irradiation is eco-friendly, bi-directional, do not require any radioactive isotopes and have a higher dose rate capability than gamma rays. E-beam & X-ray irradiation shows direct & indirect effects on DNA molecules of spoilage-causing microorganisms in food products. The ultimate goal of X-ray & E-beam irradiation lies in various applications like sprout inhibition, insect disinfestation, delay of ripening, shelf-life extension, microbial decontamination, maintaining quality parameters, improvement of re-hydration, increase of juice yield and reduction of off-flavors in food products, at low doses. The E-beam & X-rays work more effectively & also show synergic impacts on foods when combined with other preservation technologies like ozonation, thermal treatments, preservatives, etc.

Keywords: *E-beam, X-ray, Irradiation, Decontamination, Shelf-life, Dosage*

1. Introduction

From farm to fork, food safety and quality has been a dominant and prevailing issue in food processing sector (Tezel & Şanlıbaba). Generally, consumers are known for their health interests & risk possibility of the food they consume. Food is an essential resource for humans. With the increasing population growth worldwide, it is always necessary to cultivate more crops, improve agriculture practices and preserve food products & commodities from spoilage (Maisonet-Guzman, 2011). According to the Food and Agriculture Organization world is producing abundant food to feed everyone living on the earth (FAO, 2008). However, the availability and accessibility of food is low due to lack of knowledge of preservation techniques in the society. Moreover, one-third of food production is lost or reduced yearly during food production and supply chain management (Elkhishin et al., 2017). Food losses and wastage generally occur during agriculture production, post-harvesting processing, distribution, and consumption steps of the food supply chain. Due to the varied physical, chemical and biological hazards, the food is undergoing spoilage which negatively impacts the safety and sensory properties of food (Rahman, 2007). According to FAO, Every year, crop microbial contamination causes significant economic losses.(Kummu et al., 2012).

Different cultures follow different technologies to preserve food from spoilage (Nummer & Brian, 2002). There are different established and conventional techniques like drying (removal of moisture by application of heat), blanching (destroying enzyme activity), sterilization (eliminating all living micro-organisms), pasteurization (inhibition of pathogenic bacteria (Fellows, 2009), and other technologies like freezing (preserving the food at a temperature less than freezing point (0° C), chilling (Preserving the food at a temperature below4° C, chemical preservation (addition of chemical preservatives like benzoates, nitrites, sodium sorbate, etc., (Amit et al., 2017). In contrast to the above, the new technologies or modifications of existing technologies like high pressure, electric fields, cold plasma or ultraviolet irradiation, etc., improve the food quality along with meeting the requirements of consumers and excessive usage of any single technique (Buckow & Bull, 2013). These novel technologies are booming out as they improve the microbial and enzymatic stability, and minimize the physiochemical changes during processing (Stoica et al., 2013).

Along with diversified benefits, the mentioned technologies have some limitations too. High-pressure processing are applicable for limited food products & it lies in the uncertain field of marketing (Nielsen et al., 2009). Pulse electric field shows no impact on enzymes and spores. It is also unsuitable for conductive materials and is only effective for treating liquid foods (Sun, 2014). Ultraviolet (UV) light treatment has adverse effects like low penetration (Guerrero-Beltr· n & Barbosa-C· novas, 2004). Ultrasound may cause physic-chemical effects, leading to the degradation of components & off-flavors in food products (Ravikumar et al., 2017). While considering all the drawbacks, Food irradiation appliesto all types of food. It does not negatively impact nutritional parameters like macro nutrients & micro nutrients which remain unaffected at the prescribed or approved high dosage in some food (Smith & Pillai, 2004).

2. About Food Irradiation

Food irradiation is promising novel & nonthermal technique which helps in improving the microbial & enzymatic stability of the food product more effectively (Deepika et al., 2017). Even though this technology is prohibited in numerous countries due to health concerns and environmental issues, some government (Food Commission, July 2002) organizations and researchers are working to develop more eco-friendlier and effective ways to enhance the product's safety. When food absorbs radiant energy, it effects the microbial load in food in two forms, i.e., directly and indirectly (Kalyani & Manjula, 2014). Each process has an optimal dose of radiant energy. Amount of radiant energy absorbed per product mass is expressed in grays or kilo grays (Visnuvinayagam et al., 2017). All food products which undergo irradiation must carry the symbol called a radura. According to the United States Food and Drug Administration (USFDA), in addition to the symbol, statements such as "Treated with radiation" or "Treated by irradiation" must appear on food labels such as packaged foods, bulk containers of unpackaged foods, on public note at the point of purchasing fresh produce (Sebranek et al., 2014).

Joint Expert Committee on Food Irradiation formed the basis for interpreting of FAO/IAEA/WHO states that irradiating any food up to an average dose of 10 kGy no toxicological risk and causes no specific nutritional or microbiological issues **(1997; Geneva, Switzerland)**. According to the FDA, the Department of food science, and NCSU, to produce shelf-stable food products, the dosage should exceed up to or above 60 kGy, leading to minor vitamin losses and higher shelf life (Nanke, 1998). Generally, high-dose irradiation is subjected to process shelf-stable products like poultry, meat, fishery, ready-to-eat foods, Space foods, etc. (Feliciano et al., 2017).

2.1. Source of Irradiation

Ionizing radiation comprise electromagnetic waves that are charge enough to detach electrons from atoms or molecules ionizing them. There are three different types of sources primarily used to irradiate food products (Farkas & Mohácsi-Farkas, 2011).

2.1.1. Gamma Radiation: This is produced from radioactive isotopes like Cobalt 60 or Cesium 137. It has high penetrating power, which can be measured in terms of electron volts (eV) or million electron volts (MeV), so it can invades across materials of diverse bulk densities (Gautam & Tripathi, 2016). The energy profile of gamma irradiation of cobalt-60 is between 1.17 and 1.33 MeV & of cesium -137 is within the radius of 0.662 MeV (Pillai & Shayanfar, 2017).

2.1.2. Electron Beam Radiation: These are generates from linear accelerators. Here the electrons released from the accelerators create a beam of electron, so the traveling electron's speed is increased to 99.99 %, the rate of light at energies not exceeding 10 MeV (CFR 1986; Codex 2003). It can release free electrons, and these ions produce secondary ions when they react with other charged molecules or atoms (Clemmons teal., 2015). EBI is produced from electricity so that it can be powered on & off (Kume et al., 2009). EBI has less penetration power than gamma irradiation, so that it can be used for foods with low thickness (Munir & Federighi, 2020).

