

Effect of Irradiation on Quality and Shelf Life of Different Fruits and Vegetables: A Review

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Abstract— Food irradiation exposes the food to various radiations and is a non-thermal, energy-efficient, non-chemical, and physical method of food preservation. By not negatively influencing a product's nutritional properties, it is utilized to increase the shelf life of that product. Irradiation techniques have been studied for fruits and vegetables to increase their shelf life and see their effect on quality. Irradiation is based on the application of different doses of radiation for processing. According to studies, irradiation has a good impact on the quality and shelf life of various fruits and vegetables. Although a promising, safe, and well-established technique, food irradiation is still not widely used. Innovative food processing technologies like food irradiation pose a challenge due to customer purchasing habits. As a result, the current analysis indicates that further research is required to establish the safety of irradiated food, and those efforts must be made to raise the technological appeal of food safety. The aim of the present review article is to summarize the application of irradiation to fruits and vegetables and its effect on their quality and shelf life.

Keywords— Food irradiation, fruits and vegetables, shelf life, quality, radiation.

I. INTRODUCTION

Food irradiation is a non-thermal method of food processing that involves subjecting pre-packaged or bulk foods to gamma rays, X-rays, or electron beams. According to Barbosa-Canovas et al. (1998) [1], foods are frequently exposed to gamma radiation from radioisotope sources, electrons, X-rays produced by electron accelerators, or a combination of these radiations. Fruits and vegetables are excellent sources of nutrients that maintain the body's health and keep it disease-free (Alegbeleye et al., 2022; Salehi and Kashaninejad, 2018) [2]. These nutrients include dietary fibers, phenolic compounds, minerals, and vitamins. Long-term storage of these agricultural products is a major concern due to their high perishability, which results in severe post-harvest losses during storage (Salehi, 2020) [3].

Over 1.3 billion metric tons of foods are reportedly wasted worldwide each year as a result of spoilage, with fruits and vegetables making up nearly 40% of the losses (Jiang et al., 2020) [5]. Food irradiation technology continues to be the most adaptable non-thermal processing method despite major attempts to reduce post-harvest losses and maintain the overall quality and safety of fruits and vegetables (Barkai-Golan and Follett, 2017) [6]. When no other acceptable technology is available, there is an increasing interest in using food irradiation to preserve fresh produce (Bisht et al., 2021) [7]. Numerous studies have been conducted to examine the effects of irradiation on fresh fruit and vegetables with the goal of delaying ripening and increasing antioxidant production. (Niemira et al., 2001 [8]; Kader, 1986) [9]. One of the most promising new techniques for ensuring the safety of fresh and newly cut fruits and vegetables is low-dose irradiation. Due to the great need to reduce the amount of pesticides used on fruits and vegetables, the non-residual property of ionizing radiation is of considerable benefit. In this review, we have focused on the applications of different radiations at different doses on fruits and vegetables and the effect of irradiation on the shelf life and quality of different fruits and vegetables.

II. METHODOLOGY AND RESULTS

A. Effect of irradiation on different fruits

The main aim of this study was to see the effect of irradiation on the quality and shelf life of fruits. In a study by Susheela et al. (1997) [10], pineapple fruit (*Ananas comosus*) was exposed to 0.15 kGy of radiation at the three-quarter and full-ripe stages and reported no appreciable loss of sugar and ascorbic acid concentrations. Drake and Neven (1998)[11] claim that 0.3 kGy or less of irradiation can be used to quarantine cherries, apricots, or peaches with no quality loss. Bing cherries treated with irradiation saw a slight decrease in

firmness compared to those treated with methyl bromide (MeBr), although irradiation did not cause a loss in the color of the fruit or the stem, whereas MeBr doses did. Peaches (Regina) and apricots (Perfection and Rival) were resistant to 0.3 kGy irradiation with no quality loss. Both apricots and peaches showed signs of internal breakdown, color changes, and loss of firmness at irradiation doses greater than 0.6 kGy.

In contrast to non-irradiated fruit, Paull (1996) [12] found that papaya fruits (*Carica papaya* L.) treated with 0.25 kGy of γ -irradiation frequently softened more uniformly. Fruits exposed to radiation that had less than 25% of their surface tinted yellow and were stored at 10°C suffered skin scald. At the mature green stage, there was no difference in the rates of softening between irradiated and non-irradiated fruits.

