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GAMMA IRRADIATION IN FOOD PRESERVATION: A CRITICAL REVIEW

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ABSTRACT

Over the last century, food irradiation had become the most studied preservation, sterilization, and treatment methods over the globe. One of the common irradiation methods used in the food industry is gamma irradiation. A variety of studies have been undertaken to specifically investigate the effects of gamma irradiation on the safety and quality of irradiated food for human consumption. Studies have shown that a low dose of gamma irradiation does not cause food radioactivity thus the foods are safe for consumption. However, the effect on physical parameters (weight, colour, texture, pH, etc.) biochemical and chemical properties (proteins, vitamins, phenolics, flavonoid, antioxidant activity, etc.) of irradiated food may vary depending on the type of food and the applied dose. In this review, the gamma irradiation method, consumer acceptance, and the effect of gamma irradiation on food are critically reviewed. It is clear that gamma irradiation treatment shows a very promising future in food preservation.

ABSTRAK

Selama abad yang lalu, penyinaran makanan telah menjadi kaedah pemeliharaan, pensterilan, dan rawatan yang paling banyak dikaji di seluruh dunia. Salah satu kaedah penyinaran yang biasa digunakan dalam industri makanan adalah penyinaran gamma. Berbagai kajian telah dilakukan untuk secara khusus menyelidiki pengaruh penyinaran gamma terhadap keselamatan dan kualiti makanan yang disinari untuk penggunaan manusia. Kajian menunjukkan bahawa dos penyinaran gamma yang rendah tidak menyebabkan radioaktif makanan sehingga makanan selamat untuk dimakan. Walau bagaimanapun, kesan pada parameter fizikal (berat, warna, tekstur, pH, dan lain-lain) sifat biokimia dan kimia (protein, vitamin, fenolik, flavonoid, aktiviti antioksidan, dll.) Makanan yang disinari mungkin berbeza-beza bergantung pada jenis makanan dan dos yang digunakan. Dalam tinjauan ini, kaedah penyinaran gamma, penerimaan pengguna, dan kesan penyinaran gamma pada makanan dikaji secara kritikal. Jelas bahawa rawatan penyinaran gamma menunjukkan masa depan yang sangat menjanjikan dalam pengawetan makanan.

Keywords: food irradiation, gamma radiation, Fricke dosimeter, antioxidant, bioactive compound, mushrooms, fruits, vegetables

INTRODUCTION

Food irradiation has been around the globe for centuries now, with the original patent for X-ray treatment of foods issued in early 1905, 20 years after W.C. Roentgen discovered X-ray in 1885 (Pillai & Shayanfar, 2017). It was then the most extensively studied and developed food treatment technology in the history of mankind. Food irradiation was not a popular concept until it was scientifically established and proven to be beneficial and safe for food treatment processing for the past 50 to 70 years (Molins, 2001; Ravindran & Jaiswal, 2019). In the 1950s, research programmes for food irradiation were initiated across Western Europe, while the International Food Irradiation Project (IPFI) was launched in 1970 to investigate and validate the overall effects of radiation on food (Ravindran & Jaiswal, 2019). A joint committee formed by the International Atomic Energy Agency (IAEA), Food and Agriculture Organisation (FAO), and World Health Organisation (WHO) was named to examine the findings of the project (József Farkas & Mohácsi-Farkas, 2011). However, until today, it has been considered as the most misunderstood technology since the food was irradiated with ionizing radiation, which could break the chemical bond of the food. This understanding always leads to public concern about the safety and quality of the irradiated food even though our food is constantly irradiated by non-ionizing radiation called microwave.

Gamma photons emitted by the radioisotopes such as ^{60}Co (cobalt-60), ^{137}Cs (cesium-137) as well as X-rays which also known as Bremsstrahlung, generated by a machine with a maximum of 5 MeV, or accelerated electrons beam with a maximum of 10 MeV kinetic energy are the common types of radiation used for food irradiation (J Farkas, 2004). In 1997, an investigation of high dose irradiation (25 – 60 kGy) on food by FAO, IAEA, and WHO has proven that these radiation types on food irradiation were safe to consume and nutritionally adequate (Diehl, 2002).

