

Shelf Life Extension of Tomatoes by Gamma Radiation

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Abstract: Gamma irradiation has been proved to inhibit microbial growth, delay ripening and extend the shelf life of fruits and vegetables. The present investigation was undertaken to evaluate the effectiveness of gamma radiation on extending the shelf life of tomatoes. Tomatoes were treated with gamma radiation doses of 0.5, 0.75, 1.0, 1.5, 2.0, 3.0 and 4.0 kGy. Shelf life of unirradiated and irradiated tomatoes was evaluated under ambient (temp. 25±2°C) and refrigerated (temp. 4±1°C) storage conditions to determine the optimum dose for control of rotting. Gamma irradiation at 0.75 to 1.0 kGy was effective in reducing rotting and enhancing the shelf life of tomatoes. Gamma irradiation treatment resulted in significant decrease in microbial load and decay of tomatoes both under ambient and refrigerated conditions. Radiation doses of 0.75 to 1.0 kGy did not affect the quality parameters of tomatoes like pectin, titratable acidity, pH, anthocyanin content and sensory attributes. The study indicates that irradiation at 0.75-1.0 kGy can improve the shelf life of tomatoes without adverse effects on quality and sensory attributes.

Keywords: Tomatoes, Gamma Radiation, Shelf Life, Storage

1. Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most important vegetable crops and has significant popularity in today's market both as a processed ingredient and as a fresh fruit. Tomato is a climacteric and short seasoned fruit. Short shelf life of tomatoes is due to its active metabolism, high respiration rate and rapid ripening behaviour at optimal temperatures. This represents a serious constraint for its efficient handling and transportation. Tomatoes are usually harvested over a limited period of time; it is therefore necessary to provide storage for the fruits to regulate marketing and preserve high quality. As a whole product, tomatoes maintain a delicate tissue structure that is extremely susceptible to chilling injury, mechanical damage and the presence of microorganisms. The shelf stability ranges from three days to three weeks depending on the time of harvest. Quick softening after harvest and subsequent microbial infestation are the major constraints in the marketing chain of the produce. Tomato is highly perishable fruit vegetable and about 20-30% post harvest losses of tomato fruits are observed every year in India. Environmental conditions have

strong impact on most of the quality traits of tomato such as colour and firmness of fruits [1]. A lot of problems related to post-harvest life of tomato are associated with microbial and fungal deterioration of fruit. A number of fungal species have been described as contributory agents of tomato decay during storage. Tomatoes are a seasonal fruit and reducing post harvest losses is very important.

Gamma radiation has been used as a post-harvest food preservation process for many years [2]. Irradiation has proved to be effective for controlling post-harvest losses and extending the shelf life by delaying the ripening and senescence of climacteric fruits [3]. Today, there is a growing interest to apply radiation for the treatment of fruits instead of using fumigation. The process is gaining much importance as it can be performed at room temperature and has high efficiency for inactivation of food borne pathogens and parasites [4, 5]. Gamma irradiation is a cold treatment that eliminates and inactivates the spoilage causing and pathogenic microorganisms with no adverse effect on nutritional and

sensory quality of foods. The safety and benefits of food processing by ionizing radiation has been studied extensively worldwide. The microbiological safety of food can be improved and its shelf life prolonged without substantially changing its nutritional, chemical, and physical properties using irradiation. The elimination of pests on agricultural commodities can also be achieved, thus reducing food losses and the use of chemical fumigants and additives. Food irradiation up to an overall dose of 10 kGy has been considered as a safe and effective technology. The Joint Expert Committee of Food Irradiation (JECFI) convened by the Food and Agriculture Organization (FAO), the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA) concluded in 1980 that the irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazards and requires no further testing [6]. JECFI further stated in the case of micro nutrients such as vitamins, losses due to irradiation treatment are comparable or lower to the conventional treatment such as heating or freezing. Later on, doses above 10 kGy were also considered safe for some niche products and markets [7]. Ionizing radiation is an economically viable technology for reducing postharvest losses, extending shelf life of perishable commodities and maintaining hygienic quality of fresh produce [8-10]. Studies have shown that irradiation increases the shelf life of various tropical and subtropical fruits such as papayas, mangoes and bananas [11-13] and also leads to the inactivation of microorganisms [14-16].