Grapefruits (*Citrus paradisi* cv. Rio Red) were given γ - irradiation at 0, 0.15, and 0.3 kGy by Vanamala et al. (2007) [13], after which they were kept at 10°C for 36 days and then 20 days. The amount of total soluble solids in grapefruits did not significantly alter as a result of storage or irradiation. However, during storage, the acid content significantly decreased. Fruits that had received 0.3 kGy of radiation exhibited more acidity than the control (0 Gy). Furthermore, their findings imply that 0.3 kGy of low-dose irradiation either increased or maintained the flavonoid concentration.

Fresh Tristar strawberries were exposed to electron beam radiation at doses of 0, 1, and 2 kGy. Fruit firmness is reduced with increasing irradiation exposure. At 0 and 1-day following irradiation with 1- and 2-kGy, water-soluble pectin increased while oxalate-soluble pectin decreased. Fruit firmness and the presence of oxalate-soluble pectin were associated. Irradiation had no effect on total pectin or pectin that couldn't be extracted. Irradiated strawberries' firmness and oxalate-soluble pectin concentration initially increased somewhat during storage at 2°C before declining over time. Water-soluble pectin, non-extractable pectin, and total pectin remained unchanged during storage (Yu et al., 1996) [14]. Kim et al. (2007) [15] studied the effects of low-dose e-beam

irradiation on the physicochemical quality and antioxidant activity of kiwifruits (0, 0.3, and 0.6 kGy). Fruits were kept at 20°C for 28 days, and then their quality was checked after 0, 1, 2, 3, and 4 weeks. Irradiation did not affect the pH or 1,1-diphenyl-2-picrylhydrazyl's capacity to scavenge free radicals. Irradiated fruits had higher vitamin C concentrations than non-irradiated fruits. The total sugar amounts and reducing sugar contents were unaffected by irradiation. For the initial storage period, the soluble solid contents of the irradiated fruits were larger than those of the non-irradiated fruits, but the rate of increase was slower. The rate of reduction in the organic acid content of the irradiated fruit did not significantly vary.

X-ray irradiation doses of 0.195 and 0.395 kGy produced negligible differences in juice yield between X-ray irradiated and cold-treated Clementine mandarin fruits (*Citrus reticulata*), with no discernible difference between the control and any irradiation treatment. This was the conclusion reached by Alonso et al. (2007) [16]. Along with the X-ray dosage and storage time (1.5°C for 14 days), the irradiated fruit had greater acetaldehyde and ethanol concentrations.

In a study by Assi et al. (1997) [17], mature green and pink tomato (*Lycopersicon esculentum* Mill.) fruits were subjected to ionizing radiation from X- or γ -ray sources between 0.7 and 2.2 kGy. Fruit exposed to radiation at the mature green stage softened after post-irradiation storage (20°C), but it showed an apparent irreversible decrease in polygalacturonase activity, with levels remaining less than 10% of those of non-irradiated fruit. Irradiated pink fruit was less severely damaged by polygalacturonase activity than mature green fruit, but activity remained lower compared to controls. In the immediate post-irradiation period, pectinmethylesterase and β -galactosidase activities in irradiated fruit of all ripening stages were greatly increased; however, declines were observed after prolonged storage. "Table 2.1" displays the effects of irradiation on the quality improvement and shelf-life extension of fruits.

TABLE I. THE EFFECTS OF IRRADIATION ON QUALITY IMPROVEMENT AND SHELF-LIFE EXTENSION OF FRUITS

Fruits	Irradiation type/ Dose	Temperature / Shelf life	Quality	Reference
Blue berries	e-beam radiation/ 1.0-3.2 kGy	5±1°C / 14 days	The total phenolic content in irradiated blue berries was higher than non – irradiated fruits. Reduction of ascorbic acid was recorded	Moreno et al., 2008 [22]
Clementine mandarins	γ and X- ray irradiation/ 0.510 and 0.875 kGy	20°C / 14 days	Soluble solids concentration, juice yield, maturity index was not influenced by irradiation	Palou et al., 2007 [16]
Gala apple slices	0.5 and 1.0 kGy	10°C / 3 weeks	Irradiation did not affect titratable acidity and pH of sliced apples. Fruit slices softened during irradiation and storage	Fan et al., 2005 [23]
Red grape fruit	γ -irradiation / 0.07, 0.2, 0.4 and 0.7 kGy	10°C / 4 weeks	Vitamin C content and soluble solids (%) were not affected due to irradiation	Patil et al., 2004 [21]
Fresh blue berries	e-beam radiation/1.1, 1.6 and 3.2 kGy	5°C/14 days	Irradiation does not affect the juiciness, acidity levels and pH of the fruits	Moreno et al., 2007 [22]

B. Effect of irradiation on different vegetables

The main aim of this study was to see the effect of irradiation on the quality and shelf life of vegetables.