2.1.3. X-ray Irradiation: These rays also rely on linear accelerators. X-ray generation takes place by adjusting the high-density target materials (Tantalum and tungsten are used due to their high atomic numbers) in a path of stream of the high-power electron beam (Maximum photon energies 5 MeV) (Marshall & Stilchelbaut et al., 2009). This process is known as bremsstrahlung conversion (Kume et al., 2009). It exhibits high penetration depth & more uniform distribution of energy, but the only drawback lies in the higher cost. Also significantly small number of incident electrons are converted into X-rays (Fellows et al., 2018).

2.2. Why EBI & X-rays over the gamma irradiation?

Generally, irradiation takes place only in an entirely shielded room. In gamma irradiation, when the source is not in use, it produces radioactive waste, leakage causes environmental and health risks to people exposed to it, and also more cost-effective for disposing of gamma rays (Ashraf et al., 2019). Cobalt-60 produces water-insoluble wastes that cause few environmental issues, and Cesium-137 produces water-soluble waste, causing significant ecological issues (Fellows et al., 2018). Considering the above issues, EBI and X-rays are used for more commercial purposes in food processing (Kashiwagi & Hoshi, 2012). Following are some of the advantages,

- Higher dose rate capability
- It does not require any radioisotopes to produce radiation
- No nuclear waste is produced
- Accelerators can be switched off & on

One of the significant advantages is the application of EBI in a bidirectional manner from the top & bottom of the sample, which lead to more uniform penetration of ionizing radiations (P. Deepika et al., 2017).

Approach of irradiation is categorized into three levels based on dosage (International Atomic Energy Agency, 2002)

1. Low dose levels (10Gy-1kGy)-Inhibiting sprouting in onions, garlic, etc., Insect disinfestation in cereals, pulse, flour, etc (IAEA, 2002).
2. Medium dose levels (1–10 kGy) Substantial depletion in microbial spillage in Fresh meat, seafood, vegetables, and fruits. It also heightens the storage life of the product. Hence this referred as radurization (IAEA, 2002).
3. High dose levels (10–100 kGy) This dosage level is mainly used in medicinal plants, space foods, frozen foods, and precooked foods (Feliciano et al., 2017)

2.3. Mechanism of microbial inactivation during irradiation

When food products absorb the gamma rays, X-rays or electron beams, produce ionization energies or radiation, showing the direct or indirect effect on DNA molecules of harmful microorganisms that grow in food products (Smith & Pillai, 2004).

2.3.1. The direct effect of ionized energies or radiation on DNA molecules

When food absorbs radiation, these cause a direct effect on genetic material (DNA or RNA), leading to structural & molecular breakage of genetic material (breakage of A-T & G-C base pairs). It creates an unfavorable condition for cell division or replication and, finally, the death of cells occurs (Lung et al., 2015).

2.3.2. The indirect effect of ionized energies or radiation on DNA molecules

Radiation absorbed by the food interacts with water and produces hazardous products like hydroxyl radical, hydrated electron, a hydrogen atom, hydrogen, hydrogen peroxide, and hydrated proton (Le Caër, 2011). So, these free radicals are highly reactive and can indirectly affect DNA, damaging cellular metabolic pathways and causing cell injury and death (Nair & Sharma, 2016).

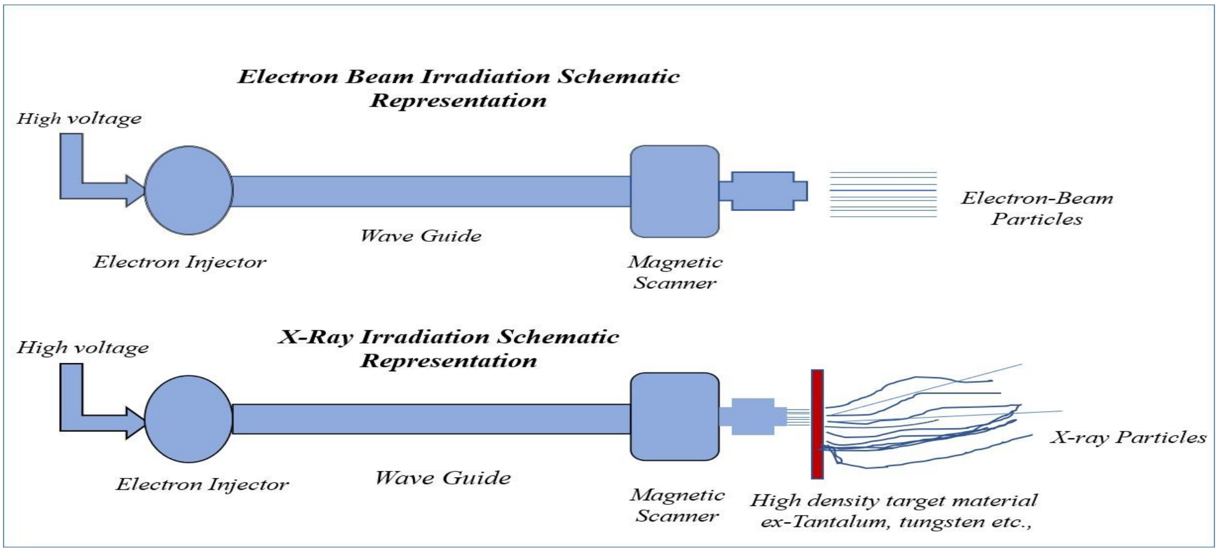

Figure 1. Schematic diagram of E-beam & X-ray irradiation

3. Applications of EBI on different food groups and commodities

3.1. Fruits and Vegetables

Fruits and vegetables are one among the highly perishable food commodities. The maximum dosage used for fresh produce is 1 kGy to delay ripening & insect disinfection and 1.5 kGy to extend the shelf-life (IAEA, 2002). According to Nguyen et al., (2020), findings indicated that phytosanitary measurements of star apple might be made using electron beam radiations. Also, after receiving the same quantities of phytosanitary treatments, the shelf life of fruits would be increased by up to 6 days (from 0.4 to 0.6 kGy). Joshi et al., (2018) demonstrated that 5D EBI of cucumber slices effectively reduced Salmonella count to extremely minimal concentrations, and its subsequential storage at 4 °C inhibits Salmonella cell multiplication. This discovery highlights the value of using suitable handling and storage procedures to productively reduce the possibility of infectious agent renewal and subsequent recontamination, hence reducing foodborne diseases. Additionally, the amount of pathogens in fresh produce is typically modest (3 log CFU/g), decontaminating cucumber slices using a 3D (1.0 kGy) e-beam should be sufficient while limiting negative effects on produce's quality.

