The effect of gamma irradiation on the properties of cucumber

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Abstract In this study, the effect of gamma irradiation on the shelf life and properties of cucumber was investigated. These properties include weight reduction, fruit density, juice, tissue firmness, total soluble solids (TSS), total titratable acidity, chlorophyll and vitamin C, pH, marketability, flavor, frostbite and fungal effects. For this purpose, cucumbers were irradiated with dose of 2, 2.5 and 3 kGy. The exposure time was calculated by MCNP4C; the Monte Carlo particle transport code. Three types of fungi (*white-Sclerotinia sclerotiorum*, *gray-Botrytis cinerea* and olive-*Cladosporium cucumerinum*), were used to infect some samples. The chlorophyll and vitamin C preservation abilities were increased to about 3 and 1.4 times, respectively with irradiation treatment. Also, the shelf life was increased about 1 week, while chilling injuries is decreased. Samples' resistance to the fungal growth was evident and the process of fungal growth on the irradiated samples was delayed up to 1 week. The best properties were obtained at the irradiation dose of 2 kGy since it had less effect on flavor, TSS and tissue firmness.

Keywords Food irradiation · Cucumber · Gamma ray · MCNP4C

Introduction

The loss of a major part of agricultural products and their waste in the production to consumption cycle has always been a common problem in the agricultural industry. About 35% of agricultural production in Iran is wasted in this cycle. This is equivalent to the meal of about 15–20 million of population. Another problem is microbial and fungal contamination of food and how to prevent them. Conventional storage procedures that have long been used and are acceptable to the customer's taste, have some disadvantages; including changes in smell, color and flavor of the food and also decrement in nutritional property. Food irradiation is a distinct method for storage and cleaning of products and can be used for a wide range of foods. Joint FAO/IAEA/WHO study group on high dose irradiation concluded that “irradiation of any commodity up to an overall average dose of 10 kGy presents no toxicological hazard: hence, toxicological testing of foods so treated was no longer required”. It also found that irradiation up to 10 kGy “introduces no special nutritional or microbiological problems” (WHO 1997).

Lammertyn et al. (2000) addressed some issues related to the non-destructive measurement of apple quality attributes by means of NIR reflectance spectroscopy. They also investigated apple skin reflectance and skin transmission properties with regard to NIR radiation. Perkins-Veazie et al. (2008) exposed blueberries with ultraviolet light-C radiation. They indicated that postharvest application of UV-C radiation could decrease decay caused by ripe rot in blueberries.

Among the vegetables that benefit from gamma rays for storage and microbial/fungal protection is cucumber; which is widely cultivated in the world. The world annual production market for cucumber is more than 70 millions

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of tones. Khattak et al. (2005) investigated the impact of radiation on biological safety, fruit tissue and taste property of cucumber and processed cabbage. Results showed that with increasing dose, tissue firmness of products had small reduction, and appearance and flavor score of cucumber were improved for dose of 2.5 and 3 kGy. Also fungal contamination of cucumbers, which were irradiated with dose of 3 kGy, was in the acceptable range. Segsarnviriya et al. (2005) carried out experiments on appearance, color, odor, flavor and overall quality of different vegetables, including cucumber, after irradiation. Based on the observations, cucumbers were consumable after 7 days storage at 10 ± 1 °C. International Atomic Energy Agency (IAEA) investigated the impact of radiation on vitamin C content, tissue and taste sensory properties of cucumber (Bandekar et al. 2006). Based on this report, irradiation at dose of 1 and 2 kGy did not significantly change the vitamin C content. Kaur et al. (2014) compared the effect of different chemical additives on the physicochemical and phytochemical parameters and antioxidant activity of cucumber juice. For the physicochemical parameters like TS, TSS, acidity and color, a very slight and non-significant change was observed. However, vitamin C, total phenols and antioxidant activity changed significantly.

Iran is the third largest producer of cucumber in the world with about 1.6 millions of tons per year. A large part of the cucumber produced in Iran is exported. The main objective of this study was to investigate the effects of gamma irradiation on the shelf life and properties of the native cucumber of Isfahan-Iran. These properties include the rate of weight reduction, the density of fruit and its juice, tissue firmness, total suspended solids (TSS), total titratable acidity (TA), Chlorophyll and vitamin C contents, pH, marketability, flavor, frostbite and fungal effects.