In a study by Fan and Sokorai (2005) [23], the radiation sensitivity of freshly cut vegetables was determined by measuring electrolyte leakage. Freshly cut vegetables were γ -irradiated at intervals of 0.5 kGy up to 3 kGy. For all vegetables, electrolyte leakage increased linearly with radiation dosage. Celery, carrots, and green onions were the most radiation-sensitive foods, whereas red cabbage, broccoli, and endive had higher radiation resistance. The endogenous antioxidant capacity and vegetable phenolic content, which varied greatly among test samples, were not always connected to radiation sensitivity.

Song et al. (2006) [24] studied carrot and kale juice kept at 10°C for three days. They stated that the irradiated (3 kGy) samples had considerably higher total phenolic contents than the non-irradiated control samples of both vegetable juices. The irradiated carrot juice has a higher antioxidant capacity than the non-irradiated control. However, despite a rise in the phenol content of the kale juice throughout the storage period, the antioxidant capacity dropped.

The total carotenoids and vitamin C in diced tomatoes (*Lycopersicon syn. L. esculentum*) did not change significantly after receiving a radiation dose of 1 kGy. However, the amount of α -tocopherol dropped by around 40% as a result of this dose, according to Mohacsi-Farkas et al. (2006) [25].

The impact of radiation processing on the vitamin C content, total carotenoids, texture, and organoleptic qualities of carrot and cucumber was investigated by Bandekar et al. in 2006 [26]. There was no significant difference between the radiation-processed (1 and 2 kGy) samples and control samples in terms of the amount of vitamin C and total carotenoids. The amount of vitamin C and carotenoids varied during storage, but not in a way that was statistically different from the control samples.

According to Adesuyi and Mackenzie's 1973 [27] study, Starch levels in yam tubers (*Dioscorea rotundata*) were nearly comparable in control and 0.15kGy treated tubers during a storage period of 5 months under normal conditions (25–37°C, 50–85% RH). A drop in starch concentration was observed in tubers that were exposed to radiation doses of 0.1 and 0.125 kGy, although those exposed to 0.025, 0.05, and 0.075 kGy had higher starch contents.

After exposure to radiation up to 0.15 kGy during the 16 weeks of storage in South African potato cultivars, no adverse effects on ascorbic acid were seen (Winchester and Visser, 1975). A considerable drop in ascorbic acid was observed in potatoes exposed to X-rays at 0.135 kGy, but not at doses as low as 0.09 kGy (Berger and Hansen, 1962) [28].

The total sulfur and thiosulfonate were stored at $3\pm 1^\circ\text{C}$ and $80\pm 5\%$ RH for 10 months; however, the contents of both components gradually decreased in irradiated garlic and control after 6–8 months of storage compared to initial values (Kwon et al., 1989) [29]. The contents of garlic bulbs were unaffected by irradiation at 0.1 kGy during storage.

According to a Canadian study, after 5 months of storage at 12.8°C, the total weight loss caused by sprouting and shrinking of onion bulbs irradiated with 0.06 and 0.076 kGy was 5.7% as compared to 23.2% for the non-irradiated bulbs (Anonymous, 1962) [30]. After a 270-day test storage in a commercial warehouse (6–32°C, 50–90% RH), weight loss in the Valenciana Sintetica 14 cultivar grown in Argentina was 43.3% in the control samples compared to only 22.8% in the 0.03kGy treated samples (Curzio and Croci, 1983) [31].

The effects of irradiation (0.5, 0.75, and 1 kGy) on the vitamin C content of lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea*), and celery (*Apium graveolens*) were investigated by Rubio et al. in 2001 [32]. The natural total ascorbic acid concentration of the vegetables under study varied noticeably, with cabbage having the highest levels. These initial quantities were not reduced by irradiation, and in the case of cabbage, they were substantially elevated. Ascorbic acid levels in lettuce, cabbage, and celery were initially 2.357, 3.085, and 0.549 mg/100 g, respectively, and were 2.036, 5.018, and 0.616 mg/100 g, respectively, following 1 kGy of irradiation treatment. "Table 2.2" displays the effects of irradiation on the quality improvement and shelf-life extension of vegetables.

