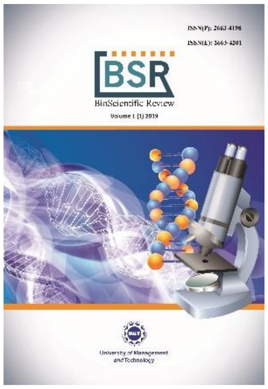

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Author(s): Khadija Shami
Shagufta Naz

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Review Article

Analyzing the Effects of Gamma Radiation (Cobalt-60) on the Shelf Life and Nutritional Quality of Carrot (*Daucus Carota*): A Review

Khadija Shami[1*], Shagufta Naz[1]
[1]Department of Biotechnology, Lahore College for Women University, Lahore, Pakistan
***Corresponding author**
Khadija Shami
Department of Biotechnology, Lahore College for Women University, Jail Road, Lahore, Pakistan. Email address: khadijashami90@gmail.com

Abstract

Carrot is recognized as a most nutritious vegetable since it contains essential nutrients, vitamins, fibers and minerals required for normal growth and development of all living beings. The quality of vegetables is affected during storage due to ethylene production, respiration, transpiration, growth, development, compositional changes, physiological breakdown, physical damage and pathological breakdown. Under optimal storage conditions carrots can be preserved for 6–8 months without affecting any quality attributes, only if they are not infected by microorganisms producing storage diseases. Internationally, gamma radiation (^{60}Co and ^{137}Cs) has been proved as a safe and effective technology in extending the shelf life of fresh products. This technology further inhibits the sprouting of vegetables, the growth of pathogens and insects and also sterilizes vegetables and fruits. Gamma irradiation is more effective in the preservation of carrots as compared to the traditional preservation methods including pasteurization, freezing, chemical, refrigeration, or canning processes. Gamma radiation can enhance the trade opportunity and export quality of fruit and vegetables produced in Pakistan. Cobalt-60 gamma irradiation has no undesirable side effects on food and don't cause any change in physico-chemical properties including the nutritional content of the treated product. It is practical in the conditions existing in the country. In Pakistan, food can be stored by incorporating gamma irradiation practically and economically under specific conditions. Hence, radiation is a promising technique for the extension of shelf life and it can contribute towards the economic growth of the country by exporting good quality carrots.

Keywords: Carrot, Shelf life, Cobalt-60, Gamma radiation

1. Introduction

Vegetables are the fresh and palatable part of herbaceous plants. They contain significant vitamins and minerals effectively used to develop and repair the body. They help in maintaining health and in the prevention of diseases (1). Carrot is among the most vital vegetables because of its different uses in culinary and its healthy composition which includes minerals, dietary fiber, and phytonutrients. Its consumption all over the world is increasing day by day due to its health benefits (2).

Carrot (*Daucus carota* L.) belongs to the family *Umbelliferae* also known as *Apiaceae*. *Daucus* is the largest genus in the family. *Umbelliferea* possesses 25 species. It has 250 genera and almost 2800 species which are widely distributed as herbaceous plant and grow in temperate and boreal regions (3). There are mainly two types of carrots, eastern carrots and western carrots. Eastern carrots are confined to Afghanistan, Russia, Iran, Pakistan and India, while western carrots were domesticated firstly in Turkey. The major root types cultivated worldwide include Nantes, Chantenay, Danvers and Imperator. The shape of storage root is conical but in other cultivars it may be cylindrical, round or various intermediates of these shapes. Root length ranges from 5 cm to 50 cm (3). Carrot is referred to as a cold season crop. It is cultivated across the world in the summer, spring and autumn seasons, especially in temperate countries and in winter in tropical and subtropical climates (4). Carrots are not sensitive to winter cold and frost as they belong to the hardy group of vegetables. The optimum temperature for growing carrot ranges between 10°C-25°C (5). Pakistan is exporting carrots and turnips to different countries like United Kingdom, Sweden, United Arab Emirates, Afghanistan, Saudi Arabia, Russian Federation, and Malaysia. Carrot crop in Pakistan is associated with Sheikhupura, Hyderabad, Lahore, and Kasur districts. It is grown from September to February and harvesting takes place from November to April. Sheikhupura and Kasur are two important districts having the largest shares of carrot cultivation in Pakistan (6).