Irradiation has been proved to inhibit microbial growth, delay ripening and extend the shelf life of fruits and vegetables. However, the data on the use of gamma irradiation to prolong the shelf life and microbiological quality of tomatoes are limited. The present investigation was undertaken to evaluate the effectiveness of gamma radiation on extending the shelf life of tomatoes. The objective of the study was to optimize the irradiation dose for the shelf life extension and to investigate the impact of gamma irradiation on physico-chemical, microbiological and sensory qualities of tomatoes.

2. Materials and Methods

2.1. Tomatoes

Local variety of tomato, Pusa Rubi, (*Lycopersicon esculentum* Mill.) was obtained from the local market of Jodhpur, Rajasthan, India. Fresh tomatoes of uniform size and maturity without wounds or blemishes were selected for study. After collection, tomatoes were divided into different groups randomly for application of the irradiation treatment and packed in perforated plastic net bags.

2.2. Irradiation Treatment

Tomatoes within the bags were irradiated on the following day of collection at Defence Laboratory, Jodhpur, India using

gamma-rays emitted from Cobalt-60 Irradiator. Fruits were exposed to different radiation doses (0, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0 and 4.0 kGy), and the dose rate was 2 kGy/h. Chemical dosimeter ceric-cerous was used for dose measurements. The uncertainty associated with the dose measurements was 2.3%. To ensure the accuracy of the radiation dose delivered, tomatoes were irradiated in small volumes of 25 pieces per net bag. The variation in dose distribution for each sample was within $\pm 6\%$. After irradiation, the tomatoes were kept separately under ambient (temp. $25\pm 2^\circ\text{C}$) and refrigerated (temp. $4\pm 1^\circ\text{C}$) storage conditions. All irradiated and non- irradiated (control) tomato fruits were evaluated for microbial test, sensory evaluation and physico-chemical parameters like titratable acidity, pH, anthocyanin, pectin content, physiological loss in weight and decay percentage.

2.3. Weight Loss

Weight loss of irradiated and unirradiated tomatoes was evaluated during storage until complete spoilage. Weight loss (%) in tomatoes was determined according to the equation (1):

$$WL = [(W_0 - W_t) / W_0] \times 100 \quad (1)$$

where WL is the percentage weight loss, W_0 is the initial weight of tomatoes and W_t is the weight of tomatoes at the testing time.

2.4. Spoilage Percentage

Shelf life of irradiated and unirradiated tomatoes kept at room temperature and under refrigerated conditions was evaluated during storage at every 2 days interval until complete spoilage. Any fruit showing sign of soft rot or mould was considered as decayed. The percentage of spoilage was calculated for each dose. The decay rate was calculated by equation (2):

$$[\text{Number of decayed fruits} / \text{Total number of tested fruits}] \times 100 \quad (2)$$

2.5. Quality Attributes

2.5.1. Titratable Acidity and pH

Titratable acidity was determined according to the AOAC methods [17] and expressed as percent citric acid. Homogenate of ten unirradiated and irradiated tomatoes was prepared and the pH was determined.

2.5.2. Anthocyanin Content

Total anthocyanin content of tomato fruits was determined by grinding (2 g of fresh weight) with 20 mL of methanol containing 1% HCl. The sample was centrifuged at 2000*g for 15 min (4°C) and the absorbance was measured at 510 nm using a Dynamica Halo DB-30 UV-Vis Spectrophotometer (Dynamica Pty. Ltd., Prahran East Victoria, Australia).