Our second author Mrs. Priyanka Sharma uses PLC & weight-based sensors as her primary element. The Vehicles of the lane whose weight data will be higher as compared to other lanes, will be made pass through. Other than traffic data it can also help detecting overloaded vehicles which will protect road infrastructure and increase safety.

Our third author Mr. Ninad Lanke uses RFID as his primary element. An RFID tag will be attached to every vehicle. As a result, each time a car passes a light, the signal will automatically count the number of vehicles that pass by it, helping to identify when there is a traffic jam. Now, based on the frequency of the vehicles passing by the signal once every second, the timer can be dynamically changed.

Next Mr. R Srinivasan uses Image Processing to calculate traffic congestion of different lanes. It is a real time monitoring system and gives quick solutions, but it is a resource intensive methodology and thus is not cost-efficient.

Further we have Mr. Abubakar Muhammad who uses Client-Server Communication based model to calculate the traffic of each lane and compare it. The algorithm used by the system SPF. It makes a calculated decision about whether or not to let the vehicle pass based on various data such as position, speed, etc. This method helps waiting time of the vehicles to be reduced. And lastly author Harsha J performs Data Analysis for congestion control. It provides accurate data for detection most of the time.

After the research and comparing various papers on IoT-based smart traffic management systems, it is evident that this technology is a great solution for solving challenges of urban congestion and transportation inefficiencies. Each study highlights the potential benefits of integrating IoT devices, real-time data collection, and intelligent algorithms to optimize traffic flow, reduce commute times, and enhance overall road safety.

TABLE II. THE EFFECTS OF IRRADIATION ON QUALITY IMPROVEMENT AND SHELF-LIFE EXTENSION OF VEGETABLES

Vegetables	Irradiation type/ Dose	Temperature / Shelf life	Quality	Reference
Onion bulbs	0.06 and 0.076 kGy	12.8°C / 5 months	Weight loss due to sprouting and shrinkage of onion bulbs was 5.7%	Anonymous, 1962 [30]
Garlic bulbs	0.1 kGy	3±1°C, 80±5% RH / 10 months	No influence on the total sulfur and thiosulfonate content	Kwon et al., 1989 [29]
Carrot and juice	γ-irradiation / 3 kGy	10°C / 3 days	Total phenolic contents were significantly higher in the irradiated samples than in the non-irradiated control. Antioxidant capacity increased	Song et al., 2006 [24]
Kale juice	γ-irradiation / 3 kGy	10°C / 3 days	Total phenolic contents were significantly higher in the irradiated samples than in the non-irradiated control. Antioxidant capacity decreased	Song et al., 2006 [24]
Cucumber	1 and 2 kGy	4°C	There was no significant difference in the vitamin C content and total carotenoids in samples and control samples	Bandekar et al., 2006 [26]

III. CONCLUSION

In order to increase the shelf life and quality of fruits and vegetables, irradiation is the best-reported method. Low-dose irradiation can be used to maintain and improve the freshness and safety of fresh produce. A lower quality of the product could be produced as a result of higher doses. Irradiation has benefits over other technologies now in use, particularly in that it maintains the original rawness of the fresh product. It can even be used on the finished product and is more environmentally friendly than other technologies. Despite these advantages, low-dose irradiation as a postharvest technique is underutilized, mostly due to labeling regulations and a lack of understanding of how ionizing energy works. Effects of low-irradiation dosage on fresh plant foods can vary widely and depend on a variety of factors, including variety, maturity, packing, storage conditions, and distribution methods.

IV. STUDENT COMMENTS

Food technologists involved in food irradiation processing should concentrate on concerns and issues related to irradiate foods and their effects on foodstuffs in order to produce a potential greener technology. Studies have demonstrated that consumers believed food was radioactive because of irradiation. Another obstacle to the potential development of this industry is frequently cited as the processing expenses of irradiated food products. Many of the irradiated products, including mangoes, papayas, and other exotic tropical fruits and vegetables, are shipped via expensive air freight as they become more widely available and sold for phytosanitary purposes. Therefore, it is necessary to immediately lower the cost of such radioactive commodities.