2. Proximate Compsition of Carrot

Carrot is a source of various crucial macronutrients and micronutrients which include carbohydrate, protein, fat, vitamins, antioxidants, minerals like K and Na, folic acid, fibers and carotenoids. (7). It contains significant quantities of thiamine, riboflavin and is also rich in sugar content (8). The analysis of chemical composition showed total ash (1.1%), moisture (86%), carbohydrate (10.6%), fat (0.2%), protein (0.9%), Ca (80 mg/100 g), P (53 mg/100 g), vitamin C (4 mg/100 g), carotenes (5.33 mg/100 g), crude fiber (1.2%), Fe (2.2 mg/100 g), and an energy value about 126 kJ/100 g (Table 1) (9, 10).

Table 1. Proximate Composition of Carrot

Proximate composition	**Concentration**
Moisture (g)	86%
Protein (g)	0.9%
Fats (g)	0.2%
Carbohydrates(g)	10.6%
Fiber (g)	1.2%
Ash (g)	1.1%
Vitamin C (mg/100g)	4 mg/100g
Energy (kJ/100 g)	126 kJ/100 g

3. Benefits of Carrot

Carrot is a source of various crucial macronutrients and micronutrients which include carbohydrate, protein, fat, vitamins, antioxidants, minerals like K and Na, folic acid, fibers and carotenoids (7). It contains significant quantities of thiamine, riboflavin and is also rich in sugar content (8). Carrot comprises several carotenoids in which β-carotene act as an antioxidant, is anti-mutagenic and helps to boost the immunity (11). Carrots also play an important role in regulating metabolism, retaining a healthy skin and vision, decreasing the risks associated with the heart disease, high blood pressure, stroke and growth of different types of cancer (7). Moreover, carrot juice is considered useful against urogenital diseases (12).

4. Storage Conditions

The quality of vegetables affected by biological processes during storage are ethylene production, physiological breakdown, respiration, transpiration, growth, physical damage, compositional changes and pathological breakdown (13). Under optimal storage conditions carrots can be preserved for 6–8 months without affecting any quality attributes, only if they are not infected by microorganisms producing storage diseases (5). Most common post-harvest diseases in carrots include watery soft rot (*Sclerotinia sclerotiorum*) and gray mold (*Botrytis cinerea*) among which watery soft rot is most prevalent (14).

5. Sterilization

Sterilization is a process, physical or chemical that efficiently eliminates nearly all microbes such as bacteria, spore forms, viruses and fungi. There are a number of sterilization methods that elaborate on the use of the sterilization and the material that will be sterilized. Conventional sterilization techniques either metabolically inactivate or break down the vital structural components of microorganisms. Microorganisms can be destroyed by recognized physical microbicide treatments, such as heating, UV or ionizing radiation and by new non-thermal methods (15).

6. Food Irradiation

Food irradiation is defined as a method of exposing food stuffs to ionizing radiation to eliminate harmful bacteria and other organisms with the increase in shelf-life. According to Codex General Standard for Irradiated Food (CAC 2003), high energy photons such as X-beams and radionuclides (^{137}Cs, ^{60}Co) obtained from machine sources with energies between 5 MeV to 10 MeV were used for food processing (16). Later on, food additive regulations were revised by Food and Drug Administration, USA and it was declared that maximum energy level of X-rays to be used in food industry shouldn't be more that 7.5 MeV. Gold or tantalum was used as target material for that process (17). Gamma radiation replaced the use of different chemicals on fruits and vegetables for preservation and prevention. Globally, food irradiation technology is considered a safe and effective technology by the International Atomic Energy Agency in Vienna, Food & Agriculture Organization (FAO), and World Health Organization (WHO) (18). Gamma radiation (^{60}Co and ^{137}Cs) is used for multiple purposes such as sterilization of foods, increase in the shelf-life of products and inhibition of the growth of insects, pathogens, etc. It decreases the sprouting of potatoes. Low dose treatments (<1kGy) kill parasites, insects, and pathogens, delay the maturation of products, and prevent the sprouting of tubers. Medium dose treatments (1 to 10 kGy) has also been reported to eliminate microbial populations and pathogens on or in meat, seafood, and poultry. Existing literature shows that high doses of irradiation (10 to 45+ kGy) are effective for shelf-stable packaged meats and specialized hospital meals (19).

