Ensure Microbial Safety and Extending Shelf-Life of Tomato Juice by γ Irradiation

Youssef, K.A.[1]; Hammad, A.I.[2]; Abd El-Kalek, H.H.[2] and Abd El-Kader, R.M.[2]

[1] Microbiology Department, Faculty of Science, Ain Shams University, Cairo, Egypt.
[2] Microbiology Department, National Center for Radiation Research and Technology, Atomic Energy Authority, Nasr City, Cairo, Egypt

Abstract: The effects of γ irradiation on both the microbial and nutritional as well as sensory evaluation of tomato juice were evaluated. Tomato juice has high microbial contamination affecting its quality and shelf-life. Irradiation (1.5, 3.0 and 4.5 kGy) as non-thermal processing have been used to improve microbial quality, ensure safety and extending shelf-life of tomato juice. Irradiation dose of 3.0 kGy greatly reduced total aerobic bacterial counts as well as the counts of total molds and yeasts without affecting sensory properties of tomato juice. It reduce lactic acid bacteria to undetectable level (<10 cfu/ml). This irradiation dose was enough for complete elimination of coliform bacteria. The ascorbic acid and lycopene content were determined, where all irradiation doses (1.5, 3.0 and 4.5 kGy) used significantly reduced ascorbic acid content of tomato juice and the reduction was proportional with irradiation dose. In contrast, the same doses did not show significant effect on the total lycopene content in the tomato juice. Irradiation dose of 3.0 kGy could improve the microbial quality, ensure safety and extend the shelf-life of tomato juice to 15 days at 4ºC±1 against only 5 days for unirradiated ones. Irradiation dose of 4.5 kGy affect the sensory properties of tomato juice, thus it is recommended to use 3.0 kGy.
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1. Introduction

The intake of fruit and vegetable juices are recommended for a healthy diet and various health effects **(Song *et al.*, 2006).** Healthy dietary behaviors such as an increased consumption of fruit, vegetable, and 100% fruit and vegetable juice and a reduced consumption of sweetened beverages have been related to a lower chronic disease risk **(Maynard *et al* ., 2003)** and body weight **(Ludwig *et al*., 2001).**

Tomato is certainly an important agricultural commodity worldwide. In Egypt, it is one the most widely consumed foodstuffs, either fresh or processed, and it is the main source of carotenoids for much of the population **(Watzl *et al.*, 2000).** A large part of the world's tomato crop is processed into tomato juice and other products. Lycopene, the pigment principally responsible for the characteristic deep-red color of ripe tomato fruits and tomato products, has received much attention in recent years because of its beneficial effect in the treatment of diseases **(Shi and Maguer, 2000).**

Extensive scientific studies have found that lycopene appears to have strong antioxidant capabilities that can inactivate free radicals and reduce damage to the body's cells, reducing the risk from some human cancers and chronic diseases **(Ghaffari and Ghiasvand, 2006).** Increased consumption of tomato and tomato-based products may reduce the risk of certain types of cancer, such as prostate, lung and stomach cancer **(Giovannucci, 1999)** and cardiovascular disease **(Sesso *et al.*, 2003).** Tomatoes ranked first as a source of lycopene (71.6%), second as a source of vitamin C (12.0%), provitamin A carotenoids (14.6%) and third as a source of vitamin E (6.0%) **(García-closas *et al.*, 2004).**

Fresh fruits and vegetables juice are highly contaminated by microorganisms. The microbial flora in the vegetable juice is thus likely to be similar to the flora in raw vegetables. Many microorganisms, in particular acid-loving or acid-tolerant bacteria and fungi (yeasts and moulds), can use fruit as substrate and cause spoilage, producing off flavors and odors, discoloration of the product, and if the contaminating micro-organisms are pathogens could also cause human illness **(Tournas *et al*., 2006).** There are a number of reports indicating that raw vegetables may harbor potential of foodborne pathogens **(Beuchat, 1996; Sumner and Peters, 1997).** The unpasteurized fresh juices can support the growth of both spoilage and pathogenic bacteria because they have high water activity (aw) and enough nutrients for microbial growth. If a bacterial pathogen is present on or in the produce or on any processing surface, it will have an almost unlimited food source for growth in the unpasteurized juice, resulting in a foodborne outbreak **(Cook *et al.*, 1998).** Therefore, vegetable juice should undergo some type of processing to inactivate most of the microorganisms. The main requirement that a process must meet is to ensure the

microbial safety of the product while preserving the sensory and nutritional characteristics to obtain products similar to fresh vegetable juice **(Song *et al.*, 2007).**