Materials and methods

Irradiation simulation

Cucumber samples were irradiated with dose of 2, 2.5 and 3 kGy, by gamma-cell irradiator of the Atomic Energy Organization in Tehran; in which 21 cylindrical Co-60 sources surround a cylindrical stainless steel container. At each irradiation stage, about 2 kg of cucumbers were put in the container. To calculate the exposure time in accordance with dose of 2, 2.5 and 3 kGy, the MCNP4C code was used. MCNP4C is a validated general-purpose Monte Carlo N-Particle code that can be used for particle transport. Specific fields of its application include radiation protection and dosimetry, radiation shielding, radiography and medical physics (ORNL 2000). The absorbed dose of cucumber was calculated with relative error less than 0.5%.

Materials and treatment

All agricultural experiments were performed as described by El-Mageed et al. (2015, 2016), Hassanien et al. (2014), Sayyari et al. (2016).

Cucumbers were prepared from a greenhouse on the outskirts of Isfahan, at the same time. After rinsing thoroughly, cucumbers were placed in plastic bags and immediately were moved to the exposure center. Also, three types of fungi: white (*Sclerotinia sclerotiorum*), gray (*Botrytis cinerea*) and olive (*Cladosporium cucumerinum*) were used to infect some samples. After exposure, irradiated cucumbers with control samples were transferred (in labeled plastic bags) to the laboratory and were kept in germinator at temperature of 13 °C with ambient humidity. On days 4, 8, 11, 16 and 21 after the harvest, two samples were selected from each bag. Then the rate of weight reduction, fruit and juice density, fruit firmness, TSS, TA, chlorophyll and vitamin C contents, pH, marketability, flavor, frostbite and fungal effects were measured for each sample.

Analysis methods

To measure the rate of weight loss, irradiated and control samples were placed in four polyethylene boxes (two sealed and two open), and were kept at temperature of 13 °C. On days 4, 8, 11, 16 and 21 after harvest, their weights and volumes were measured with a digital scale and a graduated cylinder, respectively. In addition, the juice weight and volume were measured by a graduated cylinder, after dewatering cucumber and passing it through the filter. Then, the density was obtained in units of grams per cc.

TSS of the samples was measured with a refractometer. A drop of fruit juice was poured on calibration charter device, and the refractive index was read in Brix. The ratio between the TSS and TA offers a taste factor, which indicates the pleasant fruit flavor.

To measure the vitamin C content, 10 ml of the juice was mixed with 20 ml of distilled water and 2 ml of 1% starch solution. This was titrated with iodine solution in potassium iodide until the solution color turned to slime green or olive. The vitamin C content was obtained from the amount of solution, in terms of mg per 10 ml.

Samples pH and chlorophyll (A, B, A + B) content were measured according to laboratory guidelines. To assess the amount of chlorophyll, 0.2 g of fruit skin was gradually grinded via 80% acetone; and the solution's volume was increased to 15 ml. The solution was centrifuged at 4800 rpm for a period of 20 min and then light absorbance of the solution was measured at 663, 645, and 470 nm using the spectrophotometer (model D 6320), previously calibrated with an 80% acetone solution.

Using the following equation, the amounts of chlorophyll were assessed based on mg per g of the fruit skin tissue (Li et al. 2010).

$$\begin{aligned}\text{Chl.A(mg/g)} &= [(12.7 \times \text{Abs}_{663}) - (2.6 \times \text{Abs}_{645})] \times V/W \times 1000 \\ \text{Chl.B(mg/g)} &= [(22.9 \times \text{Abs}_{645}) - (4.68 \times \text{Abs}_{663})] \times V/W \times 1000 \\ \text{Chl.total(mg/g)} &= \text{Chl.A} + \text{Chl.B}\end{aligned}$$

A texture analyzer model STM-20, with drill speed of 30 mm per minute, was used to measure the tissue firmness, by recording the force entered to the drill.

To evaluate chilling injuries, the samples were stored in a refrigerator at temperature of 5 °C. On days 10 and 14 after the harvest, the samples were removed from the refrigerator, and troughs and folds on the pill of fruits were recorded.