In order to determine the effectiveness and practicality of EBI as a phytosanitary treatment, the focus of this study was on examining the impact of EBI (0, 0.15, 0.4, 0.6, and 1 kGy) on strawberry postharvest quality. Post harvesting, strawberries exposed to EBI saw a dose-related reduction in microbial culture (including total aerobic bacteria and yeasts/molds), decay extent, and weight loss without experiencing any appreciable changes in TSS, pH, or TA. As well, the total plate count (TPC), total aerobic count (TAC), particular phenolic content, and antioxidant activity were all delayed by this treatment during storage. Also, during storage, no changes in colour, hardness, and sensory quality were observed. It concluded was that low-dose EBI of 1 kGy is a viable method for enhancing postharvest preservation and can be used as a phytosanitary application on strawberries (Y. S. Yoon et al., 2020).

3.2. Meat processing

Maxim et al., (2014), introduced Maxim's Electron Scatter Chamber (Maxim Chamber) in e-beam irradiation (EBI) to obtain uniform dose by applying in multiple angles on Escherichia coli O157: H7 inoculated (6 logs CFU/cm2) rabbit carcasses. It was concluded that greater than 5 log cycles depletion of inoculated Escherichia coli O157: H7 was observed. This technique has been shown to be efficient in decreasing micro-organism to undetectable levels and providing a relatively equal dosage of energy over uneven surfaces. To scale up from a small-scale rabbit corpse to bigger species like beef or pig corpse, more extensive study is required. The Maxim Chamber employed here has a lot of scope for lower penetration, uniform dosage disposal of irradiation for the eradication of microorganisms on food commodities.

Quail meat's fat content is vulnerable to radiation. A dose of 1.5 to 3 kGy is suggested for quail meat irradiation in order to maintain the degree of fineness and health of the meat. Enhancing lipid oxidation in irradiated meat and animal products has been noted by several studies. Ionizing radiation does increase hydroxyl radicals in the water system; because meat contains a lot of water, irradiation speeds up oxidative changes in meat. TBA levels in meat samples rise with radiation dosage and storage duration. This study exhibited that the overall quantity of volatile basic nitrogen, a marker for microbial damage, may be decreased by exposing quail flesh to an electron beam. The amount of TBA rose as a result of irradiation, however this rise had no detrimental effects on the organoleptic qualities of quail meat. With the removal of the corrosion-causing microbes, enhancement of the microbiological quality, and preservation of sensory qualities, irradiation might increase the meat's shelf life to at least two weeks at refrigeration temperature. (Derakhshan et al., 2018).

3.3. Seafoods processing

Tropomyosin from *Solenocera melantho* underwent alterations in structure and immunoreactivity as a result of electron beam irradiation. The dosage of 7 kGy produced the best results. These findings demonstrate the significance of structural modifications in reducing tropomyosin immunoreactivity. This work also serves as a foundation for additional investigation into the probable mechanism by which electron beam irradiation, has significant commercial potential for reducing allergenicity of dietary protein (Guan et al., 2018). The Pseudomonas total for 2.5 kGy served samples demonstrated one log reduction compared to control, according to analysis of the influence of electron beam irradiation on specific spoilage organisms. In addition, H2S producing bacteria showed a 1 log reduction with dosages of 2.5, 5.0, and 7.5 kGy compared to controls, whereas served with 10 kGy led to a 2 log depletion. Based on the psychrophilic count in the current investigation, control samples were eliminated on the fifth day (Fig. 2), Althrough 7.5 kGy and 10 kGy served samples demonstrated improved shelf stability with regard to microbiological deterioration and were deserted on the 19th day of cold storage, 2.5 and 5.0 kGy irradiation samples were deserted on the 15th day (Annamalai, Jeyakumari et al., 2020).

3.4. Dairy products

In the investigation of Hoseinpour Ganjaroudi et al., (2016), a depletion in the number of *Brucella* strains exists at all irradiation dosages. Yet, after receiving 1 kGy of radiation therapy, both strains of *Brucella* were monitored for over 21 days. According to the findings, a dosage of 2 kGy electron beam radiation enough to kill *B. abortus* after 14 days. All B. abortus strains were administered 3 kGy were wholly killed after 14 days, suggesting the right dosage and window of time to eradicate the microbes. Depending on the virulence and pathogenicity of the pathogen, a 3 kGy irradiation dosage may significantly lower the microbial load. As heat processing and other conventional procedures have limits for reducing *Brucella spp*. contamination in traditional ice cream, electron beam irradiation technology is found to be a viable option. Huo and team investigated the effect of irradiation on cheese samples. The tensile stretching of the irradiated cheese at a dosage of no more than 2.0 kGy was found to be identical to the control. The qualities of cheese melting and oil-off were unaffected by irradiation. A dosage of 2.0 kGy prevented the spoilage microorganisms such as coliforms and Pseudomonas sp. in absence of any noticeable difference in the sensory attributes of products (Huo et al., 2013).

3.5. Fermented food products

Gram-negative rods, gram-positive cocci and rods, yeast, molds, fungal spores, aerobic and anaerobic spore formers, are some among the microorganisms that are most vulnerable to radiation. Pork sausage products were exposed to electron beam irradiation, which led to a dose-dependent decline in the total viable counts and a depletion or eradication of pathogens. All the control and Salmonella spp. were detected in irradiated pork sausage samples up to the ninth day of storage, none of the irradiated samples at various dosages revealed the existence of *Salmonella Spp.* Recent developments of electron beam technology have elevated this method of sterilizing to the level of a serious challenger to conventional gamma processing (Deepika et al., 2017).

The research performed by song and team revealed that a 50% drop in sodium chloride (from 1.5% to 0.75%) might affect the emulsified sausage's textural, sensory, and microbiological qualities. Microbiological safety of low-salt emulsion sausages might be significantly increased with the use of irradiation technology. Nonetheless, radiation independent of the irradiation source, might have a detrimental influence on consumers' perception of low-salt emulsion sausages. Consequently, this study implies that the irradiation approach might be utilized to increase the microbiological stability of inferior-salt meat products and recommends more research to assure its empirical application for inferior-salt meat products by preventing and/or concealing radiolytic off-flavor (Song et al., 2017)

In this study, total aerobic bacteria, lactic acid bacteria, yeast, & mold populations in kimchi paste prevail significantly decreased by e-beam irradiation (2–10 kGy). In instance, after irradiation at 8 and 10 kGy, coliforms were not found. In addition, after electron beam irradiation at 2- 10 kGy, *L. monocytogenes* inoculated into kimchi paste showed a decrease in CFU/g of 1.58-2.67 log. The diverse in O_2 and CO_2 concentration, pH, titratable acidity, and lowering sugar content that were seen in kimchi paste during storage were also greatly postponed by irradiation. Hence, enhancing the microbiological stability and quality of kimchi pastes using e-beam irradiation holds potential. To develop an optimised processing method with a beam energy >2.5 MeV, which should preferably ensure a physiochemical and sensory properties of kimchi paste independent of the quantity and kind of microbial contamination, more study is required (Cheon et al., 2016).