2.5.3. Pectin Content

Pectic substances were analysed by the method described

by Prakash *et al.* [18] Alcohol soluble solids were extracted using 95% ethanol and discarded to obtain the alcohol insoluble solids (AIS). Water-soluble pectin (WSP) was extracted from the dried AIS with water and mixed with H₂SO₄/tetraborate solution (12.5 mM sodium tetraborate in concentrated H₂SO₄). To develop colour, 0.2 mL aliquots of 0.15% (w/v) m-hydroxydiphenyl were added to the sample whereas sample blanks received 0.2 mL of 0.5% (w/v) NaOH. The absorbance of the samples following chromogen formation was measured at 520 nm using a Dynamica Halo DB-30 UV-Vis Spectrophotometer (Dynamica Pty. Ltd., Prahran East Victoria, Australia).

2.5.4. Sensory Evaluation

Sensory attributes namely colour, texture, and overall acceptability were evaluated on a nine point scale. Sensory testing was performed by panelists and numerical values were assigned to each attribute on a 9-point scale where, 9 = excellent, 8 = very good, 6 = acceptable and 4 = poor.

2.5.5. Microbial Analysis

Irradiated and unirradiated samples of tomatoes were analysed for the bacterial, fungal and coliform colony forming units (CFU) by standard plate count methodology. Analysis was also carried out after 12 days of storage at room temperature (25°C) and under refrigerated conditions (4°C). Serial dilutions were prepared using sterile phosphate buffer. Plate count agar (PCA) for bacterial plate count, potato dextrose agar (PDA) for fungal count and violet red bile agar (VRBA) for coliform counts were used. PCA and VRBA plates were incubated at 32±2°C for 48 h, and PDA plates were incubated at 22±2°C for 72 h. Plates with CFUs between 25 and 300 were utilized to calculate the CFU/100g. The CFUs reported reflect the average of 4 plates.

2.6. Data Analysis

All data are reported as mean ± standard deviation. One way analysis of variance (ANOVA) was performed using statistical software MINITAB, USA (Version 13). ANOVA was performed within irradiated and unirradiated tomatoes to see whether there are any significant differences. P ≤ 0.05 was considered significant.

3. Results and Discussion

Physiological loss in weight of tomatoes was determined periodically with respect to storage time and irradiation dose. Radiation treated and control unirradiated tomatoes stored at ambient temperature were observed at every 3-4 days interval for their weight loss till spoilage (Table 1). Gamma irradiation at lower doses of up to 1.5 kGy decreased the weight loss in tomatoes as compared to the control (non treated tomato fruits). Weight loss in tomatoes at dose of 1.5 kGy was 9.95% and 16.29% as compared to 11.7% and 18.42% in unirradiated tomatoes after 14 days and 21 days of storage.

Table 1. Weight loss (%) of the unirradiated and gamma irradiated tomatoes.

Dose (kGy)	Days of storage					
	2	7	10	14	18	21
0.0	1.19±0.6	5.30±1.3	7.68±1.7	11.70±2.6	14.62±2.8	18.42±3.6
0.50	1.17±0.2	5.22±0.8	7.58±1.1	11.22±1.7	14.25±2.0	17.67±3.0
0.75	1.18±0.4	5.00±1.3	7.02±1.1	10.81±2.0	13.90±2.6	16.67±2.9
1.0	1.04±0.3	4.54±1.0	6.97±1.5	10.53±2.2	13.93±2.1	16.43±2.3
1.5	0.97±0.2	4.46±1.1	7.02±1.8	09.95±2.1	12.71±2.5	16.29±3.9
2.0	1.13±0.2	5.31±1.2	7.72±1.8	11.86±2.6	15.01±2.4	18.71±3.4
3.0	1.18±0.4	5.91±1.7	8.44±2.3	12.34±3.2	15.06±3.1	17.18±3.1
4.0	0.86±0.3	4.18±1.3	6.58±2.3	10.62±4.4	11.84±2.9	15.00±4.2

Values represent mean ± SD.