7. Reviewing the Literature Supporting the Effect of Gamma Radiation (Co-60) on Nutritional Quality of Carrot

7.1. Effect of Gamma Radiation on Raw Carrot and Other Vegetables

Sarker *et al.* (2014) reported that raw, uncooked or undercooked foods are not suitable for immuno-compromised people because of the high risk of infection. To overcome this problem, ionizing radiations were applied to some salad, which had a high level of microbial contamination not used for immuno-compromised patients. Cucumber, tomato, carrot, green leaf lettuce and green capsicum were treated with 1, 2, 2.5 and 3 kGy radiation from a ^{60}Co gamma irradiator. It was observed that 1 kGy irradiated samples showed less nutritional loss and better sensory score than other samples irradiated with higher doses. So, it was concluded that the initial microflora of the samples has to be reduced before irradiation to meet microbiological sanitary criteria at low dose treatment and for safely recommending irradiated salads for hospitalized immuno-compromised people and other target groups (Table 2) (20).

Table 2. Effect of Irradiation Treatment on Moisture, Ash and Ascorbic Acid Content of Carrot

Doses	Moisture g/100g	Ash g/100g	Ascorbic Acid mg/100g of sample
0 kGy	92.26±0.16[a]	0.475±0.010[a]	4.643±0.219[ab]
1 kGy	91.29±0.29[a]	0.460±0.006[a]	5.376±0.272[bc]
2 kGy	91.57±0.62[a]	0.459±0.023[a]	4.144±0.374[ac]
2.5 kGy	90.76±0.11[a]	0.475±0.004[a]	4.184±0.296[ac]
3 kGy	92.14±0.55[a]	0.480±0.001[a]	3.250±0.270[d]

Each value in the table indicates the mean of five replicates with standard error (mean±S.D). According to Duncan's new multiple range test, mean followed by different letters in the same column differ significantly at $p<0.05$

Chaudry *et al.* (2004) reported that carrots were cut into cubes and exposed to 0, 0.5, 1.0, 2.0, 2.5, 3.0 kGy doses from the source of ^{60}CO gamma irradiation. Afterwards, triplicates of both irradiated and non-irradiated samples were stored for two weeks in the refrigerator and analyzed at 0, 7th and 15th day for hardness, microbial load and organoleptic properties. The mean firmness of the all irradiated and non-irradiated samples was observed between 4.31 kg and 4.42 kg of force, exhibiting no harmful effect of radiation dose. The 2.0 kGy dose completely prevented the growth of the fungal and bacterial colonies. Therefore, 2 kGy was considered as appropriate dose to maintain sensorial and textural quality and the reduction in microbial load of minimally processed carrots for 14 days at 5ºC (21).

7.2. Effect of Gamma Radiation on Minimally Processed Carrot

Arvanitoyannis *et al*. (2009) explained that there is a great demand of centrally processed fresh fruits and vegetables, properly packaged for supply and marketing, in both developed and developing countries. Irradiation technology is considered as the best method for controlling insects, microorganisms and post-harvest losses in products during storage. Irradiation technology is recognized as beneficial in increasing the shelf-life of fruits and vegetables by 3–5 times. There is another approach in which fruits and vegetables are not exposed to high irradiation doses known as "hurdle technology," which is to apply more than one technologies toward better quality and longer shelf life (22).

Farkas *et al.* (2014) conducted the study in which precut tomatoes and carrots were irradiated at different doses such as 1.0, 1.5 and 2 kGy. The gamma radiation at 1.5 and 2 kGy showed reduction in microbial growth in precut tomatoes but yeast was resilient among other organisms. However, the dose of 2 kGy decreased them below the detection limit. Tocopherol and some carotenoids at the dose of 2 kGy were decreased to one third of their initial amounts in tomatoes and in the same way the level of ascorbic acid was reduced to one-third of the original level in sliced carrots. The results confirmed that 1 kGy dose was suitable for reducing microbial count with adequate nutritional quality and organoleptic parameters of the precut samples (23).

Nunes *et al.* (2011) reported that carrot is a notable vegetable due to its different uses in the food industry and it can be utilized as a raw or minimally processed vegetable or amassing value to the product, transforming fresh carrots to baby carrots. The effect of gamma radiation was analyzed on the texture of minimally processed baby carrots. It is obvious from the results that gamma radiation helps in maintaining the quality of food. The study was conducted with different doses including 0, 3.0, 5.0 kGy. It was concluded from the results that low doses of gamma radiation were accepted in keeping the quality of fresh-cut baby carrot (24).