For sensorial evaluation, the irradiated and control samples were presented to untrained panelists, who were asked to evaluate them by scoring the flavor and appearance with grades ranged from 1 to 10, where 1 = weakly accepted and 10 = excellent quality.

Statistical analysis

All experimental results were analyzed using the SPSS software according to analysis of variance; and means were compared using Duncan's multiple range tests at the 5% level of probability.

Results and discussion

The MCNP4C code was used to calculate the exposure time in accordance with dose of 2, 2.5 and 3 kGy. For 10^8 histories, the cucumber absorbed dose was calculated with relative error less than 0.5%, by using tally F6. Accordingly, the exposure time required for dose of 2, 2.5 and

3 kGy was obtained 13 min and 14 s, 16 min and 34 s and 19 min and 54 s, respectively.

The first question was that whether irradiation was effective on storage or superiority of the appearance of the fruits or not? Initially, no obvious difference was observed between irradiated and control samples, however, after day 8th, the difference was quite evident. Subsequently, irradiated fruits were quite brighter, greener and fresher as compared to control fruits.

Weight reduction of the irradiated fruits must not be too much, after the harvest. Figure 1 shows the weight reduction of samples irradiated and stored in sealed and open container after harvest. The diagram slope shows samples' weight reduction rate. As shown in Fig. 1a, in a closed container, cucumbers' weight loss is increased slightly with increase in dose. Figure 1b shows weight reduction for the samples in an open container and exposed to the air. According, it was found that the weight of samples was reduced, however the rate of weight reduction of the irradiated samples was lower than the control samples. Duncan test results for samples in a sealed container revealed that average of the samples in terms of dose, all together were in one group, which means that irradiation had no significant effect on the weight reduction. But for average of the samples in terms of time, days 11, 16 and 21 after harvest were in a group and 4, 8 and 11 were in another group. For samples in an open container, average of the irradiated samples with dose of 2, 2.5 and 3 kGy are in a group and control samples are in another group. In terms of time, averages of each sample was in a separated group.

Figure 2a shows TSS changes on certain days after the harvest. Accordingly, TSS over the time was increased, due to surface perspiration, and then was reduced, due to ingress of cellular water into the tissue. The maximum amount of TSS in control and irradiated fruits with dose of 2, 2.5 and 3 kGy was observed on days 16, 16, 11 and 8

Fig. 1 Weight reduction of samples irradiated and stored in **a** sealed and **b** open container after harvest (The diagram slope shows samples' weight reduction rate by a factor of X)

after harvesting, respectively. The statistical analysis showed a significant difference between the averages of TSS in terms of time. Duncan test results also showed the mean of the samples in terms of dose, all together were in one group that means irradiation had no significant effect on TSS.

Figure 2b shows that although the density of fruits is reduced over time, but this reduction is less than control fruits in irradiated ones. The reduction of density was evident after the second week, so that cucumbers shelf life was increased 1 week. Also, no difference was found between the dose of irradiation. Statistical analysis revealed that the samples' means in terms of dose, all together were in one group. But the samples' means in terms of time on days 11, 16 and 21 were in a group, while days 4, 8, 11 and 21 were in another group.

Figure 2c shows density variations in the samples' juices during days after harvest. The trend of the variations is clearly like TSS graphs (Fig. 2a) and this confirms the correctness of the data. According to this figure, the juice density of control fruits as well as samples irradiated by dose of 2 kGy, was increased up to day 16th. Also, the graphs reached earlier to the maximum, for higher dose. Duncan analysis showed the samples' means in terms of

dose, all together were in one group. Also for the samples' means in terms of time, days 4 and 21 were in a group and days 8, 11, 16 and 21 were in another group.

Figure 2d shows the effect of irradiation on TA of the samples. TA was lower in control fruits than other samples, and was increased during the post-harvest period. The irradiation process increased TA of the samples in comparison with control ones. TA graph of 2 kGy dose was like control samples, and was superior in this respect. As this similarity was also observed in TSS figure, it is predicted that fruits irradiated with a dose of 2 kGy have the same taste as the control fruits. Statistical analysis showed that for the samples' means in terms of dose, control samples and 2 kGy were in a group, 2 and 3 kGy were in another group and 2.5 and 3 kGy were also in a separated group. For the samples' means in terms of time, days 4 and 8 were in a group, days 8 and 11 were in another group, and days 16 and 21 were also in a different group.