Weight loss in tomatoes treated with 0.5, 0.75, 1.0 and 1.5 kGy was lower than that of the control during 21 days of storage. There were no significant differences (p>0.05) in loss of weight among fruits irradiated using the doses of 0.5 to 1.5 KGy. However, increase in weight loss in tomatoes irradiated at higher doses of 2 and 3 kGy as compared to the untreated tomatoes was observed. Tomatoes treated with 4.0 kGy were almost decayed, indicating that the irradiation treatment with 0.5-1.5 kGy could prolong the shelf life of tomatoes, and the high dose would cause damage to fruit. After 14 days storage period significant number of the control fruits were discarded due to complete rotting whereas irradiated fruits (0.5-1.5 kGy) continued to keep well up to 25 days. The shelf life of tomatoes could be prolonged by treatment with doses of 0.5-1.5 kGy. The dose range of 0.5-1.5 kGy recorded lower weight loss in tomatoes as compared to unirradiated tomatoes over the storage period of 21 days at ambient temperature. The reduced weight loss observed is due to the effect of gamma-irradiation on the respiration rate and in delaying the onset of climacteric, ripening process and senescence [19, 20]. However, increase in weight loss in case of tomatoes irradiated to 2.0 kGy and 3.0 kGy is attributed to the severe membrane degradation at higher irradiation dose [21, 22].

Effect of gamma radiation on the shelf life extension of red tomatoes at room temperature (25±2°C) and in refrigerator (4±1°C) was studied. The physical conditions of the radiation treated and control tomatoes were observed at every 2 days interval till spoilage and the results for 7, 14 and 21 days storage are shown graphically in Fig. 1. In control samples, decaying (16%) was observed at day 2 and were fully decayed within 14 days of storage at ambient temperature. No significant decay was recorded in samples irradiated at 0.75 kGy up to 7 days of ambient storage. Decay rate was less than 50% after 14 days of storage for tomatoes irradiated at 0.5-1.5 kGy as compared to 100% decay in untreated control tomatoes. Tomatoes irradiated at 0.75 kGy had the least decay rate of 12% after 14 days of storage at ambient temperature. Decay rates of tomatoes treated with doses 2.0, 3.0 and 4.0 kGy reached 60% to 80% after 14 days of storage.