The general method for reducing a microbiological contamination level of fresh vegetable juice is a washing practice of raw materials in water with a combination of ozone and/or chlorine treatment. However, it has a limited effect on microflora and sometimes can contaminate the products **(Nguyen-the and Carlin, 1994).** On the other hand, the use of heat can destroy nutrients such as thermally labile vitamins and also the components responsible for a products flavor and taste. Therefore, a non-thermal pasteurization technology such high hydrostatic pressure (HHP) is required to apply in the processing of fresh vegetable juice to avoid the deleterious effects that heat has on the flavor, color, and nutrient value of the foods **(Barbosa-Canovas *et al.*, 1998).** However, the HHP method still has several problems such as the limitations of a mass production and an increased cost. For the reasons, an industrial application of HPP is still limited. Ionizing radiation, another non-thermal sterilization method, has approved highly effective in inactivating food microorganism and has many advantages for industrial use. Recently, it has offered a safe alternative as a decontamination method of food and public health products **(Hammad *et al.*, 2010).** The prescribed advantages of ionizing radiation (gamma radiation, electron beam, x-rays) arises from its ability to destroy viable cells of microorganisms without arising the temperature of the product, hence keeping it's freshness, nutrients, chemical and physical properties **(Tiwaria *et al.*, 2009)**.

The main objective of the present study is to use γ -irradiation to improve the microbiological quality, eliminate foodborne pathogens, and extend the shelf life of fresh tomato juice. In addition the microbiological, nutritional, physiochemical, chemical and sensory quality of juice treated by gamma irradiation during storage at refrigeration temperature were investigated.

2. Materials and Methods

Commercially sound, mature and fresh tomatoes (*Solanum lycopersicum*) were bought from a local vegetable market at Cairo. Lycopene standard were obtained from Sigma Chemical Co. (St. Louis,MO). 2, 6 dichlorophenolindophenol were purchased from Fluka (Deisenhofen,Germany). All solvents used throughout the present work were purchased from El-Nasr Company (Cairo, Egypt). Plate count agar (PCA), Malt extract agar (MEA), Baird-Parker agar (BPA) were purchased from Difco (Difco labs., Detroit, Michigan, USA). MacConkey agar (MCA), MacConkey broth (MCB), Kanamycin aesculine azid agar (KAAA), Man, Rogosa and Sharp (MRS) agar medium and starch ampicillin agar medium (SAA) were obtained from Oxide (Oxide Comp., Basigstoke, Hants, UK).

Squeezing:

All the tomatoes were washed with running tap water to remove dirt and each was cut into eight pieces, which were then squeezed by a direct squeezing in a commercial juicer (National juicer blender, Model MJ-130N).

Packaging:

The juice samples were packaged in aluminum foil bags (each 100 ml) and kept frozen for 12 h to keep the cold temperature of the juice during irradiation.

γ -irradiation

Gamma irradiation of the packaged prepared juice samples was carried out using cobalt 60 irradiator source (Gamma Chamber 4000 India), located at National Center for Radiation and Technology (NCRRT), Nasr City, Cairo, Egypt. The tomato juice bags were divided into four groups; the first group was left without irradiation and considered as control, while the second, third and fourth group were exposed to gamma irradiation at doses of 1.5, 3.0 and 4.5 kGy. The dose rate of the irradiator source at that time was 3.771 kGy /h. Dosimetry was performed using reference alanine dosimeters traceable to national physical laboratory (NPL), UK.

Storage:

Both unirradiated and irradiated samples were stored at 4°C±1 until rejected. Samples were withdrawn each 5 days for microbiological, chemical, physiochemical and sensory analysis.

Microbiological analysis

Total bacterial counts (TBC), lactic acid bacteria (LAB) and total mold and yeast counts (TM&Y) were counted on PCA, MRS and MEA agar media, respectively **(APHA, 1992).** Total coliform and *Escherichia coli* were counted on MacConkey broth using Most Probable Number (MPN) technique according to **WHO (1993).** *Enterococcus faecalis* was enumerated on KAAA medium according to **Mossel (1978).** *Staphylococcus aureus* was counted on BPA medium according to **ICMSF (1978).**

Nutritional analysis:

a)Vitamin C (ascorbic acid) measurement

Ascorbic acid was determined using 2, 6

dichlorophenol indophenols reagent according to the method described by **AOAC (2000).**

b) Lycopene Content:

For determination of lycopene content, 4 ml of fresh tomato juice was put in a 200 ml flask wrapped with aluminum foil to keep out light. A 100 ml mixture of hexane – acetone – ethanol, 2:1:1 (v/v %) was added to the flask and agitated continuously for 10 min. After that, 15 ml of water was added followed by another 5 min agitation. The solution was separated into polar and non polar layers. Non polar layer, i.e. hexan solution containing lycopene was filtered into by filter paper; the filtrate was then diluted with a mixture of hexane-acetone-ethanol (2:1:1, vol/vol %). Lycopene concentration was estimated by measuring the absorbance of the hexane solution containing lycopene at 472 nm on a spectrophotometer (ATI unicam, 5600 series uv/vis spectrophotometer, Model (V-200-RS). The lycopene was quantified by use of a standard linear curve (R^2 = 0.9982) of lycopene solution in hexane in concentrations from 0.25 to 1.25 µg/mL. The contents of lycopene were expressed as milligrams per 100 g wet weight **(Markovic *et al.*, 2006).**

Physiochemical analysis

a.Viscosity:

The viscosity of the juice was measured using a (Brookfield digital Rheometer (Model DV-II, Brookfield Engineering Laboratories, Inc., Stonghton, MA).