3.6. Cereal & cereal products

According to the study's findings, low-dose electron beam irradiation therapy altered the water distribution in both dried rice (11.97%) and freshly harvested rice with high moisture (15.03%). Radiation caused the degradation of biomolecules in both types of rice and mostly damaged the free moisture components of low moisture rice and the combined water and free mositure components of High Moisture rice. Rice's viscosity was decreased by electron beam irradiation, and the difference in low moisture rice was more noticeable than it was in high moisture rice. After irradiation, rheological moduli also altered, and the change in High Moisture rice was gradual. Water molecules were encouraged to enter due to this impact. The increased depolymerization of starch chains, which led to improved particle hydration, might be the cause of the irradiation samples' greater solubility. Most rice samples' gelatinization, texture, and rheological characteristics were scarcely affected by low-dose irradiation. While LM rice had greater nutritional value, HM rice had superior quality and flavour. By examining its impacts, this effort aimed to improve the results of the EBI treatment of rice for storage(Pan et al., 2020).

Zearalenone and ochratoxin A in maize kernel and corn flour were shown to be effectively degraded by electron beam irradiation. When the irradiation dose enchanced, the deterioration rate rose. Irradiation had an impact on the quality characteristics of maize, and high moisture content was advantageous for the degrading effect. When the irradiation dosage rose and the fatty acid value enhanced, a* and b* decreased. Irradiation considerably ($p<0.05$) decreased the pasting attributes, including peak, trough, breakdown, final, and setback viscosities. Therefore, it is important to look at additional variables that are beneficial for optimal electron beam irradiation, such as temperature, pH, and grain thickness. Zearalenone and ochratoxin's toxicities and degradation products should be investigated further. The next electron beam radiation. Corn is exposed to e-beam radiation at doses of 5, 10, 30, and 50 kGy in order to lessen secondary toxins such zearalenone and ochratoxin that result from natural contamination. They are basically downgraded to 71.1% and 67.9%, respectively, by the outcomes (Luo et al., 2017).

3.7. Ready-to-Eat foods

Our study's findings conclusively shown that electron beam irradiation may reduce the growth of inoculated Listeria innocua and natural microflora while retaining a superior quality of fresh noodles throughout freezer storage. The L. innocua population was suppressed to an untraceable level at dosages of 4.0 kGy or 5.0 kGy, and the microbiological attributes of the fresh noodles was maintained at an acceptable level during the 28-day storage period. The pH value, colour, cooking properties, texture, and sensory alterations in freshly prepared noodles that had undergone electron beam irradiation were also postponed during storage. The fresh noodles might be sterilised before being preserved using a higher dosage of electron beam irradiation (4.0 kGy or 5.0 kGy). The methods of sterilisation and preservation, as well as the connections between the dynamic shifts in the natural microbiota and the quality of the fresh noodles throughout storage, require more study (Shi et al., 2020).

Saengshik powder is a cereal functional food that is consumed by health-conscious individuals that is uncooked and ready to eat. An efficient and cutting-edge method for guaranteeing cleanliness, microbiological safety, extended shelf life, and functional attributes in goods is e-beam or gamma ray irradiation. The effects of this study were assess the chosen electron-beam and gamma-ray irradiation dosages (kGy) on the physicochemical and functional characteristics of Saengshik. Regardless of irradiation, we found negilble discernible variation in the reducing sugar and amino nitrogen concentrations. In contrast to non-irradiated samples, irradiated samples had a greater total phenolic content. Yet, regardless of the kind of irradiation, total carotenoids and total chlorophyll content decreased with higher irradiation doses. Saengshik that had been exposed to gamma and electron beam radiation showed a highly significant improvement in antioxidant activity with an increase of up to 10 kGy, despite a little loss in total chlorophylls and carotenoids and an increase in total phenolics. There was no discernible difference between gamma and electron beam radiation. Saengshik, which gets between 10 kGy and 0.31% of the total amount of chlorophyll, carotenoids, phenolics, and antioxidant activity, may experience physicochemical and functional quality alterations as a result of dose acceleration during electron-beam and gamma-ray irradiation processes (Kim et al., 2020).

3.8. Spice & Condiments

Using a physical colorimeter, a descriptive sensory analysis, and a quality scoring technique, research was done to identify the impact of electron beam irradiation on the sensory qualities of Fuzhuan brick-tea. It was established that Fuzhuan brick-typical tea's flavour qualities include leather, musty-dry, straw-like, bitter, hay-like, brown, medicinal, and woody notes. The sensory attributes and primary chemical compositions of Fuzhuan brick-teas were not significantly affected by 1 kGy electron beam irradiation according to the study. Nevertheless, using a scoring system, irradiation at 4 kGy enhanced the sensory quality of Fuzhuan brick teas in terms of appearance, fragrance, and flavour. In addition, the functional component content—including catechins, free amino acids, and flavonoids—increased or remained steady. With the exception of the barnyard, woody, tobacco scent and the almond, green, metallic, and bitter tastes, irradiation had little to no effect on the majority of the objective sensory qualities of Fuzhuan brick teas. Irradiation therapy can therefore enhance functional component content and increase sensory quality. The stability of the sensory factors and chemical attributes of irradiation Fuzhuan brick-tea can be the subject of further study. Comparing aged Fuzhuan brick tea with Fuzhuan brick-tea (FBT) powder irradiated with e-beam at doses of 0, 1, 4, and 7 kGy shows that at 4kGy exhibits positive effects on FBT improves sensory attributes & also the mass of polyphenols such as catechins, especially EGCG (induces to ~57%), compared to aged tea which lowers to 10% (Haiwei Zhang et al., 2020).

The data shows that, as compared to the irradiated samples, all three blank samples of the Naadu natural (NN), Naadu natural pesticide (NNP), and Naadu natural Mundu (NNM) kinds had the highest levels of Total Viable Count (TVC), E. Coli, and fungus. When we compare the Total Viable Count, E. Coli, and Fungi values of Irradiated Samples of NNP and NNM we find that Fungi and E. Coli are missing and that the Total Viable Count value decreases with dose. In contrast, Naadu Natural was discovered to be devoid of E. coli and fungi, and surprisingly, the overall viable count increased when the dosage was increased. To achieve a stronger defence against microorganisms, it is thus advised to irradiate the NNP variety and NNM variety (Manivannan & Muthukumar, 2017),.