REFERENCES

- [1] Barbosa-Canovas, G. V., Pothakamury, U. R., and Palou, E. (1998). Non thermal preservation of foods. Marcel Dekker, New York.
- [2] Alegbeleye O., Odeyemi O.A., Strateva M., Stratev D. Microbial spoilage of vegetables, fruits and cereals. *Appl. Food Res.* 2022.
- [3] Salehi F., Kashaninejad M. Mass transfer and colour changes kinetics of infrared-vacuum drying of grapefruit slices. *Int. J. Fruit Sci.* 2018; 18:394–409.
- [4] Salehi F. Recent applications and potential of infrared dryer systems for drying various agricultural products: a review. *Int. J. Fruit Sci.* 2020; 20:586–602.
- [5] Jiang Q., Zhang M., Xu B. Application of ultrasonic technology in post harvested fruits and vegetables storage: a review. *Ultrason. Sonochem.* 2020;69.
- [6] Barkai-Golan R., Follett P.A. Academic Press; 2017. Irradiation for quality improvement, microbial safety and phytosanitation of fresh produce.
- [7] Bisht B., Bhatnagar P., Gururani P., Kumar V., Tomar M.S., Sinhar R., Rathi N., Kumar S. Food irradiation: effect of ionizing and non-ionizing radiations on preservation of fruits and vegetables—a review. *Trends Food Sci. Technol.* 2021; 114:372–385.
- [8] Sommers, C., Fan, X., Niemira, B., & Handel, A. (2001, November). Effect Of Ionizing radiation on beef bologna containing soy protein concentrate. *Journal Of Food Safety*, 21(3), 151–165. 10.1111/j.1745-4565.2001.tb00315.x
- [9] Kader, A. (1986, September). Effects of postharvest handling procedures on tomato quality. *Acta Horticulturae*, 190, 209–222. 10.17660/actahortic.1986.190.21.
- [10] Susheela, K., Damayanti, M., & Sharma, G. J. (1997). Irradiation of Ananas comosus: Shelf-life improvement, nutritional quality and assessment of genotoxicity. *Biomedical Letters*, 56(223–224), 135–144.
- [11] Drake, R., & Neven, L. G. (1998). Irradiation as an alternative to methyl bromide for quarantine treatment of stone fruits. *Journal of Food Quality*, 21(6), 529–538.
- [12] Paull, R. E. (1996). Ripening behavior of papaya (*Carica papaya* L.) exposed to gamma irradiation. *Postharvest Biology and Technology*, 7, 359–370.
- [13] Vanamala, J., Cobb, G., Loaiza, J., Yoo, K., Pike, L. M., & Patil, B. S. (2007). Ionizing radiation and marketing simulation on bioactive compounds and quality of grapefruit (*Citrus paradisi* c.v. Rio Red). *Food Chemistry*, 105, 1404–1411.