Viscosity measurements were made by using 8-16 ml of juice samples in small sample adapter. The temperature was adjusted at 20ºC. The temperature degree was adjusted using water bath circulator and coolers.Each sample measured against non-irradiated control.

b.pH:

Changes in pH value of juices during storage were determined by a Bench pH meter (pH 211 Microprocessor pH meter, Hanna instruments) and pH electrode (Epp-1) at room temperature **AOAC (2000).**

Sensory evaluation:

Unirradiated and irradiated tomato juice was given to panelists immediately after irradiation for sensory evaluation. The procedure carried out for this evaluation was similar to that described by **Min *et al.* (2003).** Ten panelists belonging to the Department of Food Microbiology at the National Center for Radiation Research and Technology Cairo, Egypt participated in the sensory tests. Fifteen milliliters of each sample were served into 20 ml ultra clear polypropylene containers with polyethylene screw-cap (Deltalab) coded with three digits randomly numbered; moreover, a glass containing potable water and a piece of non-salted cracker were provided to panelists for eliminating the residual taste between samples. The panelists were asked to rate the preference of odor, color, taste and overall acceptability in a hedonic scale from 0 to 9. where (9= like extremely, 8= like very much, 7= like moderately, 6= like slightly, 5= neither like nor dislike, 4= dislike slightly, 3= dislike moderately, 2= dislike very much, 1= dislike extremely). A score of 4 or below was regarded as unacceptable and taken to indicate the end of shelf-life.

Statistical analysis:

The significance of the data with different factors was evaluated using Two-way analysis of variance ANOVA. All analyses were performed with SAS software package version 6.12 **(SAS, 1997).**

3. Results and Discussion

Effect of γ irradiation and storage on the microbial load of tomato juice

Table (1) indicates that the non irradiated tomato juice was highly contaminated with aerobic mesophillic bacteria, lactic acid bacteria and yeasts and molds. The total log counts of these microorganisms were 3.98, 3.67, 3.57 cfu/ml, respectively. The microbial obtained counts exceeded the level of codex standard for tomato juice **(Codex stan 49-1981).** The obtained high contamination levels of microorganisms was expected and could be due to the high natural microflora of the raw tomato, that come from soil, water or the hands of workers, as well as the contamination during blending and packaging. The obtained results were almost similar to those reported by **Prakash *et al.* (2002)** who found that the diced tomato were highly contaminated with mesophillic bacteria and mold and yeasts at level of 4.40, 4.58 Log cfu/ml, respectively. **Hsu *et al.* (2008)** also found that the tomato juice were highly contaminated with mesophillic bacteria, Lactic acid bacteria and mold and yeasts at the levels of 4.1, 4.2 and 3.7 Log cfu/ml, respectively. The high microbial counts found in tomato juice would affect its quality and shelf-life.

Table (1) also shows the effect of different doses of gamma irradiation (1.5, 3.0 and 4.5 kGy) on total mesophillic bacteria, Lactic acid bacteria, mold and yeast populations in tomato juice. Generally, irradiation caused a significant ($p<0.05$) decrease in all microbial counts under investigation and the decrease was proportional with irradiation doses. Irradiation dose of 1.5 kGy reduced the number of the initial mesophillic bacteria by almost 1.3 log

cycle. As well as, it could be successfully reduce the lactic acid bacteria to below the detectable counts (<10 cfu/ml). On the other hand, irradiation at 1.5 kGy reduced total mold and yeasts by only 0.5 log cycles indicating that mold and yeasts are relatively more resistance to gamma irradiation than bacteria. **Fan *et al.* (2003)** observed decay in Cilantro irradiated at 3.0 kGy during storage and supported his observation that fungi are more resistant to irradiation than bacteria. On the other hand, irradiation doses of 3.0 and 4.5 kGy were sufficient to reduce the number of the initial molds and yeasts by 0.68 and 1.37, respectively. Therefore, a dose of 3.0 and 4.5 kGy could be used to reduce microbial counts of tomato juice to satisfactory level**. Prakash *et al.* (2002)** reported that a dose of 3.07 kGy eliminated all microorganisms contaminating diced tomatoes to no detectable counts. Where **Song *et al*. (2007)** found that the irradiation doses of 1, 2 and 3 kGy could reduce the microbial populations of carrot juice by 2.4, 3.8 and 5.9 log cycles, respectively and these irradiation doses could reduce the microbial counts of kale juice by 1, 1.5 and 2.0 log cycles, respectively. These results indicate that the microflora of the tomato, kale and carrot juice is fairly different, so the radiation sensitivity of the microorganisms composing the microflora should be considered in the radiation processing.