Many kinds of food items might be decontaminated using an electron beam with an energy of 300 keV or less. In the trials described, *Bacilli* that produce spores or endospores dominated the microbial ecology of spice samples. Both the low energy (300 keV) and the high energy (10 MeV) electron beams were used to disinfect spice samples, indicating that the most of spillage causing bacteria were found on or near the surface of the spice grains. In the conditions used, the log decrease of spillage causing bacteria by the low energy e-beam (300 keV, 5 min) equated to a dosage of around 6 kGy with the high energy e-beam (10 MeV). The presence of *Cronobacter sakazakii* resulted in the deletion in microbial contamination seen in the case of black pepper. Regardless of the electron beam's intensity, the *Cronobacter sakazakii* strain that was found was radiation-resistant. As evidenced, when bacteria are present on the surface of spices, both low and high energy electrons are equally efficient in killing them. In addition to having less of an impact on food components, low energy e-beam machines have the benefit of being used for in-line irradiation and do not require thick shields. This might do away with the need to transfer lots of spices to an irradiation plant. The low energy electron beam is a substitute technique for the highly penetrating ionising radiation that is currently employed to destroy microbial contamination of spices, despite its limited penetration capabilities (Gryczka et al., 2020).

The objective restriction of bacterial contamination for raw pharmaceutical matter, 1.0 3 103 cfu/g, was reached bacterial survival rates in turmeric powder following 4.8 MeV Electron Beam irradiation at a dosage of 7 kGy. After one year of storage, survival counts after 10 kGy of electron beam irradiation were fewer than 10 cfu/g. Moreover, the extraction yield for turmeric powder was marginally enhanced by electron beam irradiation. At the degree of electron beam irradiation required for microbial cleaning, there was negligible degradation of the curcuminoids. We discovered that electron beam irradiation significantly reduced the number of bacteria while having little radiolytic side effects. Moreover, the look, odour, and flavour of irradiated foods may have an impact on whether or not they are accepted by consumers. Future research should concentrate on sensory evaluation of electron beam-irradiated turmeric powder (Yamaoki & Kimura, 2018),.

3.9. Space foods

According to Bhatia et al., (2018), Foods for space travel require sterilisation for two reasons: safety and shelf life. The shelf life of these items must be handled by completely inactivating any and all possible spoiling bacteria once the safety of the product has been guaranteed by the total inactivation of pathogens. The purpose of this research was to ascertain if a lower dose of 15 kGy might accomplish the identical degree of sterility without causing the sensory and nutritional characteristics damage found at 44 kGy, which is the dose that the FDA now mandates be given to irradiated space meals. Although a treatment of 15 kGy rendered all background organisms inactive and produced a decrease in Shigatoxin-producing Escherichia coli of over 10 log it did not produce the reduction in Clostridium spores required by the current industry standard for conventionally retorted foods. Because volatiles with negative aroma descriptors were detected at lower levels at the end of a one month accelerated shelf-life study in products irradiated at 15 kGy than in products irradiated at 44 kGy, there is reason to believe that a lower dose will help maintain the quality of the irradiated fajitas for a longer period of time. It is important to keep in mind that e-beam processing and traditional cooking will, when combined, yield a minimum 12-log reduction in the dish's volume. To achieve the relevant nutritional, microbiological, and quality requirements, the hurdle technique of along with cooking with ebeam method is appropriate for space food sterilising.

3.10. Protein isolates

After being exposed to an electron beam, rice proteins underwent significant structural alterations. The Rice Proteins' microcosmic surface structure was altered, and the surface of the Rice Proteins experienced fragmentation. The UV visible spectrum and the endogenous fluorescence spectrum demonstrated the increased exposure of the tryptophan microenvironment. A reduction in a-helices and concurrent enhance b-sheets, b-turns, and random coils were seen when the secondary structure was redistributed. Also, the molecular basis for the reactions of rice proteins subjected to electron beam pretreatment, comprising the subjection of hydrophobic groups and the rise in SHE content, was examined. The functional capabilities of the irradiated rice protein were increased dose-dependently, with a utmost occurring at 30 kGy, including their capability to emulsify, absorb water, and absorb oil. Electron beam irradiation also improved the foaming qualities, Althrough the result was dose-independent. In contrast, all of the samples exposed to electron beams had less stable emulsions than the control samples (0 kGy). According to structural studies, electron beam irradiation results in conformational alters and the fragments of Rice protein improves the functional characteristics of numerous buried groups that are intimately connected to protein activities by enhancing their release. These findings offer a theoretical foundation for future use of electron beam irradiation to enhance protein characteristics (Zhang et al., 2019).

Table 1. Application of EBI on different types of food commodities or food groups

S. No	Food Product	Dosage range (kGy)	Observation	Reference
1	Star apple fruit	0.4, 0.6, 0.8, 1.0	Extension of Shelf life upto six days	(Nguyen et al., 2020)
2	Strawberry	0.15, 0.4, 0.6, 1.0	Microbial decontamination (3.8 and 4.0 log CFU/g log depletion of total bacteria count, fungal & yeast count	(Y. S. Yoon et al., 2020)
3	Sliced Cucumber	0.1 to 1.0	Microbial decontamination reductions of 5 log CFU/g Salmonella Poona	(Joshi et al., 2018)
4	Quail meat	0.5, 1.0, 3.0	Shelf life enhancement up to 15 days	(Derakhshan et al., 2018)
5	Shrimps	0, 1.0, 3.0, 5.0, 7.0, 9.0	Allergen-causing protein tropomyosin reduced to 59%	(Guan et al., 2018)
6	Shrimp	2.5, 5.0, 7.5, 10	Extension of shelf-life up to six days	(Visnuvinayagam et al., 2017)
7	Ice Cream	1.0, 2.0, 3.0, 5.0	Eliminate the Brucella spp. Upto 21 days	(Hoseinpour Ganjaroudi et al., 2016)
8	Pork sausage	3.0, 3.5, 4.5	Microbial decontamination (reducing the microbiological load upto 6 logs CFU/g Total Viable Count, 3 log CFU/g S. aureus counts up to 29 days)	(Deepika et al., 2017)

9	Low-salt Sausage	5.0	Microbial decontamination (Reduces to a non-detectable limit of aerobic count plates, coliform, Enterobacteriaceae)	(Song et al., 2017)
10	Kimchi Paste	2.0, 4.0, 6.0, 8.0, 10.0	Microbial decontamination (Reduces to non-detectable limit total aerobic bacteria, lactic acid bacteria, and yeast and molds)	(Cheon et al., 2016)
11	Harvested Rice and Sun-dried Rice	0, 1.0, 2.0, 3.0, 4.0	Improve rheological and textural properties	(Pan et al., 2020)
12	Corns	5.0, 10.0, 30.0, 50.0	Degradation of toxin (71.1% and 67.9% Zearalenone and Ochratoxin A respectively)	(Luo et al., 2017)
13	Fresh Noodle	0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0	Microbial decontamination (L. innocua count to an undetectable level	(Shi et al., 2020)
14	Saengshik	0, 1.0, 3.0, 5.0, 10.0	Improving the antioxidant activity (Enhancing in total phenolic content 139.63-168.56 mg/100 g, GR & <0.13% reduction of chlorophyll)	(Kim et al., 2020)
15	Fuzhuan brick-tea	0, 1.0, 4.0, 7.0	The concentration of polyphenols such as catechins, especially EGCG (induces to ~57%)	(Haiwei Zhang et al., 2020)
16	Chilies	2.0, 4.0, 6.0, 8.0	Microbial decontamination reduces to no detectable level	(Manivannan & Muthukumar, 2017)
17	Black pepper, White pepper, Allspice	300 keV (low energy e-beam) and 10 MeV (high energy e-beam)	6.45 log reduction of spore or endospore-forming bacillus subtilis	(Gryczka et al., 2020)
18	Turmeric Powder	5.0 to 30.0	Disinfection of microbes (Microbial load is reduced to lower than 10 cfu/g after 1 year of storage at room temperature in 10 kGy treated sample)	(Yamaoki & Kimura, 2018)
19	Beef fajitas (Space Food)	15.0	Microbial decontamination (10 log reduction of Escherichia coli & minimum 12 reductions of Clostridium spores)	(Bhatia et al., 2018)