- [14] Yu, L., Reitmeir, C. A., & Love, M. H. (1996). Strawberry texture and pectin content as affected by electron beam irradiation. *Journal of Food Science*, 61(4), 844–850.
- [15] Kim, K.-H., Kwon, J.-S., Lee, J.-O., Lee, B.-C., Park, S.-H., & Yook, H.-S. (2007). Physicochemical changes of electron beam-irradiated Korean kiwifruits at low dose levels. *Journal of the Korean Society of Food Science and Nutrition*, 36(5), 603–608.
- [16] Alonso, M., Palou, L., Angel del Rio, M., & Jacas, J.-A. (2007). Effect of X-ray irradiation on fruit quality of clementine mandarin cv. "Clemenules." *Radiation Physics and Chemistry*, 76, 1631–1635.
- [17] Assi, N. E., Huber, D. J., & Brecht, J. K. (1997). Irradiation-induced changes in tomato fruit and pericarp firmness, electrolyte efflux, and cell wall enzyme activity as influenced by ripening stage. *Journal of the American Society for Horticultural Science*, 122(1), 100–106.
- [18] Moreno, M. A., Castell-Perez, M. E., Gomes, C., Da Silva, P. F., Kim, J., & Moreira, R. G. (2008). Treatment of cultivated high bush blueberries (*Vaccinium corymbosum* L.) with electron beam irradiation: Dosimetry and product quality. *Journal of Food Process Engineering*, 31, 155–172.
- [19] Palou, L., Marcilla, A., Rojas-Argudo, C., Alonso, M., Jacas, J.-A., & Angel del Rio, M. (2007). Effects of X-ray irradiation and sodium carbonate treatments on postharvest *Penicillium* decay and quality attributes of clementine mandarins. *Postharvest Biology and Technology*, 46, 252–261.
- [20] Fan, X., & Sokorai, K. J. B. (2005). Assessment of radiation sensitivity of fresh-cut vegetables using electrolyte leakage measurement. *Postharvest Biology and Technology*, 36, 191–197.
- [21] Patil, B. S., Vanamala, J., & Hallman, G. (2004). Irradiation and storage influence on bioactive components and quality of early and late season "Rio Red" grapefruit (*Citrus paradisi* Macf. *Postharvest Biology and Technology*, 34, 53–64.
- [22] Moreno, M. A., Castell-Perez, M. E., Gomes, C., Da Silva, P. F., & Moreira, R. G. (2007). Quality of electron beam irradiation of blueberries (*Vaccinium corymbosum* L.) at medium dose levels (1.0–3.2 kGy). *LWT – Food Science and Technology*, 40, 1123–1132.
- [23] Fan, X., & Sokorai, K. J. B. (2005). Assessment of radiation sensitivity of fresh-cut vegetables using electrolyte leakage measurement. *Postharvest Biology and Technology*, 36, 191–197.
- [24] Song, H. P., Kim, D. H., Jo, C., Lee, C. H., Kim, K. S., & Byun, M.-W. (2006). Effect of gamma irradiation on the microbiological quality and antioxidant activity of fresh vegetable juice. *Food Microbiology*, 23(4), 372–378.
- [25] Mohacsi-Farkas, C. S., Farkas, J., Andrassy, E., Polyak-Feher, K., Bruckner, A., Kisko, G., & Agoston, R. (2006). Improving the microbiological safety of some fresh pre-cut and pre-packaged chilled produce by low-dose gamma irradiation. In use of irradiation to ensure the hygienic quality of fresh, pre-cut fruits and vegetables and other minimally processed food of plant origin. Proceedings of a final research coordination meeting organized by the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture and held in Islamabad, Pakistan, 22–30 July 2005 (pp. 130–169). Vienna: International Atomic Energy Agency.
- [26] Bandekar, J. R., Dhokane, V. S., Shashidhar, R., Hajare, S., Saroj, S., & Sharma, A. (2006). Use of irradiation to ensure hygienic quality of fresh, pre-cut fruits and vegetables and other minimally processed foods of plant origin. In use of irradiation to ensure the hygienic quality of fresh, pre-cut fruits and vegetables and other minimally processed food of plant origin. Proceedings of a final research coordination meeting organized by the Joint FAO/ IAEA Programme of Nuclear Techniques in Food and Agriculture and held in Islamabad, Pakistan, 22–30 July 2005 (pp. 170–187). Vienna: International Atomic Energy Agency.
- [27] Adesuyi, S. A., & Mackenzie, J. A. (1973). The inhibition of sprouting in stored yams, *Dioscorea rotundata* Poir, by gamma irradiation and chemicals. In radiation preservation of food. Vienna: International Atomic Energy Agency.
- [28] Berger, A., & Hansen, H. (1962). The preservation of thin skin potatoes with low dosage X-rays. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung*, 117, 215–225.
- [29] Kwon, J. H., Choi, J. U., & Yoon, H. S. (1989). Sulfur-containing components of gamma irradiated garlic bulbs. *Radiation Physics and Chemistry*, 34(66), 969–972.
- [30] Anonymous. (1962). An application to the Food and Drug Directorate for the approval of the use of gamma radiation from cobalt-60 for the prevention of sprouting in onions. Ottawa: Department of National Health and Welfare, Atomic Energy of Canada.
- [31] Curzio, O. A., & Croci, C. A. (1983). Extending onion storage life by gamma-irradiation. *Journal of Food Processing and Preservation*, 7(1), 19–23.
- [32] Rubio, T., Araya, E., Avendado, S., Lopez, L., Espinoza, J., & Vargas, M. (2001). Effect of ionizing radiation on fresh vegetables artificially contaminated with vibrio cholerae. In Irradiation to control vibrio infection from consumption of raw seafood and fresh produce. Results of a co-ordinated research project organized by the Pan American Health Organization and the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. April 2001 (No. IAEA-TECDOC-1213). Vienna: International Atomic Energy Agency.