GAMMA IRRADIATION IN THE FOOD INDUSTRY

Radiation has been applied in so many industries for decades such as medical imaging, sterilization of surgical instruments and medical devices, non-destructive testing (NDT), carbon dating in archeology, space exploration, and food sterilization. Food irradiation is a process where the food product will be exposed to certain types of the ionizing radiation source with a specific applicable dose rate and exposure time. The key goal of this process is to increase the shelf-life of the food product by applying radiation that can kill harmful organisms (Anuradha Prakash, 2016). Irradiation is gaining worldwide's interest due to its non-thermal process in sterilizing and preserving the food product without degrading their bioactive compounds and antioxidant activities (Naresh, Varakumar, Variyar, Sharma, & Reddy, 2015).

In 2002, the United States have amended its drug legislation and regulation to allow the irradiation of certain food in order to control foodborne pathogens that can cause disease (Piri, Babayan, Tavassoli, & Javaheri, 2011). Nowadays, there are over 60 countries that have been permitted to preserve and sterilize food products by food irradiation with the purpose to destroy microbes, worms, insects, and parasites as well as for the inhibition of sprouting (Kume, Furuta, Todoriki, Uenoyama, & Kobayashi, 2009). This method of preserving and sterilizing food is considered safe and effective due to the evolution of irradiation technology through research activities for the past 100 years (Ihsanullah & Rashid, 2017). In Malaysia, there are already 3 existing gamma irradiation facilities that can provide food irradiation services offered at SINAGAMA located at Malaysian Nuclear Agency, Synergy Sterilization (M) Sdn Bhd located at Rawang, Selangor, and Kuala Ketil, Kedah. Meanwhile, there are two more gamma irradiation facilities to be constructed soon in Sepang, Selangor, and Kuching, Sarawak (Ihsanullah & Rashid, 2017).

Based on the study of the status of food irradiation in the world, it can be concluded that irradiated food obtained worldwide can be classified into 5 categories as shown in Table 1. The data obtained from this investigation are collected from 4 global regions (America, Europe, Asia & Oceania, and Africa) in 2005. The results show that the total quantity of food irradiation globally in 2005 reached 405,000 tons and continues to increase each year (Kume et al., 2009). All these illustrate the ever-increasing demands for gamma irradiation facilities, which in turn necessitates more researches and studies to improve the food irradiation technology.

Table 1. Classification of irradiated food items (Kume et al., 2009).

Group	Food Items
1	Disinfection of spices and dried vegetables
2	Disinfection of grains and fruits
3	Disinfection of meat and seafood
4	Sprout inhabitation of root crops and bulbs
5	Other food items (mushrooms, honey, etc)

Source of gamma radiation

There are 3 types of commonly used and approved sources of radiation for use on food which are gamma rays naturally emitted from the decay of element ^{60}Co (cobalt-60) or ^{137}Cs (cesium-137), X-rays (machine-generated source produced by reflecting high energy electron off a targeted metal plate that are usually tungsten), and electron beam (machine-generated source produces by high energy electron projected from an electron accelerator) (Hallman, 2017). Generally, the most common radiation source in food preservation and sterilization is gamma irradiation from the element ^{60}Co (cobalt-60). The use of ^{137}Cs (cesium-137) however is highly discouraged due to the high solubility of the isotope in water (Ravindran & Jaiswal, 2019). There is an increasing demand for ^{60}Co (cobalt-60) gamma irradiation for non-food products such as cosmetics and pharmaceuticals due to their non-thermal processes. Higher doses of radiation exposure may result in changes in the physical, structure, chemical or biochemical properties of the irradiated food (Stewart, 2001). Therefore, according to the Codex Alimentarius General Standard, the maximum and legal dose rate for food irradiation was set to 10 kGy (Keener, 2013). Meanwhile, the United States Food and Drug Administration (FDA) have already set the maximum allowed dose for certain type of foods such as culinary herbs, seeds, spices, and vegetable seasoning to 30 kGy.

According to the IAEA, irradiators can be divided into two broad groups which are self-contained irradiator and panoramic irradiator (International Atomic Energy Agency, 2004). Self-contained irradiator types are suitable for small-scale applications and are designed specifically for research purposes. In the previous research on gamma food irradiation, food samples are irradiated in a gamma radiation chamber (self-contained irradiator type) as shown in Figure 1. The gamma irradiation chamber consists of rectangular with dimensions of 65 cm × 50 cm × 20 cm (h × d × w) and surrounded by a radiation shield made of lead. There are four ^{60}Co (cobalt-60) radiation sources with an activity reading around 305 TBq (8.233 kCi) which are placed in stainless-steel tubes inside the lateral wall of the chamber located above the chamber floor (Antonio et al., 2011).