20	Salt-soluble pork gel	5.0	Lowers the physicochemical and textural properties	(Kim et al., 2017)
21	Rice protein	5.0, 10.0, 20.0, 30.0	Improve functional properties such as water adsorption capacities to 62.25% and oil adsorption capacities to 81.25%	(Zhang et al., 2019)

4. Application of soft X-ray irradiation on different food groups & food commodities

4.1. Fruits & vegetables

Y. Yoon et al., (2020), assessed the effects of X-ray irradiation (0, 0.15, 0.4, 0.6, and 1 kGy) on strawberry quality traits (microbial, physicochemical and sensory attributes, phenolic component levels, and antioxidant activities) during storage at 15 °C for 9 d. No matter how long the samples were stored, dose-dependent drops in TAB counts were seen in the irradiation samples. The TAB count was much lower in samples held for 9 days than it was in the control group (5.3 log CFU/g) even though the dosage of 1 kGy was the most efficient at decreasing it. The nonirradiated (control) samples had high Y&M counts that tended to rise as storage time increased from 0 to 9 days. The 0.15 kGy dose showed a sterilising effect since all storage days saw a small decline in Y&M numbers. Nevertheless, following exposure to X-ray irradiation at applied doses of 0.4, 0.6, and 1 kGy, dose-dependent drops in the Y&M counts were noted. For irradiated fruits during all storage periods, X-ray irradiation therapy resulted in substantial ($p<0.05$) decreases in weight loss and decay incidence compared to the control. Despite the fact that fruit firmness initially tended to decline following exposure to irradiation, no significant ($p > 0.05$) alterations were noticed after 3 days of storage. Fruit TSS, pH, and TA were not significantly affected by irradiation treatment or storage time, however all treatments prevented colour changes and PE buildup. With increasing storage duration, strawberry fruit's TPC, EA, and CA levels and antioxidant capacity steadily rose, reaching maximum values at the end of the storage period (9 d); however, the 1 kGy irradiation sample showed declining tendencies. At the conclusion of the storage period, the irradiated fruits had increased sensory qualities in comparison to the nonirradiated sample. Our findings suggested that X-ray irradiation therapy at an applied level of 1 kGy would be a useful tactic for strawberry fruit preservation, as it can delay decay and block harmful physicochemical changes while also increasing shelf life and preserving fruit quality. In order to comply with the phytosanitary criteria for the international commerce of fresh food commodities like strawberries, this study confirmed the applicability of X-ray irradiation as a prospective substitute for the currently used methyl bromide.

4.2. Fermented foods

A non-thermal method known as X-ray has been discovered to be effective in lowering rotting germs in Fiordilatte cheese. The possible usage of X-ray radiation on Fiordilatte was investigated in this study for the first time. The effectiveness of X-ray therapy against Pseudomonas spp. and Enterobacteriaceae at the studied circumstances (0.5, 2 and 3 kGy) is highly noteworthy since all the treatments fully reduced microbial population. The findings specifically demonstrate that X-rays may greatly extend the life time of irradiated cheese, with superior outcomes for samples served with 2 and 3 kGy (shelf life more than 40 days). From a sensory perspective, the irradiation only had a little impact on the cheese smell during the first several days of storage. In contrast to the control samples, the irradiation samples underwent a radically distinct development of sensory characteristics. Comparing the brine from X-ray treated and untreated samples using SPME-GC/MS revealed no appreciable differences in the migration process or the development of dangerous chemicals. Just a novel chemical, identified as a marker of the X-ray therapy, was created. Certain antioxidants, plasticizers, and chemicals derived from the oxidative breakdown of fatty acids that were previously available in the brine of the control package showed a rise as a result of the treatment, whereas other plastic additives showed a notable decrease. Furthermore, the experimental data supported the ability to treat samples that have already been packaged, so resolving the issue of post processing contamination, which is crucial for industrial applications. To enhance this technique and assess the impact of ionizing energy on the nutritional value of cheese and any potential safety concerns, more study is still required (Lacivita et al., 2019).

(Ricciardi et al., 2019), Artisanal and commercial ricotta were satisfactorily evaluated for X-ray compatibility. In particular, the shelf life of the artisanal product sample treated at 0.5 kGy was 14 days, as opposed to 3 days for the untreated sample. Samples that were exposed to 2 and 3 kGy remained acceptable for more than 20 days, in contrast. The industrial product, after being thermally pasteurized, had a storage life of around 40 days, even without any further care. The storage life of treated samples was significantly heighten, lasting till 84 days without a single microbiological or sensory flaw. This study emphasises the significant sanitizing power of X-rays and the various impacts depending on the starting product quality. For both handmade and commercial ricotta cheese, an intensity of 2 kGy is sufficient to provide great results. Low-salt Sausage (0.75% NaCl) was irradiated with X-ray at 5kGy, then stored at 4° C for 28 days. Evaluated that applied dose helped maintain microbial safety with No Detectable and decreased the sensory acceptability of cooked sausage due to radiolytic off-flavor (Song et al., 2017).

(Mahmoud et al., 2016), To the best of our knowledge, this is the first report of Salmonella inactivation, intrinsic microflora, colour, and hardness on raw tuna fillets by X-ray. In this study, we looked at how raw tuna business may employ X-ray radiation at levels of 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 kGy to assure the safety of raw tuna fillets & increase their shelf life. The effectiveness of X-ray irradiation against Salmonella and local microbiota on raw tuna fillets improved with higher X-ray doses, as was predicted. After treatment, X-ray exposure had a noticeable impact on the colour of the tuna (day 0). Nevertheless, following (day 0), there were no discernible variations between the control and treated samples in terms of colour or hardness ($p > 0.05$). The study's findings showed that X-ray is a useful method for lowering Salmonella and microorganisms associated with deterioration in tuna fillets. The raw tuna sector may save millions of dollars by using X-ray to prevent product recalls (during an epidemic in 2012, some 60,000 pounds of raw yellowfin tuna product were taken off the market). Moreover, by eliminating the need to treat affected customers, employing X-ray can guarantee the safety of raw tuna and recuse hundreds of millions of dollars in future medical costs.