In addition, table (1) illustrated that during storage of tomato juice at 4ºC ±1, the viable counts of mesophillic bacteria, lactic acid bacteria and mold and yeast in the non irradiated tomato juice were progressively increased and reached 7.94, 6.96 and 7.07 log cfu/ml, respectively after 10 days . However, these microorganisms reached almost similar counts in tomato juice receiving 1.5 and 3.0 kGy but after 15 and 20 days, respectively. Total mesophillic aerobic bacterial count, lactic acid bacteria and total mold and yeasts in tomato juice receiving 4.5kGy reached 5.79, 6.47 and 7.34 log cfu/ml after 25 days of storage at 4ºC ±1. It is worthy to mention that at day 5 and 10 of storage, these microbial counts in irradiated samples were significantly less than the microbial counts of the unirradiated ones. Similar results on microbial counts of irradiated (0.5, 1.24 and 3.70 kGy) diced Roma tomatoes stored at 4ºC ±1 have been shown by **Song *et al.* (2007).**

Table (1): The effect of γ -irradiation and subsequent storage (4°C±1) on the microbial counts (log cfu/ml) contaminating tomato juice.

Micro-organisms	Storage (days)	Irradiation doses (kGy)			
		0.0	1.5	3.0	4.5
Total mesophilic bacteria	0	$3.98^{a}_{a}\pm0.045$	$2.69^{b}_{a}\pm0.002$	$1.93^{c}_{a}\pm0.02$	<1
	5	$5.86^{a}_{b}\pm0.011$	$2.84^{b}_{b}\pm0.007$	$2.11^{c}_{b}\pm0.029$	<1
	10	$7.94^{a}_{c}\pm0.02$	$5.27^{b}_{c}\pm0.003$	$3.97^{c}_{c}\pm0.01$	$2.55^{d}_{c}\pm0.006$
	15	R	$6.86^{b}_{d}\pm0.006$	$4.66^{c}_{d}\pm0.01$	$3.04^{d}_{d}\pm0.01$
	20	R	R	$6.89^{c}_{e}\pm0.037$	$4.11^{d}_{e}\pm0.001$
	25	R	R	R	$5.79^{d}_{f}\pm0.34$
Lactic acid bacteria	0	$3.67^{a}_{a}\pm0.017$	<1	<1	<1
	5	$5.14^{a}_{b}\pm0.045$	<1	<1	<1
	10	$6.96^{a}_{c}\pm0.004$	$4.00^{b}_{c}\pm0.025$	$3.00^{c}_{c}\pm0.01$	<1
	15	R	$6.54^{b}_{d}\pm0.01$	$3.96^{c}_{d}\pm0.001$	$3.00^{d}_{d}\pm0.006$
	20	R	R	$5.92^{c}_{e}\pm0.014$	$4.14^{d}_{e}\pm0.017$
	25	R	R	R	$6.47^{d}_{f}\pm0.004$
Total mold and yeasts	0	$3.57^{a}_{a}\pm0.027$	$3.07^{b}_{a}\pm0.02$	$2.89^{c}_{a}\pm0.008$	$2.20^{d}_{a}\pm0.03$
	5	$5.63^{a}_{b}\pm0.011$	$3.92^{b}_{b}\pm0.007$	$3.00^{c}_{b}\pm0.01$	$2.25^{d}_{b}\pm0.013$
	10	$7.07^{a}_{c}\pm0.03$	$6.00^{b}_{c}\pm0.01$	$5.96^{c}_{c}\pm0.005$	$4.17^{d}_{c}\pm0.016$
	15	R	$7.07^{b}_{d}\pm0.03$	$6.39^{c}_{d}\pm0.005$	$5.34^{d}_{d}\pm0.008$
	20	R	R	$6.82^{c}_{e}\pm0.01$	$6.71^{d}_{e}\pm0.019$
	25	R	R	R	$7.34^{d}_{f}\pm0.017$

R = Samples sensorially rejected. <1 = below detectable limit (<10 cfu/ml).

Mean values followed by different superscript (within rows) and different subscripts (within columns) are significantly different ($p < 0.05$).