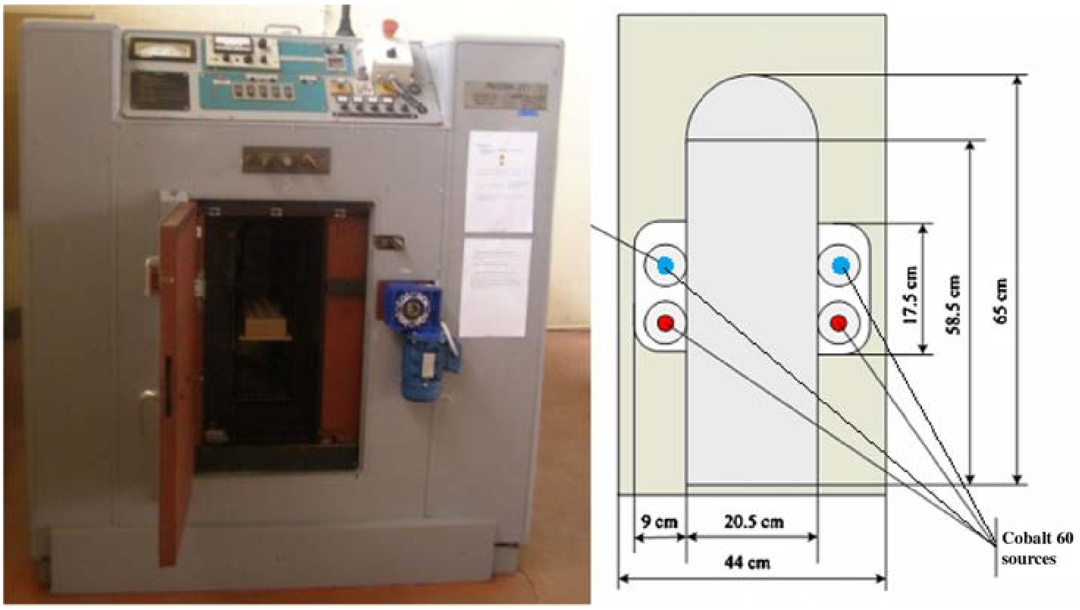

Figure 1. Irradiation chamber dimensions (Belchior, Botelho, & Vaz, 2007).

In the food industry, gamma irradiation treatments are used on a full commercial scale. A typical industrial ^{60}Co (cobalt-60) gamma irradiator (panoramic irradiator type) is shown in Figure 2. The major components of a typical gamma irradiation facility consist of shielded storage room, source hoist mechanism, radiation shielding surrounding the irradiation room, control room, product containers, product transport system (shielding maze), control and safety interlock system, product loading and unloading area, and supporting service equipment (International Atomic Energy Agency, 2004). During the product irradiation process, the radiation source capsules are being lift-up into the irradiation room. All capsules (400 g weight, 45.2 cm length, 11.1 mm diameter each) are arranged in a source rack system and stored 5.5 m deep at the bottom in the storage pool when not in use. To prevent radiation exposure towards the operator, workers, and the public, the irradiation room is surrounded by concrete radiation shielding (Solyman, Roman, Keshk, & Sharshar, 2016).