Experiment done by Fan and Sokorai (2008) showed that 1 kGy dose of gamma radiation kills *E. coli* on 13 different vegetables including green onion, carrot, iceberg, red cabbage romaine, parsley, red and green leaf lettuce, celery spinach, tomato, broccoli, and cilantro. According to results, irradiated samples had the same appearance as non-irradiated ones. The aroma and texture of irradiated samples were better than non-irradiated ones. It was observed that vitamin C content of most vegetables was not affected at 1 kGy dose, except red and green leaf lettuce which showed 24% to 53% decrease in vitamin C after irradiation as compared to controls. Therefore, this study suggested 1 kGy as the most preferred dose for most fresh-cut vegetables and fruits because it didn't affect the quality and content of food samples(25).

Dhokane *et al.* (2006) concluded that minimally processed vegetables had a great demand in market, therefore, the effect of gamma radiation was studied to sterilize the precut carrot and cucumber. The results showed that gamma irradiation at 1 kGy significantly decreased the microflora especially *Listeria monocytogenes* and *Salmonella typhimurium* in minimally processed and packaged cucumber and carrot samples inoculated with *S. typhimurium* and *L. monocytogenes*. Furthermore, at 2 kGy dose pathogens were decreased by 5 log CFU/g. Inoculated control samples showed the growth of both bacteria at 108ºC, whereas, radiated samples were free from microbial growth even after 8 days of storage (26).

Hajare *et al.* (2006) studied the effect of 2 kGy gamma irradiation to ensure the safety of minimally processed carrot and cucumber. The effect of gamma irradiation were examined for various quality attributes such as sensory quality, vitamin C content, texture, total carotenoids content, and color over a storage period of 16 days at 8°C to 10°C. There was no significant change in vitamin C content of cucumber during the treatment of irradiation as well in storage period. Carotenoids content and sensory attributes were not affected in carrots. According to textural studies, firmness in central region was not affected, whereas peripheral region was observed with the reduction of firmness in carrot. The color of carrot samples was not significantly changed (26).

Kamat *et al.* (2005) conducted a research in which they found that low-dose irradiation can play an important role in reducing the microbial load of minimally processed (MPR) vegetables without disturbing their chemical composition. In their study, samples of carrots were sliced manually and exposed to different doses, that is, 0.0, 0.5, 1.0, 1.5, 2.0, and 2.5 kGy. Irradiated and non-irradiated samples were maintained at 5 and 10˚C. Pathogens like *Escherichia coli* and *Yersinia enterocolitica* in carrot paste were found in a small range as compared to that of *Listeria monocytogenes*. At the end, 2 kGy dose was optimized which showed effective results in eliminating the pathogens from minimally processed sliced carrot with minor losses in nutrients such as sucrose, total carotenes and ascorbic acid content as compared to controls and provided 2 to 4-fold increase in shelf-life at refrigeration temperature (27).

Lacroix and Lafortune (2004) increased the shelf-life of vegetables by modifying atmospheric packaging. Researchers inoculated grated carrots with *E. coli*, packed under Modified Atmospheric Packaging (MPA) (60 samples) and under air (60samples) irradiated at 0.15, 0.3, 0.6 and 0.9 kGy. Microbial burden on two bags of each treatment lot was analyzed at 4ºC for the period of 50 days. The findings of the study suggested 0.15 kGy as an effective dose that significantly reduced *E. coli* on day 1. The study further confirmed 6 to 2 log decrease in microbial load in samples treated in air, whereas bioburden was decreased by 3 to 4 log in samples treated under MAP. To conclude, 0.6 kGy was rendered as an optimized dose of gamma irradiation that completely inhibited *E. coli* growth under MAP, while the same results could be achieved at a dose of 0.9 kGy when treatment was done under air (28).

Chervin and Boisseau (1994) used gamma irradiation as a substitute of spin-drying treatment and chlorination rinsing to manufacture ready-to-eat shredded carrots. One half of all carrot samples (*Daucus carota* cv. Nandor) were simply irradiated after packaging and the remaining half was washed in chlorinated water followed by rinsing in running water, spin drying, and packaging in plastic bags. The researchers selected 2 kGy against four tested doses (0.5, 1, 2 and 3 kGy) as it was regarded beneficial for microbiological effectiveness and increased the shelf-life of carrot by reducing tissue softening. The irradiated samples had twice the level of sugar in tissues as compared to chlorinated ones. The research showed that irradiation processing retained the carotenes and orange color in carrot samples. Moreover, the growth of aerobic mesophilic and lactic microflora was significantly reduced. It was confirmed by the results that irradiation provides high sensory quality and nutritive values in comparison with conventional industrial processes for more than 7 days storage at 10ºC (29).