Table (2) shows the presence of coliform bacteria in unirradiated tomato juice at level $2.1x10^2$ MPN/ml. On the other hand, *Escherichia coli*, *Enterococcus faecalis* and *Staphylococcus aureus* were not detected in unirradiated tomato juice. coliform bacteria present in unirradiated tomato juice were eliminated by the lowest irradiation dose used (i.e. 1.5 kGy) since the MPN was below detectable level (< 3) indicating the sensitivity of coliforms to gamma radiation. Where coliform in the fresh carrot juice were eliminated by irradiation at 3 kGy as reported by **Song *et al.* (2007).**

During storage of tomato juice at 4ºC ±1 there was progressive and continuous increase in coliform bacteria, at day 5 and 10, the MPN of coliform bacteria reached 2.1×10^4 and 4.3×10^4, respectively. On the other hand, the MPN of coliform bacteria in the irradiated tomato juice were below detectable level thoughtout the storage period. Where there was a progressive and continous increase in coliform bacteria in carrot and kale juice where it reached 8.93 and 9.98 log cfu/ml, respectively after 3 days storage at 10°C. However, the viable coliform in the juices treated with irradiation were decreased during storage for 3 days at 10°C, which was significantly lower than those of the non-irradiated fresh vegetable juice ($p < 0.05$) as reported by **Song *et al.* (2007).** It was considered that the decreasing of the microbial population was due to the post-irradiation effect where the surviving cells that had been damaged by an irradiation were gradually inactivated, thus not adapting to the surrounding environment during a storage **(Byun *et al.*, 2001).**

Table (2): The effect of γ -irradiation and subsequent storage (4°C±1) on the some pathogens contaminating tomato juice.

Micro- organisms	Storage (days)	Irradiation doses (kGy)			
		0.0	1.5	3.0	4.5
Coliforms (MPN/ml)	0	$2.4x10^2$	< 3	< 3	< 3
	5	$2.1x10^4$	< 3	< 3	< 3
	10	$4.3x10^4$	< 3	< 3	< 3
	15	R	< 3	< 3	< 3
	20	R	R	< 3	< 3
	25	R	R	R	< 3
Escherichia coli (MPN/ml)	0	< 3	< 3	< 3	< 3
	5	< 3	< 3	< 3	< 3
	10	< 3	< 3	< 3	< 3
	15	R	< 3	< 3	< 3
	20	R	R	< 3	< 3
	25	R	R	R	< 3
Enterococcus faecalis (log cfu / ml)	0	<100	<100	<100	<100
	5	<100	<100	<100	<100
	10	<100	<100	<100	<100
	15	R	<100	<100	<100
	20	R	R	<100	<100
	25	R	R	R	<100
Staphylococcus aureus (log cfu / ml)	0	<100	<100	<100	<100
	5	<100	<100	<100	<100
	10	<100	<100	<100	<100
	15	R	<100	<100	<100
	20	R	R	<100	<100
	25	R	R	R	<100

R = Samples sensorially rejected. < 3 = No positive tubes have been shown in the first three dilutions.
<100 = Below detectable level

Nutritional quality of irradiated tomato juice

The nutritional quality of irradiated fresh tomato juice in comparison with unirradiated fresh tomato juice were investigated by analyzing the contents of ascorbic acid (Vitamin C) and Lycopene pigment.

Ascorbic acids content:

Fruit juices are an important source of vitamin C in the total diet. However, ascorbic acid of fruit juices is readily oxidized and lost during staying of the juices. Fig (1) shows that the ascorbic acid content of unirradiated (control) of tomato juice was 15.63 mg/100 ml. Similar result have shown by **Hsu *et al.* (2008)** who found that ascorbic acid in tomato juice was 18.6±0.8 mg/100 ml. The content of ascorbic acid in tomato juice could vary according to the variety of tomato, cultivar, plant origin, condition of planting, harvesting, squeezing process…etc. Generally, all irradiation doses used significantly ($p<0.05$) decreased ascorbic acid content of tomato juice and the decrease was proportional with irradiation dose. This significant decrease of ascorbic acid is apparent and could be due to the partial oxidation of ascorbic acid to dehydroascorbic acid which not affecting tomato on vitamin C (vit. C = ascorbic acid + dehydroascorbic acid) **(Song *et al.*, 2007).** This is expected due to the fact that ascorbic acid is sensitive to oxidation and gamma radiation cause water radiolysis of tomato juice producing free radicals (H°, oH°, e^-) and oH° radicals are strong oxidizing agent **(Variyar *et al.*, 2004). Kilcast (1994)** reported that ionizing radiation can cause a partial conversion of ascorbic acid to dehydroascorbic acid. So, it is useful in the next studies to determine the amount of ascorbic acid and dehydroascorbic acid. **Graham and Stevenson (1997)** found that the dehydroascorbic acid content of tomato samples increased immediately following irradiation. It should be mentioned that both ascorbic acid and dehydroascorbic acid have a vitamin C activity in the body.