4.3. Ready-to-eat foods

S. Typhimurium, E. coli O157:H7, and *L. monocytogenes* were successfully deactivated by X-ray irradiation on sliced ham without any negative effects on the product's quality. Slicing deli meat is the final processing operation prior to packing or wrapping, which has been identified as a cause of foodborne pathogen contamination in deli goods. Deli meats can acquire L. monocytogenes from a contaminated slicer and can support its survival or growth there. Because of its penetrability, the ability to disinfect packaged beef slices is a benefit of the X-ray process technology. As a post packaging antimicrobial intervention, it may be broadly used to packaged foodstuffs as well as sliced ham because our trial findings were achieved after the repackaging step (Cho & Ha, 2019).

4.4. Protein isolates

According to the results of the current study, 5 kGy irradiation of pork muscles lowers WHC and the heat-induced gel created from the radioactively treated pork muscles had decreased textural characteristics. This was probably caused by muscle protein denaturation, which was assisted by decreases in myofibrillar protein solubility and apparent viscosity. Additionally, gamma radiation had a greater influence than electron-beam or X-ray radiation on the WHC's degeneration and the texture of the heat-induced gel. Above research so implies that one of the key variables influencing the meat's ability to gel may be the irradiation source (Kim et al., 2017).

4.5. Other food products like a bird nest

This is the first research to describe the inactivation of inoculated *S. typhimurium* and *E. coli O157:H7* by low-energy X-ray in dried edible bird's nest. *E. coli O157:H7* and *S. typhimurium* may be successfully reduced to below detectable limits by being exposed to radiation doses of 350 Gy and 400 Gy, respectively. *E. coli O157:tR1 H7's* value was 37.6 6.9 Gy and *S. typhimurium's* D10 value was 83.3 7.0 Gy, respectively. Furthermore, a consistent dosage distribution could be produced throughout the stack of 10 pieces of dried Edible Birds Nest by two-sided low-energy X-ray processing. No sulfur-containing compounds were produced despite the low-energy X-ray irradiation having a considerable impact on the volatile component profile of edible birds' nest which is dose upto 350 Gy of radiation. These findings indicated that low-energy X-ray could represent a viable replacement for the existing inactivation methods for disinfection and food sterilization. To assess the impact of low-energy X ray treatment on the sensory quality and shelf life of treated samples, more investigation is required. To assess the impact of low-energy X-ray treatment on damaged cells, sensory quality, and sample shelf life, more study is required (H. Zhang et al., 2020).

Table 2. Application of Soft X-rays irradiation on different types of food commodities orfood group

S.No	Food Product	Dosage range (kGy)	Observation	Reference
1	Maehyang Strawberry	0.15, 0.4, 0.6, 1.0	Phytosanitary treatment & maintains physicochemical properties	(Y. Yoon et al., 2020)
2	Low-salt Sausage	5.0	Microbial decontamination	(Song et al., 2017)

			to no detectable limit	
3	Fiordilatte cheese	0.5, 2.0, 3.0	Extension of shelf-life upto 40 days	(Lacivita et al., 2019)
4	Ricotta cheese	0.5, 2.0, 3.0	8.5, 7, 7.5 cfu/g log reducing the microbial count of pseudomonas spp., Enterobacteriaceae, and Yeasts, respectively	(Ricciardi et al., 2019)
5	Raw tuna fillets	0.1 to 6.0	Microbial decontamination (6 log CFU reduction of Salmonella count)	(Mahmoud et al., 2016)
6	Ready to Eat (RTE) Sliced Ham	0.2, 0.4, 0.6, 0.8	Lethal effect on Salmonella Typhimurium, Escherichia coli O157: H7, and Listeria Monocytogenes (non-detectable limit or < 0.7 logs CFU/g without producing any sub lethally injured)	(Cho & Ha, 2019)
7	Salt-soluble pork protein gel	5.0	Maintains physicochemical & textural properties lower chewiness value of 0.19	(Kim et al., 2017)
8	Bird nest	0.35 & 0.40	Microbial decontamination (E. coli O157: H7 & S. Typhimurium)	(Hongfei Zhang et al., 2020)

5. Combination process of different food groups & food commodities

Spinach, coriander, and mint optimized by using a combination process washing with potable water (300 sec), sodium hypochlorite (200 ppm,300 sec) and then followed irradiation (E-beam & gamma) at 2 kGy results that improve hygiene by reducing the coliform count below detection level without effecting nutritional, sensory & total phenolics and also extend the shelf life by maintaining quality till 15 days at 4-6º C for up to 15 days compared to the control sample's 2 day spoilage, E-beam works more effective than gamma irradiation due high throughput and equal efficiency in microbial reduction (Khade et al., 2020).

M. Semimembranosus 14 ºC is irradiated with e-beam & x-ray at 2.95- 5 kGy before it was subjected to aging at an elevated temperature of 14º C kept for 14 days evaluated irradiation before aging reduces the microbial count to 1.40 and 2.07 CFU/g for e-beam and X-ray from 4.73 log CFU/g in the untreated sample. Furthermore, it prolongs the shelf life of beef that has been matured by cutting down on the amount of time it spends maturing by seven days at a higher temperature of 14 o C without sacrificing its physicochemical properties such as tenderness by reducing autolysis of calpain-1 during aging. Our findings imply that low-dose X-ray and electron beam irradiation of beef before ageing is helpful in reducing microbial growth while preserving desired physicochemical attributes. The amount of time needed to age beef can be greatly reduced by combining high temperature (14 °C) ageing with low-dose X-ray and electron beam irradiation (5 kGy). Calpain-1 autolysis during beef age may be somewhat decreased by electron beam and X-ray irradiation, although these effect are not powerful enough to affect the ultimate meat softness. Hence, irradiating beef with modest doses of EB and XR radiation may be a useful method for high temperature ageing (Kim et al., 2018).