Figure 3a shows the taste factor (TSS ratio) for irradiated samples. According to this figure, as predicted by the results of TSS and TA, a dose of 2 kGy was less effective on fruits' taste compared to other dose. This confirmed the results of Khattak et al. (2005).

Fig. 2 a TSS changes after the harvest, b cucumber density changes after the harvest, c juices density variations after harvest, d TA changes after the harvest

Fig. 3 **a** Taste factor (TSS ratio) after the harvest, **b** cucumbers tissue firmness after the harvest, **c** pH of the fruit juice after the harvest, **d** Cucumbers rating in terms of appearance (marketability) after the harvest

Figure 3b shows the tissue firmness of cucumbers. According to this figure, tissue firmness of irradiated fruits was lower than control samples. The softening of control, 2, 2.5 and 3 kGy samples began on days 16, 16, 8 and 8 after the harvest, respectively. The fruit tissue softening may be attributed to decomposition of cell wall, making the fruit tissue favorable for fungal growth. Accordingly, the dose of 2 kGy was preferred. Duncan test showed that for the samples' means in terms of dose, 2.5 and 3 kGy were in a group, 2 was in another group and control was also in separated group. For the samples' means in terms of time, day 21 was in a group, while days 4, 8, 11 and 16 were in another group.

According to Fig. 3c, pH of the fruit juice during storage after the harvest was reduced and the reduction rate was higher in irradiated ones. Also, no difference was found between the reduction rates in irradiated samples. Statistical analysis showed that the samples' means in terms of dose as well as time, all together were in a group.

Figure 3d shows the fruits rating in terms of appearance (marketability). It was observed that irradiated samples remained more stable apparently. However as time goes on, control cucumbers quickly changed in terms of the appearance and after 16 days were almost unusable (in terms of marketability, fruits with a score under 5 are not

attractive to the customer). This change was in the form of troughs and folds, bruise or fungus. The results reported by Khattak et al. (2005) confirm the results obtained by this research. According to Duncan Statistical analysis for the samples' means in terms of dose, control samples were in a group and dose of 2, 2.5 and 3 kGy were in another group. Also for the samples' means in terms of time, days 8, 11, 16 and 21 were in a group, while days 4, 8, 11 and 16 were in another group.

Figure 4 shows the difference between the amount of chlorophyll A, B and A + B in 0.5 g of fruit skin of control and irradiated (with dose of 2 kGy) samples. It was observed that irradiated samples had the ability to keep these three types of chlorophyll, more than control samples. The chlorophyll preservation ability was increased about three times on the eleventh day.

Figure 5a shows the changes in vitamin C content for irradiated and control samples, on days after the harvest. According to this figure, vitamin C in control fruits was reduced, but in irradiated samples it remained constant. In addition, it was found that irradiated samples had the ability to maintain vitamin C more than control samples, which increased at higher. This enhancement was about 35% for dose of 3 kGy. Statistical analysis showed that for the samples' means in terms of dose, control samples were

Fig. 4 The amount of chlorophyll a A, b A + B and c B in 0.5 grams of fruit skin of control and irradiated (with dose of 2 kGy) samples after the harvest

Fig. 5 a The changes in vitamin C content after the harvest, b the effects of frost on cucumbers after the harvest

in a group, dose of 2 kGy was in another group and dose of 2.5 and 3 kGy were also in a different group. The analysis for the samples' means in terms of time showed that the samples' means on days 8, 11, 16 and 21 were in a group, while days 4 and 8 were in another group.

The results related to the effects of frost on cucumbers are given in Fig. 5b. Irradiated samples clearly got frostbite less than the control samples, and by increasing the dose, frostbite was reduced. The rate of frostbite of 2 kGy samples was less than other dose. It was also observed that control samples were completely withered at day 14 after transferring to an isothermal environment, while this was observed less in irradiated samples.