During storage, Fig (1) illustrated that ascorbic acid content of non-irradiated and irradiated tomato juice were significantly ($p < 0.05$) decreased but at different levels. After 10 days of storage at 4°C±1 ascorbic acid content of non-irradiated samples decreased by 61.2%, while it decreased in samples irradiated at 1.5, 3.0 and 4.5 kGy by 53.7, 24.9 and 25.5 %, respectively. It is clear that the percentage loss of ascorbic acid content during storage of irradiated samples was lower than that of non-irradiated samples and was dose dependent. The loss of ascorbic acid in samples irradiated at 4.5 kGy was 38.6 % after 25 days of storage. It is worthy to mention that both thermal treatments and high hydrostatic pressure processing of fruit and vegetable juice as irradiation cause loss in ascorbic acid but at different levels **(Song *et al.*, 2007 and Hsu *et al.*, 2008).**

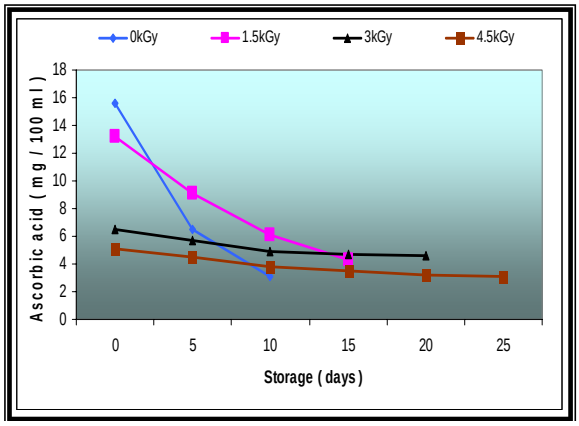

Fig (1): Ascorbic acid content (mg/100 ml) of tomato juice treated with irradiation during storage.

Lycopene content

Most authors studied the thermal effect on lycopene degradation but there is few data, if any, available in the literature on the effect of ionizing radiation on the lycopene content in foods. Therefore, the objectives of this research were to investigate the effect of γ irradiation on lycopene content of tomato juice. Fig (2) illustrated that the total lycopene content of non-irradiated (control) samples was 8.55 mg/100g wet weight, this value are within the range (6.93-42.74 mg/100g wet weight) reported for other tomato juice **(Markovic *et al.*, 2006).** The results indicated that γ irradiation at doses of 1.5, 3.0 and 4.5 kGy did not show significant effect on the total lycopene content in tomato juice.

The results also show that the storage for 5 days resulted in a significant ($p < 0.05$) decrease in the total lycopene content of both the non irradiated and irradiated tomato juice samples, where the loss reached 46.78, 20.42, 28.26 and 28.26% for samples irradiated at 0.0, 1.5, 3.0 and 4.5 kGy, respectively. This loss in total lycopene content of irradiated samples was lower than non irradiated samples. Apparently, during further storage total lycopene content gradually decreased in all samples. This decrease may related to lycopene degradation as a result of processing and storage of tomato products **(Nguyen and Schwartz, 1999)** and the main causes of lycopene are isomerization and oxidation and the first stage of degradation is the reversible isomeriztion of all-trans-lycopene to less colored, more oxidizable cis isomers **(Boskovic, 1979).**

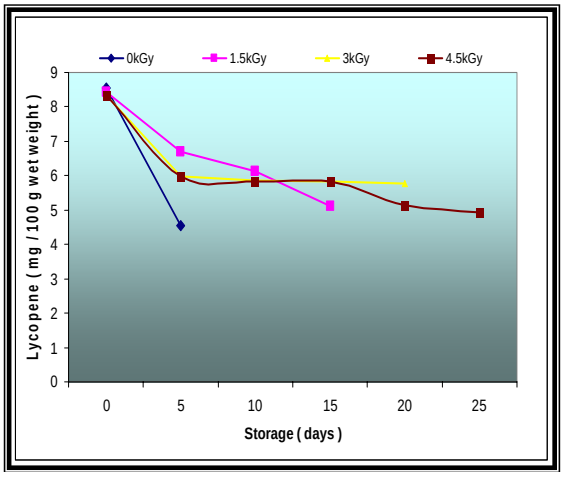

Fig (2): Lycopene content in irradiated and non-irradiated tomato juices (mg / 100 g wet weight).

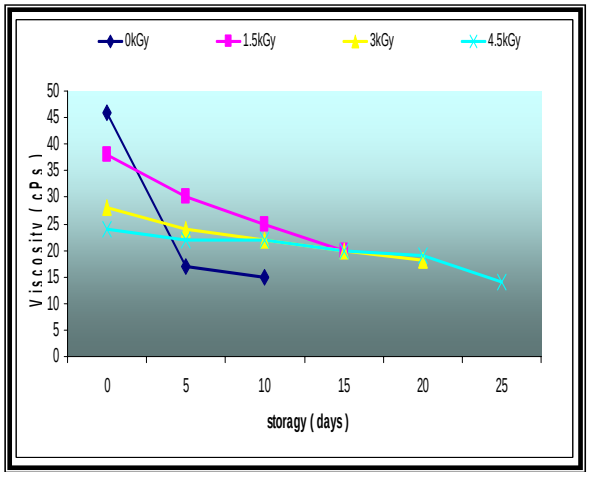

Fig (3): Viscosity (cPs) of tomato juices treated by irradiation during storage at 4°C±1 for 25 days.