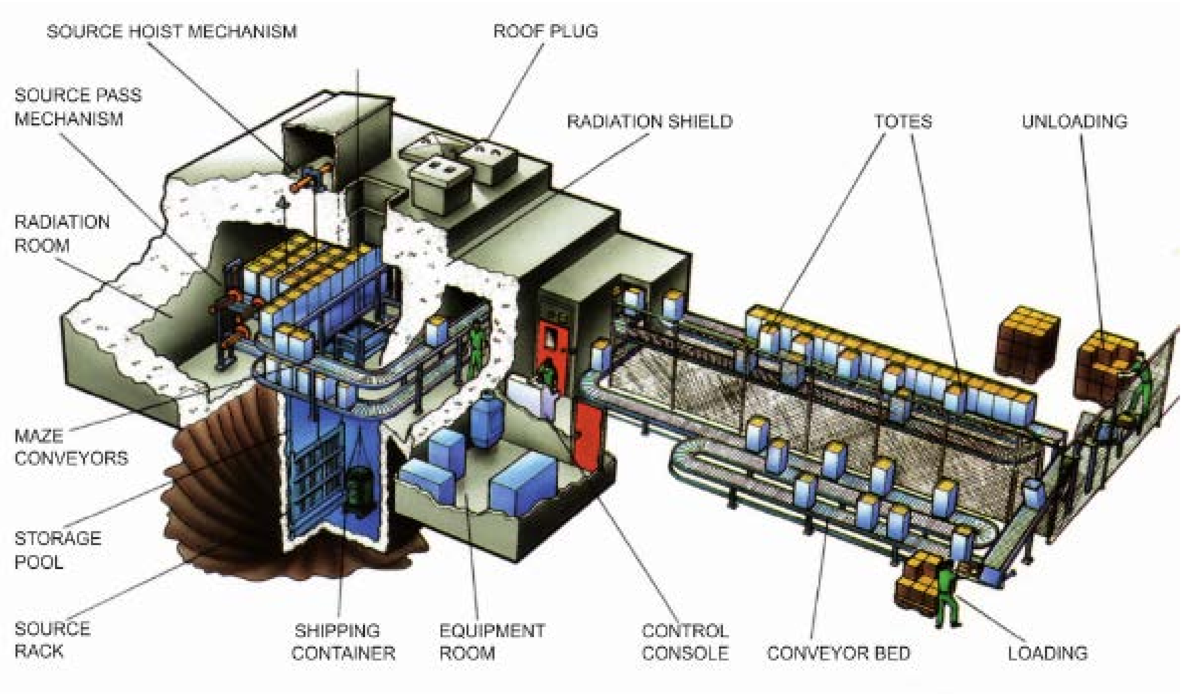

Figure 2. Schematic diagram of a typical gamma industrial irradiator (International Atomic Energy Agency, 2004).

Fricke Dosimeter

A dosimeter is a device used to measure the absorbed dose, equivalent dose, kerma, and exposure of radiation whether it is measured directly or indirectly. There are many types of dosimeters used based on certain circumstances, which are film dosimetry, luminescence dosimetry, semiconductor dosimetry, alanine dosimetry, plastic scintillator dosimetry, diamond dosimeter, and chemical dosimeter (Galante, 1999). Fricke dosimeters are categorized as chemical dosimeters and are often used in the food irradiation process to measure the absorbed dose. In the Fricke dosimetry system, the absorbed dose is determined by measuring the chemical change produced by the radiation in the volume of the Fricke dosimeter solution. Fricke dosimeter solutions as shown in Figure 3 are very sensitive to ionizing radiation.

Figure 3. Fricke dosimeter solution in a glass ampoule (Agensi Nuklear Malaysia, 2011)

Five studies are identified to use Fricke dosimeter to measure the radiation dose absorbed by the food sample during the irradiation process. In summary, to prepare the Fricke dosimeter solution, following the standard (ASTM E10226, 1992), 0.392 g of ferrous ammonium sulfate and 0.058 g of sodium chloride were dissolved in sulfuric acid (12.5mL, 0.4 mol L^{-1}) and then diluted with triply distilled or de-ionized water into 1 L using a volumetric flask at 25 °C (Antonio et al., 2011; Schreiner, 2004). The resultant dosimetry solution then was air saturated with pure oxygen for 10 min before it was kept in the dark covered with aluminium foil (Antonio et al., 2011). In the irradiation chamber, the Fricke dosimeter solution is placed almost in a similar position as the food sample so that it can be exposed to radiation in the irradiated area. The irradiation process of Fricke solution will oxidize the ferrous ion (Fe^{2+}) into ferric ions (Fe^{3+}). Consequently, the increased concentration of the ferric ions (Fe^{3+}) will be measured using a spectrophotometer set at 305 nm wavelength (deAlmeida et al., 2014).

Consumer acceptance on Irradiated Food

Consumer concerns on the gamma irradiation technology used in food have been identified and studied over the years. The common concerns that arise among the consumers are the nutritional quality of the irradiated food and the toxicological effect on human health. Over the decades, many researches have been conducted to study the advantages and disadvantages of preserving and sterilizing food using radiation. This led to international bodies such as World Health Organization, International Atomic Energy Agency (IAEA), and Food And Agriculture Organization (FAO) endorsing that food irradiation is a safe processing method (Ravindran & Jaiswal, 2019). Based on United States consumer's attitude studies, it was shown that 60% to 90% of respondents prefer irradiated food rather than other food processes such as chlorination or pasteurization (Bruhn, 1998). In further investigation, 29% of respondents considered irradiation a potential hazard on health compared to 77% who considered bacteria as a more serious hazard, and 66% who considered pesticide to be hazardous (Dept & Corporation, 1996).