Figures 6a, b show the extent of the white, olive and gray fungus, respectively, on cucumber tissue in two cases of fungal inoculum after radiation, and radiation after fungal inoculums, within 28 days after harvest. According to Fig. 6a, it was found that irradiated fruits had fungal decay more than control fruits, after the irradiation process. It seems that irradiation, due to softening the tissue of cucumbers, made them more susceptible to the fungal damage. In this regard, if dose was higher, fruits were less likely susceptible to the fungal damage. The important point was the time of beginning fungal growth in fruit tissue. This process was delayed about 1 week in irradiated fruits. Fungal growth in control fruits started after the harvest around the 16th day. As seen in Fig. 6b, irradiation of cucumbers after fungal inoculums had no significant effect on reducing the levels of fungus at day 28 post-harvest; so that the infection was greater in samples with higher dose. This can be due to tissue softening by irradiation. The important point was also beginning of fungal growth in fruit tissue. This process was started about 1 week later in irradiated fruits. Fungal growth in control fruits started after the harvest around the 16th day.

Fig. 6 **a** The extent of the white, olive and gray fungus, on cucumber tissue (fungal inoculum after radiation), within 28 days after harvest, **b** the extent of the white, olive and gray fungus on cucumber tissue (radiation after fungal inoculum), within 28 days after harvest

Conclusion

Non-irradiated cucumber samples completely lost apparent attraction after 2 weeks while irradiated samples still showed consumer acceptability after 3 weeks (acceptable quality). The irradiated cucumbers showed better retention of vitamin C and chlorophyll in peel and lost less water as compared to non-irradiated samples.

Whereas the irradiated cucumbers were juicier, softer and had longer shelf life, they exhibited similar TSS, fruit density and tissue firmness compared to non-irradiated cucumbers. Furthermore, irradiation delayed the process of fungal growth up to 1 week. However, once started, the rate of propagation of fungi was more in irradiated fruit.

References

- Bandekar JR, Dhokane VS, 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: Proceedings of a final research coordination meeting organized by the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture, pp 170–187
- El-Mageed TAA, Semida WM (2015) Effect of deficit irrigation and growing seasons on plant water status, fruit yield and water use efficiency of squash under saline soil. *Sci Hortic* 186:89–100
- El-Mageed TAA, Semida WM, El-Wahed MHA (2016) Effect of mulching on plant water status, soil salinity and yield of squash under summer-fall deficit irrigation in salt affected soil. *Agric Water Manag* 173:1–12
- Hassanien R, Hou T, Li Y, Li B (2014) Advances in effects of sound waves on plants. *J Integr Agric* 13(2):335–338
- Joint FAO/IAEA/WHO study group on high dose irradiation, wholesomeness of food irradiated with doses above 10 kGy, (1997: Geneva, Switzerland), WHO Technical report series: 890
- Kaur G, Aggarwal P, Javed M (2014) Effect of chemical additives on the shelf life of cucumber juice. *Int J Eng Res Appl* 4(1):206–209
- Khattak AB, Bibi N, Chaudry MA, Khan M, Qureshi MJ (2005) Shelf life extension of minimally processed cabbage and cucumber through gamma irradiation. *J Food Prot* 68(1):105–110
- Lammertyn J, Peirs A, Baerdemaeker JD, Nicolai B (2000) Light penetration properties of NIR radiation in fruit with respect to non-destructive quality assessment. *Postharvest Biol Technol* 18(2):121–132
- Li G, Wan SH, Zhou J, Yang ZH, Qin P (2010) Leaf chlorophyll fluorescence, hyperspectral reflectance, pigments content, malondialdehyde and proline accumulation responses of castor bean (*Ricinus communis* L.) seedlings to salt stress levels. *Ind Crops Prod* 31:13–19
- Oak Ridge National Laboratory-ORNL (2000) MCNP4C user's manual
- Perkins-Veazie P, Collins JK, Howard L (2008) Blueberry fruit response to postharvest application of ultraviolet radiation. *Postharvest Biol Technol* 47(3):280–285
- Sayyari M, Aghdam MS, Salehi F, Ghanbari F (2016) Salicyloyl chitosan alleviates chilling injury and maintains antioxidant capacity of pomegranate fruits during cold storage. *Sci Hortic* 211:110–117
- Segsarnviriya S, Malakrong A, Kongratarpon T (2005) The effect of gamma radiation on quality of fresh vegetables. In: International symposium “new frontier of irradiated food and non-food products”, 22–23 September, KMUTT, Bangkok, Thailand