Physiochemical analysis

Viscosity

The consistency of tomato juices expressed in viscosity and level of syneresis (serum separation) is important for the quality of tomato juices. Fig (3) shows the effect of irradiation on the viscosity of tomato juice, it is clear that γ irradiation significantly decreased the viscosity of the tomato juice. The consistency of tomato products is strongly affected by the composition of the pectins **(Hsu *et al.*, 2008).** Irradiation at 1.5, 3.0 and 4.5 kGy significantly lowered the viscosity (38.0, 28.0 and 24.0 cPs, respectively) against 46.0 cPs for control samples.

The irradiation of pectin in aqueous solutions caused degradation of macromolecules rather than the radiation induced desertification of polysaccharide chains which in turn caused the decrease in viscosity of pectin solution **(Zegota, 1999).** The increase in pectin methylesterase (PME) activity in response to irradiation is in sharp contrast to the behavior for polygalacturonase (PG). Increased PME activity was also reported for sweet cherries irradiated at 2.0 and 5.0 kGy **(Somogyi and Romani, 1964).**

Fig (3) also revealed that the storage for 5 days at 4°C resulted in a significant ($p < 0.05$) decrease in viscosity of all tomato juice samples (non irradiated and irradiated), where the viscosity was 17.0, 30.0, 24.0 and 22.0 cPs for samples irradiated at 0.0, 1.5, 3.0 and 4.5 kGy, respectively. The viscosity gradually decreased during further storage in all samples.

pH

Fig (4) revealed that the pH of unirradiated (control) tomato juice was 4.65 indicating acidic medium. Irradiation at 1.5, 3.0 and 4.5 kGy showed no significant effect on the acidity (pH) of the tomato juice. The results also show that there were no significant differences in pH as a result of irradiation and storage. Similar results were recorded by **Prakash *et al.* (2002)** as a result of irradiation of diced tomato.

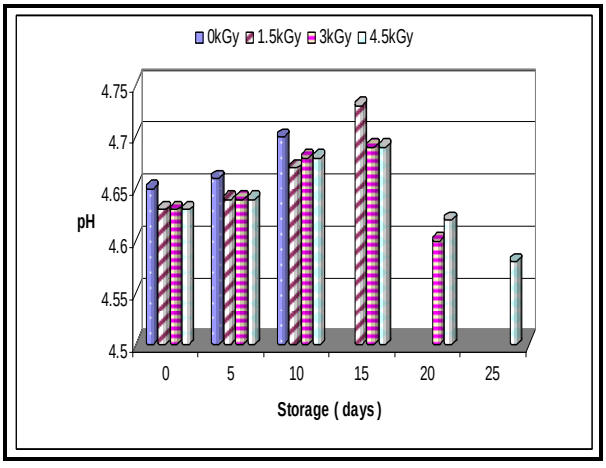

Fig (4): pH value of irradiated and non-irradiated tomato juices during storage.

Sensory evaluation

Sensory evaluation of the tomato juice was performed in the parameters of color, odor, taste, and overall acceptability. Table (3) indicated that γ irradiation at doses of 1.5 and 3.0 kGy had no significant changes in the color, odor, taste and overall acceptability. On the other hand, the highest

irradiation dose used (4.5 kGy) didn't affect the color of the tomato juice significantly but significantly affect the odor, taste and overall acceptability of tomato juice samples where the panelists gave these samples the lowest scores but still acceptable.

Table (3) also indicated that during storage, the sensory quality scores of non-irradiated and irradiated tomato juice samples decreased but at different levels. The decline of sensory scores was higher in non-irradiated tomato juice samples in comparison with irradiated ones. The sensory evaluation of irradiated diced tomatoes indicated higher dosages of gamma irradiation impacted aroma, flavor and textural properties and with increasing levels of irradiation, panelists noted a decrease in fresh tomato aroma and flavor and an increase in ripe tomato aroma **Prakash *et al.* (2002).** The non-irradiated sample was mainly rejected at the 6th day of storage. After 10 days of storage the panelists rejected non-irradiated (control) samples because of off-odor and color changes. Thus the control samples could not be used for taste evaluation at day 10 as well as the overall acceptability was bad. Thus, the panelists evaluated that the control samples could not be used for further evaluation because of the deterioration in quality and spoilage. Panelists rejected tomato juice samples receiving 1.5, 3.0 and 4.5 kGy after 15, 20 and 25 days of storage at 4°C±1, respectively. The overall sensory scores of the irradiated and non-irradiated samples of vegetable juice were not significantly different immediately after irradiation. However, the sensory quality of the non-irradiated carrot and kale juice decreased with the storage time, and it appeared to be the worst at storage of day 3 as mentioned by **Song *et al.* (2007).**