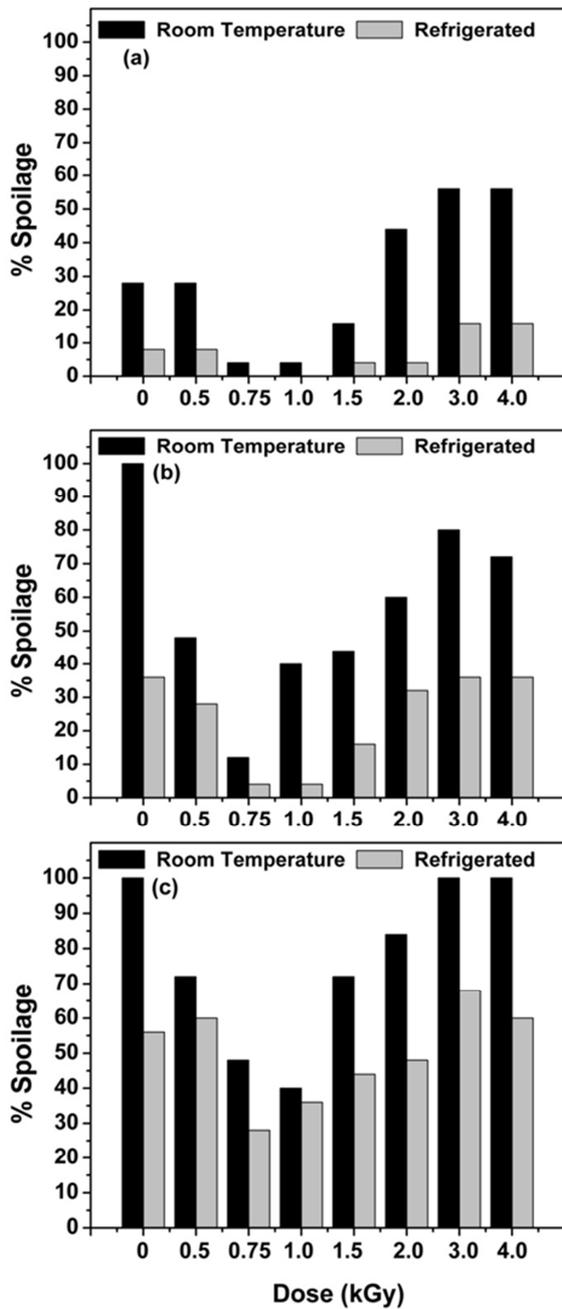


Figure 1. Effect of different doses of gamma radiation on % decay of tomatoes under different storage conditions after (a) 7 days (b) 14 days and (c) 21 days.

The irradiation doses 0.75 and 1.0 kGy had a preservative effect on tomatoes and the decay rate was less than 50% even after 21 days of storage. Under refrigerated conditions, no decay was recorded up to 3 days in all the treatments including control. Control samples started decaying after 7 days of storage and about 25% decay was observed after 10 days. No decay was recorded up to 10 days for tomatoes irradiated at doses of 0.75 and 1.0 kGy. 21 days after irradiation, the decay rates of control unirradiated group was more than 50%, while the 0.75 kGy and 1.0 kGy treated fruits still kept the lowest decay rates of 28% and 36%. Decay percentage on storage of tomatoes at ambient and

refrigerated condition indicate that synergistic effect of gamma irradiation and refrigeration in delaying physiological processes and inhibiting microbial proliferation has resulted in delayed decaying of tomatoes. Gamma irradiation of tomatoes at doses of 0.75-1.0 kGy was found appropriate for extending the shelf life and also fall within the approved limits up to 1.0 kGy set up by the IAEA for delaying ripening and shelf life extension of fruits [23, 24].

Data for pH is presented in Table 2. There was slight decrease in pH of gamma irradiated tomatoes as compared to control untreated tomatoes. pH of untreated tomatoes was 5.25 ± 0.3 and it varied from 4.6 ± 0.14 to 5.13 ± 0.26 for treated tomatoes. Titratable acidity was found to decrease in gamma irradiated tomatoes. Titratable acidity was significantly lower (2.05-2.26%) in fruits treated with 0.75 to 2.0 kGy as compared to unirradiated tomatoes (3.02%). During fruit ripening, titratable acidity was reported to increase up to the climacteric peak and declined afterwards in papaya, mango and guava [25]. The retention of acidity is an indication of delay in ripening due to effect of gamma radiation.

Colour is an important component of tomato fruit appearance, and it is defined by the anthocyanin content. The amount of anthocyanins is important for the maturity evaluation of tomato. The index of maturity used for harvesting is the red color resulting from anthocyanin synthesis. Changes in anthocyanin content due to gamma irradiation of tomato fruits was evaluated (Table 2).

Table 2. Quality attributes of unirradiated and irradiated tomatoes.

Dose (kGy)	pH	Titratable Acidity	Anthocyanin Content
0	5.25 ± 0.30	3.02 ± 0.07	0.119 ± 0.012
0.5	4.97 ± 0.24	2.95 ± 0.11	0.095 ± 0.003
0.75	4.84 ± 0.28	2.26 ± 0.07	0.091 ± 0.002
1.0	5.13 ± 0.26	2.14 ± 0.02	0.087 ± 0.001
1.5	4.97 ± 0.25	2.05 ± 0.22	0.086 ± 0.001
2.0	4.63 ± 0.12	2.16 ± 0.11	0.085 ± 0.001
3.0	4.60 ± 0.14	2.70 ± 0.07	0.089 ± 0.002
4.0	4.63 ± 0.12	2.62 ± 0.09	0.092 ± 0.006