Meanwhile in Santiago, Chile, a study has been conducted among their consumers by surveying the knowledge and acceptance towards irradiated food. Out of 497 respondents, 76.5% are not aware of the use of irradiation methods for preserving food. However, 91% would definitely be consumers of irradiated food if only they knew that the foods are not radioactive, while 46% believe that irradiated foods are radioactive (Junqueira-Gonçalves et al., 2011). The first arising public interest in utilizing the irradiation food product for preservation is due to the outbreak of E. coli 0157:H7 in the west coast of the United States, which lead to the death of several children (Bruhn, 1998). Over the decades, many studies on food irradiation technology have led to many other new concerns on the nutritional quality of food products. If food items are exposed to extremely high levels of radiation, certain components can undeniably become radioactive. (Ravindran & Jaiswal, 2019). Due to numerous previous studies on the effect of irradiation on food quality, there were many new findings on the maximum permissible dose rate on a certain type of food. Table 2 shows the current maximum allowable dose to be exposed on permitted food regulated by the Food and Drugs Administration (FDA) in 2007.

Table 2. Foods permitted to be irradiated by FDA under 21 CFR 179.26(b) as of October 2007 (Vanee Komolprasert, 2017).

Food	Purpose	Dose (kGy)
Fresh, non-heated processed pork	Control of *Trichinella spiralis*	0.3 min to 1.0 max
Fresh foods	Growth and maturation inhibition	1.0 max
All foods	Arthropod disinfestation	1.0 max
Fresh or frozen, uncooked poultry products	Pathogen control	3.0 max
Frozen packaged meats (NASA)	Sterilization	44.0 min
Frozen, uncooked meat products	Pathogen control	7.0 max
Fresh shell eggs	Control of *Salmonella*	3.0 max
Fresh or frozen molluscan shellfish	Control of *Vibrio* species and other foodborne pathogens	5.5 max
Dry or dehydrated enzyme preparations	Microbial disinfection	10.0 max
Dry or dehydrated spices/seasonings	Microbial disinfection	30.0 max
Refrigerated, uncooked meat products	Pathogen control	4.5 max
Seeds for sprouting	Control of microbial pathogen	8.0 max

EFFECT OF GAMMA IRRADIATION IN FOOD COMPOSITION

Fresh Mushroom

Mushrooms provide a wide range of nutrition including protein, folate, niacin, vitamin B, low calories, a high antioxidant such as selenium, and many more. Due to their benefits, many people worldwide consume mushrooms in their everyday diet. However, the short shelf-life of mushrooms is a big problem in the distribution, exportation, and marketing of edible fungi. Their short shelf-life is due to many post-harvest changes, such as browning, cap opening, stipe, elongation, cap diameter increase, weight loss, and texture changes, as well as being due to their high respiration rate and lack of physical protection to avoid water loss or microbial attack (Akram & Kwon, 2010). There are several ways to preserve mushrooms and extend their postharvest shelf-life, in fact, there have been years of research on finding the most effective technology of mushrooms preservation

(Sommer, Schwartz, Solar, & Sontag, 2010). Commonly applied methods for mushroom preservations are chemical treatments, cooling, and hyperbaric storage (Gautam, Sharma, & Thomas, 1998).

In the past few years, gamma irradiation has gained popularity in mushrooms preservation although there is so much to be investigated regarding the effect of gamma irradiation in chemical and biochemical composition, antioxidant activity, and physico-chemical parameters (weight, colour, texture, pH) of the mushrooms. The influence of gamma irradiation on mushroom's chemical and biochemical composition have been reported in numerous studies. An investigation of *Pleurotus nebrodensis* mushrooms irradiation at a dose of 1.2 kGy reported a significant delay (by 6–9 days) in the onset of fruit body softening, splitting, and browning compared to the non-irradiated samples. In this study, polyphenoloxidase activity, also known as the cause of the post-harvest browning shows lower activity in irradiated samples. Furthermore, the irradiation with 1.2 kGy and 1.6 kGy doses also had a positive effect on *Pleurotus nebrodensis* mushroom tissue senescence, resulting in smaller decreases in soluble protein levels and more protracted increases in proteinase activity (Xiong, Xing, Feng, Tan, & Bian, 2009). Weight loss in irradiated mushrooms has been identified in several studies for the past years. The final weight loss of irradiated *Hypsizygus marmoreus* mushrooms is 8.3–9.7% average (at dose 0.8 kGy, 1.2 kGy, 1.6 kGy, 2.0 kGy), compared to 8.2% average weight loss in non-irradiated samples (Xing, Wang, Feng, Zhao, & Liu, 2007). However, in another reported study, it was shown that weight loss is marginally higher in non-irradiated samples of *Agaricus bisporus* mushrooms after 11 days than in irradiated samples (2.0 kGy) (Gautam et al., 1998). The studies of the effect of gamma irradiation on mushrooms on other compositions are summarized in Table 3.