Table (3): Effects of irradiation on the sensory scores of tomato juice during storage at 4°C±1 for 25 days

Sensory parameters	Storage (days)	Irradiation dose (KGy) 0	1.5	3.0	4.5
color	0	$8.8^{a}_{a}\pm0.05$	$8.7^{a}_{a}\pm0.05$	$8.7^{a}_{a}\pm0.1$	$8.6^{a}_{a}\pm0.05$
	5	$7.5^{a}_{b}\pm0.05$	$8.3^{b}_{b}\pm0.05$	$8.4^{b}_{b}\pm0.05$	$8.3^{b}_{b}\pm0.05$
	10	$4.0^{a}_{c}\pm0.03$	$7.6^{b}_{c}\pm0.15$	$7.6^{b}_{c}\pm0.25$	$7.5^{b}_{c}\pm0.05$
	15	R	$3.9^{b}_{d}\pm0.05$	$6.4^{c}_{d}\pm0.05$	$6.3^{c}_{d}\pm0.05$
	20	R	R	$3.8^{c}_{e}\pm0.25$	$4.0^{c}_{e}\pm0.1$
	25	R	R	R	$3.7^{d}_{f}\pm0.25$
odor	0	$8.7^{a}_{a}\pm0.05$	$8.6^{a}_{a}\pm0.05$	$8.6^{a}_{a}\pm0.1$	$8.0^{b}_{a}\pm0.05$
	5	$7.4^{a}_{b}\pm0.05$	$7.9^{b}_{b}\pm0.1$	$7.9^{b}_{b}\pm0.05$	$7.2^{c}_{b}\pm0.1$
	10	$3.6^{a}_{c}\pm0.05$	$6.7^{b}_{c}\pm0.25$	$7.1^{c}_{c}\pm0.25$	$7.2^{c}_{c}\pm0.45$
	15	R	$4.0^{b}_{d}\pm0.20$	$6.6^{c}_{d}\pm0.15$	$7.1^{d}_{d}\pm0.55$
	20	R	R	$4.0^{c}_{e}\pm0.15$	$6.6^{d}_{e}\pm0.15$
	25	R	R	R	$3.9^{d}_{f}\pm0.1$
Taste	0	$8.9^{a}_{a}\pm0.05$	$8.8^{a}_{a}\pm0.05$	$8.7^{a}_{a}\pm0.1$	$8.2^{b}_{a}\pm0.05$
	5	$7.7^{a}_{b}\pm0.20$	$7.9^{b}_{b}\pm0.10$	$7.7^{c}_{b}\pm0.20$	$7.1^{d}_{b}\pm0.10$
	10	$3.7^{a}_{c}\pm0.25$	$6.7^{b}_{c}\pm0.20$	$7.2^{c}_{c}\pm0.25$	$7.2^{c}_{c}\pm0.15$
	15	R	$3.6^{b}_{d}\pm0.40$	$6.6^{c}_{d}\pm0.10$	$7.1^{d}_{d}\pm0.15$
	20	R	R	$3.9^{c}_{e}\pm0.15$	$6.3^{d}_{e}\pm0.05$
	25	R	R	R	$4.0^{d}_{f}\pm0.05$
Overall acceptability	0	$8.8^{a}_{a}\pm0.05$	$8.7^{a}_{a}\pm0.05$	$8.7^{a}_{a}\pm0.1$	$8.1^{b}_{a}\pm0.05$
	5	$7.7^{a}_{b}\pm0.20$	$7.9^{b}_{b}\pm0.10$	$7.7^{c}_{b}\pm0.20$	$7.5^{d}_{b}\pm0.05$
	10	$3.6^{a}_{c}\pm0.30$	$6.7^{b}_{c}\pm0.20$	$7.2^{c}_{c}\pm0.10$	$7.2^{c}_{c}\pm0.05$
	15	R	$3.9^{b}_{d}\pm0.40$	$6.6^{c}_{d}\pm0.10$	$7.2^{d}_{d}\pm0.10$
	20	R	R	$3.9^{c}_{e}\pm0.15$	$6.6^{d}_{e}\pm0.15$
	25	R	R	R	$3.8^{d}_{f}\pm0.10$

Where 0 (dislike extremely) to 9 (like extremely)

Corresponding author
Youssef, K.A
Microbiology Department, Faculty of Science, Ain Shams University, Cairo, Egypt.
hanan.hassan210@gmail.com

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