No significant differences in the anthocyanin content between gamma irradiated fruits and the control were observed. Nevertheless, the anthocyanin content of tomatoes on irradiation up to 2.0 kGy kept decreasing with increasing gamma radiation dose. This decrease may be ascribed to a delay in ripening, which is associated with the higher firmness of irradiated fruit. The result is in agreement with Heinonen *et al.* [26] who showed that the biosynthesis and accumulation of carotenoids were responsible for development of yellow-orange color of the papaya fruit skin and that this event was correlated to maturation. In addition, it has been demonstrated that there is an increase in the activities of phenylalanine ammonia lyase and flavonoid glucosyl transferase, the two key enzymes involved in the anthocyanin biosynthesis during ripening of the fruit [27, 28].

The effect of gamma irradiation on pectin content at different doses was evaluated. The results showed that the water soluble pectin content decreased with the increase of radiation dose (Fig. 2). There were no significant differences

($p > 0.05$) between the fruits treated with 0.5, 0.75, 1.0 and 1.5 kGy and the control group in the content of pectin. Irradiation dose above 2.0 kGy caused significant reduction ($p \leq 0.01$) in pectin content. Softening of fruits induced by irradiation has been reported to be associated with increased water soluble pectin and decreased oxalate soluble pectin content.

Both the water-soluble and the oxalate-soluble pectin fractions have been correlated with the decrease in firmness by irradiation [29]. Zegota [30] showed that the threshold dose of 1 kGy led to degradation of pectin in apple tissues. Yu *et al.* [31] found a significant correlation between the firmness and oxalate-soluble pectin and also, solubilization of pectin by irradiation has been reported for whole apples and strawberries. Our results show that the irradiation at 0.5-1.5 kGy had no negative effect on the water soluble pectin content and firmness during storage.

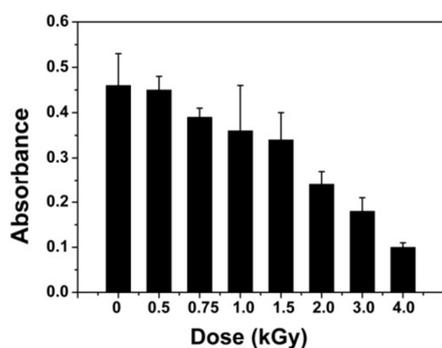


Figure 2. Effect of gamma irradiation on pectin content of tomatoes.

Tomato fruits treated with different doses of gamma radiation (0.5-4.0 kGy) were assessed for sensory attributes. The mean scores for color, texture and overall acceptability of the tomatoes have been presented in Fig. 3. Radiation doses of 0.5 to 3.0 kGy had no significant affect on colour of tomatoes as compared to the control untreated tomatoes. The sensory score of irradiated (0.5-3.0 kGy) tomatoes for colour ranged from 6.62 ± 0.49 to 8.0 ± 0.77 as compared to 6.69 ± 0.86 for control tomatoes. However, the radiation dose of 4.0 kGy had effect on colour and had significantly lower scores as compared to unirradiated tomatoes. Tomatoes gamma irradiated at 0.5-1.5 kGy were significantly preferable to that of unirradiated tomatoes in terms of overall acceptability.

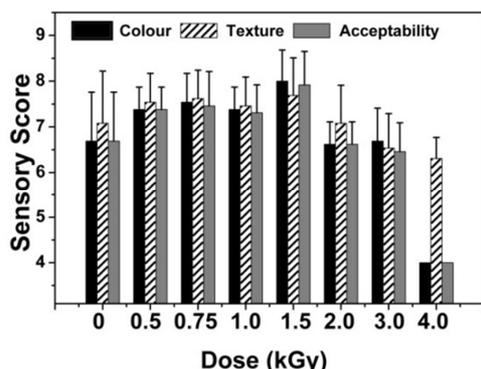


Figure 3. Effect of gamma irradiation on sensory attributes of tomatoes.