At every step of vinification, sulphurization is a reliable means of eliminating yeast. Yet given that sulphur compounds have allergenic properties, it is important to consider using alternative methods. In addition to effectively eliminating the yeast in fermenting wine, modest doses of ionising radiation (1–5 kGy) had no impact on the chemical and organoleptic qualities that were being studied. Irradiation is frequently used to preserve food items, thus using it to prevent vinification or to keep complete wine fresh might be an alternative to sulphurization. Expectations for the ozonation of fermenting wine (i.e., at least 95% percent yeast elimination) were not met. Even though the ozonation process was gradually extended to last for an hour, the yeast population was at worst cut in half and at best, their number was larger than in the control (based on the ozonation period and the initial wine yeast count). Wine quality was negatively impacted by ozonation. The destruction of polyphenol compounds—particularly anthocyanins—began to take place at the administered level of 3.5 g ozone at the sixth minute. Moreover, the wine's colour and organoleptic characteristics underwent adverse modifications. Microbial stabilisation of wine was made possible by irradiation at a dosage of 2.5 kGy. This dosage very slightly decreased the amount of polyphenols and had a negligible impact on wine colour. It can be suggested as an alternative to wine cleaning methods based on sulphurization (Błaszak et al., 2019).

The commercial sterility of food items is now achieved using harsh thermal processing, which can negatively impact the nutritive & sensory attributes of the food materials. Hence, when combined with electron beam irradiation, combination therapy enables the less harsh application of thermal treatment (EBIThe efficiency of combination therapy was compared with higher EBI dosage of 7.5 kGy administered alone for its ability to extend the shelf-life of RTE-Idli. Thermal treatment with an EBI dose of 2.5 kGy were shown to be superior to 7.5 kGy alone in avoiding microbiological degradation of Idli while barely impacting its sensory value. One of the most striking findings was that, although giving Idli a 60-day shelf life extension, the 7.5 kGy EBI dose dramatically reduced its sensory value. As a result, we deduce that RTE-Idli samples can be preserved for up to 60 days with enhanced organoleptic property preservation using heat processing and a modest EBI dose of 2.5 kGy.A promising future is anticipated for the food processing sector as India prepares for the growth of electron beam technology (Mulmule et al., 2017).

The current study's findings unmistakably show that E-beam irradiation significantly improve the storage life of salmon fillets & has a preservative impact on them. This finding may be useful in improving fisheries goods. Moreover, salmon fish fillet characteristics and edible quality are considerably impacted by E-beam irradiation. The shelf life of the vacuum-packed, E-beam-irradiated salmon fillets was 12 days based on biochemical and sensory features, which was longer than the shelf life of the non-irradiated fillets, which was 6 days.10 MeV electron linear accelerator has been successfully used to treat salmon fillets, and it is advised that 0.5 kGy of radiation is the optimal dose to retain fish quality. (Yang et al., 2014).

While calcium improves the texture of freshly cut fruits and vegetables, it proved ineffective when applied to sliced mushrooms using VI, and fungal deterioration led to a reduction in quality. Just the irradiation treatment softened the cut mushrooms; Nevertheless, impregnation with a calcium lactate-ascorbic acid solution diluted to 1 g/100 g helped to keep the stiffness of the mushroom. A microbiological examination showed that e-beam irradiation had an effect on lowering the populations of aerobic and psychotrophic microorganisms, although greater dosages were necessary to suppress yeasts and moulds. Consumer approval of the impregnated, irradiated, and impregnated-irradiated mushrooms was determined by sensory testing. The most crucial aspect of a product's quality was its look. Due to less microbially-induced browning, irradiated and impregnated-irradiated samples got the greatest overall sensory rankings. The findings of this investigation showed that the shelf life of sliced mushrooms may be increased by using e-beam irradiation and VI of a solution comprising 2 g/100 g of ascorbic acid and 1 g/100 g of calcium lactate. Future work will assess the impact of impregnation irradiation on poyphenoloxidase activation to comprehend the mechanism of browning inhibition, irradiate at doses greater than 1 kGy to reduce yeast growth and the impact on quality, assess the effectiveness of combining ascorbic acid and citric acid solutions, and optimise the impregnation solution and irradiation dose combinations. Sliced white button mushrooms subjected to vacuum impregnation by using an anti-browning solution such as 1 g/100 g chitosan + 1 g/100 g calcium lactate, 2 g/100 g ascorbic acid + 1 g/100 g calcium lactate, 2 g/100 g citric acid + 1 g/100 g calcium lactate, & 1 g/100 calcium lactate at varies vacuum pressures & times and atmospheric restoration time, then exposed e-beam irradiation at 1 kGy results that irradiated product with vapor impregnation 2 g/100 g ascorbic acid + 1 g/100 g calcium lactate at 50 mm Hg pressure for 300 sec & atmospheric restoration time of 300 sec increase the shelflife of sliced mushroom with sensory quality such as texture and color (Yurttas et al., 2014).

Table 3. Combination Process (irradiation with any other processing or preservation technology) on different food groups & commodities

S.No	Combination Technologies	Food Product	Observation	Reference
1	Sodium hypochlorite (200 ppm, 300 sec) & Irradiation 2 kGy (gamma & EBI)	Leafy vegetables like spinach, coriander, and mint	Improve Hygiene & Extend shelf-life by maintaining quality for upto 15 days	(Khade et al., 2020)
2	Aging at elevated temperature 14° C & Irradiation 2.95 to 5 kGy (EBI & X-Ray)	M. semimembranosus beef	Shelf-life extension (reduces the microbial count to 1.40 and 2.07 CFU/g for e-beam and X-ray)	(Kim et al., 2018)
3	Irradiation (EBI)	Wine	Microbial decontamination (Reduces the yeast count by 95.5% at 1 kGy and 99.9% at 2.5 kGy)	(Błaszak et al., 2019)
4	Thermal treatment 80 ° C for 20 minutes & irradiation (EBI)	RTE Idli	Shelf-life extension of upto 60 days	(Mulmule et al., 2017)

	2.5 & 7.5 kGy			
5	Vacuum packaging & Irradiation (EBI) 0, 0.5, 1.0, 2.0, and 3.0 kGy	Salmon Fillets	Shelf-life extension of upto 12 days	(Yang et al., 2014)
6	Vacuum impregnation by using an anti-browning solution (4 types) & e-beam irradiation 1 kGy	Sliced white button mushrooms	Shelf-life extension	(Yurttas et al., 2014)

6. Conclusion

To reduce microbial contamination & food losses during the production & food supply chain, different types of advanced & emerging trends are introduced. E-beam &x-ray irradiation is a non-thermal, non-chemical, eco-friendly, bi-directional application that does not require any radioactive isotopes & having a higher dose rate capability than gamma rays. Furthermore, the most promising technology is applied to all products without adversely affecting quality parameters. X-ray & e-beam irradiation results in sprout inhibition, insect disinfestation, delay of ripening, shelf-life extension, microbial decontamination, maintaining quality parameters, an increase of juice yield, improvement of re-hydration, and reduction of off-flavors on food products which helps to meet consumer requirements at low doses due to high uniformity penetration. It works more effectively & shows positive impacts on food when combined with other preservation technology. So, it is necessary to identify that E-beam& X-ray irradiation is good & commercial application in agricultural & food practices helps to maintain quality & safety.

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