Table 3. Species of irradiated mushrooms and γ-irradiation effect on mushrooms composition.

Mushroom species	**Origin**	**γ-irradiation dose (kGy)**	**Effect of γ-irradiation in mushroom composition**	**References**
Agaricus Bisporus	Hungary	1.0, 3.0, 5.0	Two out of three 5'-nucleotides (AMP, GDP) concentrations were reduced by 46% and 22% respectively. GMP and two free amino acids (tyrosine & phenylalanine) were not affected.	(Sommer et al., 2010)
Agaricus Bisporus	Hungary	1.0, 3.0, 5.0	The total phenolic content and antioxidant capacity were not significantly ($p = 0.05$) influenced by irradiation.	(Sommer, Schwartz, Solar, & Sontag, 2009)
Macrolepiota procera	Northeast Portugal	0.5, 1.0	γ-irradiation did not cause any noticeable change in total tocopherols. Results in higher antioxidant activity & phenolics compound.	(Fernandes et al., 2014)
Lactarius deliciosus	Northeast Portugal	0.5, 1.0	Tocopherols content significantly decreased. Phenolics and antioxidant activity increased at a dose of 0.5 kGy.	(Fernandes et al., 2013)
Boletus edulis	Northeast Portugal	2.0, 6.0, 10.0	No noticeable effect on tocopherols, phenolics, and cinnamic acid despite the slightly lower EC_{50} values found in irradiated samples.	(Fernandes et al., 2017)

Agaricus Bisporus	Canada	2.0, 4.5, 32.0	Browning was delayed, no significant difference in phenolic content, decreased PPO activity, thinning of the cellular membrane.	(Beaulieu, D'Aprano, & Lacroix, 2002)
Lentinus edodes	China	1.0, 1.5, 2.0	Small declines insoluble protein, higher increases in total sugar content and low malondialdehyde accumulation, high phenolics, and antioxidant activity at dose 1.0 kGy. High microbial reduction at dose 2.0 kGy.	(Jiang, Luo, Chen, Shen, & Ying, 2010)

Fruits and Vegetables

Some fruits and vegetables categories are also known to have a short shelf-life. The minimum shelf-life of some fruits and vegetables are around 2 to 10 days depending on the surrounding temperature, storage conditions, pathogenic attacks, and postharvest handling (Zhang, Li, & Liu, 2011). These problems are more serious and massive in developing countries due to the lack of experience in handling and storing postharvest fruits and vegetables (Jeffries & Jeger, 1990). However, many studies show that the alternative effective way to reduce microbial counts and extend the shelf-life without any significant changes in the physical and bioactive compound of food is through applying gamma irradiation treatment (Crawford & Ruff, 1996). Based on FDA regulation, approved doses that can be applied on fruits and vegetables are set to 1.0 kGy maximum.

Several studies have reported the effect of gamma irradiation along with storage after irradiation specifically on microbial counts, colour, texture, flavour, weight loss, bioactive compound, and many more other compositions of fruits and vegetables. These are to make sure of the quality and safety of the fruits and vegetables for public consumption. In a previous study, it was reported that at 0.5 kGy gamma irradiation treatment on diced celery (*Apium Graveolens*) decreased initial microbial counts by 1.5 logs, while at 1.0 kGy treatment reduced initial counts by more than 4 logs (A Prakash, Inthajak, Huibregtse, Caporaso, & Foley, 2000). In the same study, yeast and mold count, *Escherichia coli*, and *Listeria monocytogenes* were determined. no yeast or mold growth was observed in the 1.0 kGy treated sample until day 20 of the storage period, same goes to *E. coli* and *L. monocytogenes* (A Prakash et al., 2000). Thus, it can be concluded that the 1.0 kGy dose would be effective to reduce pathogen in diced celery.