Bourke *et al.* (1967) studied the effect of gamma radiation on the radio sensitivity of free amino acids in metabolizing carrot tissue and on the synthesis of free amino acids from specifically labeled acetate. The results showed that concentrations of some amino acids decreased at 100 kRad doses. At 500 kRads, all were decreased and at 1000 kRads the concentration of all amino acids was severely reduced. Except isoleucine, glycine, valine and phenylalanine, synthesis from labeled acetate of all amino acids occurred with glutamate, serine and aspartate synthesized in the greatest amounts. Radiation processing at all doses above 100 kRads reduced synthesis with labeled acetate and severely repressed synthesis at 1000 kRads. Incorporation of the carboxyl carbon of acetate was generally less extensive and more radiation-reduced than that of the methyl carbon (30).

7.3. Effect of Gamma Radiation on the Nutritional Quality of Fresh Carrot Juice

Hammad *et al.* (2013) reported in their study that carrot is one of the most important vegetables used that is rich in functional food constituents such as vitamins and minerals. Samples of carrot juice were irradiated with 1.5, 3.0 and 4.0 kGy using cobalt-60 irradiator as the source. Irradiation treatment at 3.0 and 4.0 kGy caused a considerable decline in ascorbic acid content. On the other hand, carotene content was not highly affected among all irradiated and control samples. Irradiation at 1.5 and 3.0 kGy did not produce significant changes in sensory properties, however, the sensory properties of juice were significantly reduced under the dose of 4.0 kGy. Therefore, a dose of 3.0 kGy is preferred as suitable dose to enhance the microbial quality and increase the refrigerated shelf-life of fresh carrot juice till 8 days as compared to non-irradiated samples which have only 2 days of shelf-life (31).

Jo and Lee (2012) compared the efficiency of gamma and UV irradiation on fresh carrot juice. One half of the fresh carrot juice packaged in a polyethylene pouch was irradiated at 0, 1, 3, and 5 kGy and the other half was treated by 4 UV light lamps and the energy doses absorbed from UV were calculated as 3.67, 4.69, and 6.50 kGy. It was concluded from the results that both methods were effective in one way or another. gamma irradiation showed reduction in microbial growth during storage but ascorbic acid content was more affected by gamma irradiation as compared to UV treatment. The quantity of flavonoids and polyphenols remained the same in fresh carrot juice after either treatment. The sensory scores were improved in gamma and UV-irradiated fresh carrot juice rather than controls. It was concluded that gamma irradiation was more effective in reducing the microbial growth after treatment (32).

Song *et al*. (2007) reported that the radiation pasteurization process was applied to enhance the microbial safety and shelf-life of fresh vegetable juice. Carrot (*Daucus carota*) and kale (*Brassica oleracea*) juice were irradiated at 0, 1, 2, 3, and 5 kGy. At 3 kGy dose, all the aerobic and coliform bacteria were eliminated from carrot juice. However, about 10^2 CFU/ml of the bacteria persisted in the kale juice irradiated at up to 5 kGy. The total ascorbic acid content, including dehydroascorbic acid, was stable at upto 3 kGy. However, amino acids were stable upto 5 kGy dose. The sensory properties of juice were not affected in irradiated juice for 3 days of storage period. The sensorial and nutritional quality estimation showed that irradiation at 3–5 kGy not only maintained the microbial shelf-stability of the juices but also extended their shelf life up to 3 days (33).

Song *et al.* (2006) studied the effect of gamma irradiation on the microbiological quality and antioxidant activity of carrot and kale juice. Samples were radiated at 1, 2 and 3 kGy. The test organisms (*S. typhimuriumin* and *E. coli)* were excluded by irradiation at 3 kGy. The total phenol contents of the irradiated juice significantly increased up to 3 days of storage, although those of the non-irradiated juice decreased. The antioxidant capacity of the irradiated carrot juice was higher than that of the non-irradiated control. So, it was concluded that irradiation treatment was suitable to ensure microbiological safety and to maintain antioxidant activity (34).

8. Conclusion

Carrot is recognized as one of the most nutritious vegetables as it contains essential nutrients, vitamins, fibers and minerals required for normal growth and development of the overall being. Food irradiation is a promising technique to enhance shelf-life, reduced storage losses and improved microbiological safety with no significant effect on the nutritional quality of carrot.

Competing interest

None

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