The treatment with gamma radiation at doses of 0.5 to 2.0 kGy did not affect the texture of tomatoes. Texture is an important quality parameter that determines the acceptability and shelf life of a fresh horticulture produce. It is primarily determined by the structural integrity of the cell wall and middle lamella as well as turgor pressure of the cells [32, 33]. No significant difference was observed in irradiated tomatoes in terms of colour, flavour and overall acceptability. The sensory attributes of the irradiated tomatoes at 0.5 to 1.5 kGy were ranked equally acceptable on the hedonic scale.

Effect of different doses of gamma radiation on microbial load of tomatoes was studied. Surface bacterial load on tomatoes was found to be in the range of ~ 3 log CFU/100g. The change in population of aerobic microorganisms on tomatoes after irradiation is shown in Fig. 4a. Surface bacterial load was reduced by 2 log cycles at the doses of 0.75 and 1.0 kGy. Further decrease in bacterial counts was observed at higher doses. No significant increase in counts was observed during storage of 12 days at ambient temperature. The counts for irradiated tomatoes remained lower than the control unirradiated during storage. Tomatoes that had been irradiated at 0.75-1.0 kGy and stored at 4°C had count of $0.5 \times 10^1 - 1.1 \times 10^1$ CFU/100g 12 days after irradiation. At the same time, the control had count of 1.65×10^2 CFU/100g. Thus, almost 2 log difference in the aerobic microbial load of irradiated tomatoes in contrast to control samples was observed. Tomatoes irradiated at doses of 1.5, 2.0 and 3.0 kGy had bacterial counts less than 10^1 CFU/100g. No viable counts were detected in tomatoes treated with dose of 4 kGy.

Fungal counts for unirradiated and irradiated tomatoes are presented in Fig. 4b. The control samples had counts of 1.31×10^2 CFU/100g. The effect of irradiation on the yeast and mould population was similar to that observed for the total aerobic population. About 1 to 2 log reduction in fungal counts was observed on irradiation and this difference was also maintained during storage period of 12 days.

Fungal count of tomatoes was markedly reduced by both irradiation and low-temperature storage. No fungal counts were recorded in tomatoes irradiated at dose beyond 0.75 kGy after 12 days of storage under refrigerated conditions. The effect of gamma irradiation on the coliform counts is presented in Fig. 4c. Significant decrease in coliforms counts on gamma irradiation was observed. Total coliforms were not detected in the irradiated samples at 1.0 kGy and higher doses under both the conditions of storage.

Microbial contamination of tomatoes can affect its quality and shelf life. The effect of gamma irradiation on the microbial load of tomatoes was evaluated. Irradiation dose of 0.75 kGy greatly reduced total aerobic bacterial counts as well as the counts of total molds and yeasts. This irradiation dose also resulted in complete elimination of coliform bacteria.