Other study of gamma irradiation effect on Okra or Okro (Abelmoschus esculentus Moench) have been identified. In this study, the okra samples have been irradiated with doses 0.1, 0.2, 0.3, 0.4, and 0.5 kGy to investigate the effect of gamma irradiation on several parameters (Days to germination, Germination percentage, Initiation of flower, Initiation of fruit, Number of fruits per plant, Fruit maturation, Fruit length, Number of seeds per plant, Fresh weight of seeds, Number of leaves, Plant length, Number of branches and Number of nodes) (Amir et al., 2018). The effect of okra on some biochemical properties such as ash %, moisture %, and protein % have been also determined. It was reported that okra fruit initiation was delayed by increasing the radiation doses. The result shows the maximum mean value obtained for 0.1 kGy (77.2 days), 0.2 kGy (75 days), 0.3 kGy (60.2 days), 0.5 kGy (56 days), and 0.4 kGy (26.2 days) compared to the non-irradiated sample (102 days) proving that okra fruit initiation has been delayed by gamma irradiation (Amir et al., 2018). Numerous studies on the gamma irradiation effect on fruits and vegetables are summarized in Table 4.

Table 4. Type of irradiated fruits and vegetables and γ-irradiation effect on their composition

Fruits/ vegetables type	**Origin**	**γ-irradiation dose (kGy)**	**Effect of γ-irradiation in fruits/vegetables**	**References**
Strawberry	Egypt	0.3, 0.6, 0.9 with dose rate of 1.9 kGy/h	Antioxidant activity and phenolics contents are increase and higher in irradiated samples. Weight loss % and decay % were greater in non-irradiated samples. Ascorbic acid, anthocyanin, acidity, and pH value were not significantly affected.	(Maraei & Elsawy, 2017)
Raspberries	Portugal	0.5, 1.0, 1.5 with dose rate of 2.2 kGy/h	Phenolic and antioxidant activity indicated a rise during irradiation and decrease significantly within 14 days of storage. Fall in raspberries texture (firmness) after irradiation and no further impaired in 5 days storage.	(Verde et al., 2013)
Mangifera indica L. (mango)	India	0.3, 0.5, 0.7, 1.0, 6.0, 10.0 with dose rate of 2.5 Gy/s	No immediate changes in physical appearance. The low dose treated fruit particularly 0.7 kGy had firmer flesh and looked after 7-14 days storage. No significant effect of irradiation on penetration strength at lower doses (0.3–0.7 kGy), but was significantly reduced at the higher doses.	(Zafar & Sidhu, 2017)
Zizyphus mauritiana (ber fruit)	India	0.25 kGy (15 min), 0.50 kGy (30 min), 0.75 kGy (45 min), and 1.00 kGy (60 min)	Antioxidant activity and phenolics content decrease, while flavonoids increase. 0.25 to 0.5 kGy is a better dose to retain the natural antioxidant in ber fruit.	(Kavitha et al., 2015)
Fresh cut Celery	China	0.5, 1.0, and 1.5 kGy with a dose rate of 0.5 kGy/h	Microbial populations decreased with an increase of irradiation dose. However, microbial numbers increased with increasing storage time (9 days). Vitamin C of nonirradiated celery was lower than irradiated (3–6 days storage).	(Lu, Yu, Gao, Lu, & Zhang, 2005)

CONCLUSION

In conclusion, gamma irradiation treatment on food does not cause any negative changes on the food molecular composition that can cause harm to the human health. The current gamma irradiation facilities in food treatment around the world are safe and scientifically established. However, in a developing country such as Malaysia, the further development of gamma irradiation facilities continues to remain a work in progress. Consumer acceptability, knowledge, and awareness on irradiated food are still low, thus greater effort on educating and providing them with scientific-based information on irradiated food is important. The permitted gamma irradiation dose and their effects are compared in many studies to prove the acceptable dose that will not cause significant changes in the food nutritional value and composition. This observation suggests that the gamma irradiation on food must be done only in low-level doses as stated in FDA regulation. Nonetheless, with the extensive research and development of gamma irradiation technology and irradiated food, this technology will gain trust and acceptability among consumers.

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