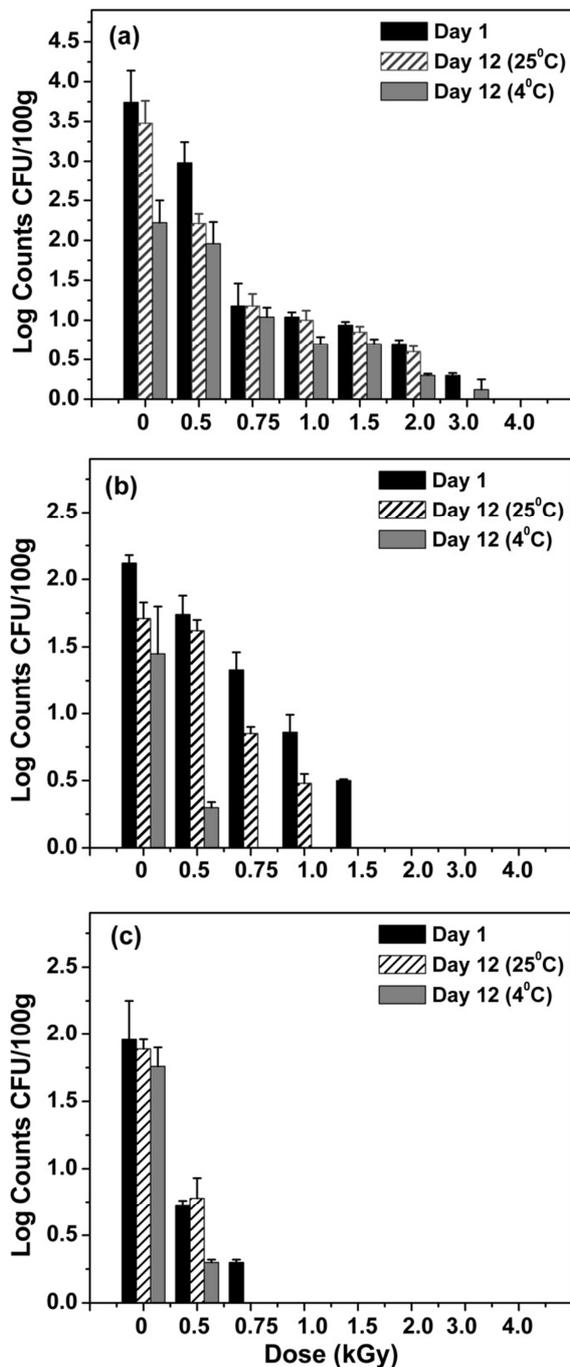


Figure 4. Effect of gamma irradiation on (a) total bacterial (b) fungal and (c) coliform counts of tomatoes.

Prakash *et al.* [18] have reported that irradiation at 0.5 kGy can reduce the microbial counts of diced tomatoes substantially to improve the shelf life without any adverse effect on the sensory qualities. Mohacsi-Farkas *et al.* [34] have also reported gamma irradiation of pre-cut tomato for improving microbiological safety and maintaining sensory and nutritional quality. Radiation treatment at 0.75 kGy reduced the surface microbial load significantly in the present study. The irradiation effect on microbial load was evident during storage both at room temperature and under refrigerated conditions. Living cells are inactivated when

exposed to factors that substantially change their cellular structure or physiological functions. Lethal structural damages include DNA strand breakage, cell membrane rupture, or mechanical damage to cell walls [35]. During the irradiation of food, DNA is strongly damaged by radiation and therefore microorganisms are prevented from reproducing [36]. DNA damage may result from a direct action of the ionizing radiation or from an indirect action of the oxidative radicals that originated from the radiolysis of cellular water [36]. The cells that are unable to repair their radiation-damaged DNA die [35]. Differences in radiation sensitivities among microorganisms are related to differences in their chemical and physical structures and in their ability to recover from radiation injury [36]. In general, the sensitivity of organisms to radiation increases with their complexity. Thus, the required radiation dose to achieve effective inactivation is higher for bacteria than fungi. Therefore, the radiation energy required to control microorganisms on or in food varies according to the type of species to be eliminated and according to their population numbers.

4. Conclusions

Gamma irradiation at 0.75 to 1.0 kGy was effective in reducing rotting and enhancing the shelf life of tomatoes. Gamma irradiation treatment resulted in significant decrease in microbial load and decay of tomatoes both under ambient and refrigerated conditions. Radiation doses of 0.75 to 1.0 kGy did not affect the quality parameters of tomatoes like pectin, titratable acidity, pH, anthocyanin content and sensory attributes. Control unirradiated tomatoes were almost fully decayed in 14 days, while the tomatoes irradiated at the dose of 0.75 kGy had extended shelf life of up to 21 days under ambient storage. Gamma irradiation at 0.75 kGy significantly extended the storage life of tomatoes by 7 days under ambient conditions.

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