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Gamma irradiation in different maturity stages of tomatoes (Lycopersicon esculentum mill.)

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Abstract

Tomato, in addition to being one of the most popular vegetables in the world, is also the most productive culture for carotenoids. Like all vegetables, tomato is highly perishable, having motivated several studies in order to increase the shelf life with minimal nutritional impact. Among the techniques for preserving food available, the use of irradiation is one of the best, for its versatility and safety, and for being environmentally clean and energy-efficient. In this context, the present study had the purpose of evaluating the action of ionizing radiation in the concentrations of lycopene and β-carotene in irradiated tomatoes to 0.5 and 1.0 kGy in two maturity stages: green and red. Based on the methodology employed in this research, the use of ionizing radiation resulted in decrease in levels of lycopene and β-carotene in green as well as in red tomatoes, indicating this technique as an effective tool in the preservation of tomatoes.

Keywords: gamma irradiation, preservation of tomatoes

INTRODUCTION

Tomato is a very popular vegetable worldwide, and can be consumed fresh, in salads and sandwiches, or industrialized, in the form of juice, sauce, paste, dehydrated, sweet, among others. In parallel, this fruit has been widely studied, since it contains many antioxidants such as carotenoids, in addition to tocopherols and flavonoids, all with action for prevention of cancers, such as cervical, prostate and pancreas, and other chronic diseases; protecting the body from bacterial infections, as well as digestive and pulmonary disorders (FRUSCIANTE *et al.,* 2007; LIU & WU, 2007; MATTEDI *et al.*, 2007; FILGUEIRA, 2008; ZHENG *et al*., 2022).

The most abundant carotenoids in tomatoes are lycopene and ß-carotene, responsible, respectively, for the red and orange color variations, which represent different stages of maturation of the fruit (BAÇ; YEMIŞ; ÖZKA, 2022).

As all vegetables, tomato is highly perishable, fact that motivated several studies in order to increase the shelf life with minimal nutritional impact. Among the techniques available for preserving food, the use of irradiation, for its versatility and safety, being environmentally clean and energy-efficient, has been authorized by institutions such as the World Health Organization (OMS), Food and Agriculture

Organization (FAO), U.S. Food and Drugs Administration and the National Health Surveillance Agency (ANVISA) (BRIGIDE et al., 2006; CAMPOS, 2012; LIZARAZO-PENA; DARGHAN; HERRERA, 2022; SABATO *et al*., 2009;).

Food irradiation is a technique which consists in using ionizing radiation to increase the shelf life of foods of plant origin, promoting the inhibition of sprouting and delaying the maturation process, and generally for all foods, reducing the proliferation of pathogenic microorganisms (POLIZEL, 2006).

During the irradiation procedure, the processed food does not suffer any kind of radioactive contamination, since it is exposed to radiation without contact with the radioactive source. However, as with any other method of conservation, some characteristics of the food may be changed (POLIZEL, 2006). Thus, the Brazilian Health Surveillance Agency or ANVISA (Agência Nacional de Vigilância Sanitária) has established that all processed food should be evaluated as far as the changes in their characteristics: physical (weight, color, odor, taste, texture) and chemical (carbohydrates, proteins, lipids) and phytochemical (sucha as carotenoids, polyphenols, Terpenoids), through its RDC n° 21 of January 2001 (BRAZIL, 2001).

The versatility of the technique allows its use in vegetables and fruits, which are easily perishable, requiring conservation methods that allow a greater shelf life, after their harvest. Post-harvest losses are mainly due to injuries (mechanical, physiological and pathological) to these products (FAO, 2011). The consequences of these losses are increasing prices and economic losses to the producer, trader and, finally, consumers.

According to the report released by FAO, in 2013, about 1.3 billion tons of food were wasted in the world, which is a waste of 750 billion dollars. In Brazil, according to figures released by the NGO Food Bank, about 26.5 tons of food is wasted. The greatest loss, about 11,920,000, are of groceries, which corresponds to 45% of waste products. In Brazil, the food waste is present throughout the production chain, 10% of which occurs in the field; 50% on the handling and transport; 30% marketing and supply and 10% retail (supermarkets) and final consumer (CARVALHO, 2009).

The present work aims to evaluate the action of ionizing radiation in the concentrations of lycopene and ß-carotene in irradiated tomatoes in two different stages of ripeness and coloring, namely, "green" (green color) and "mature" (red color).

METHODOLOGY

Plant material: the experiments were conducted using tomatoes of the cultivar Debora, both green and red, about 3 days after harvest. The samples were acquired in the Supply and Logistics Center of Pernambuco (CEASA), in Recife-PE, being considered only tomatoes without apparent damage on its surface and that fit the criteria of uniformity in size and coloration, i.e. about 30 g tomatoes, with green and red colorations.

In this study, 144 tomatoes were divided into two maturity groups: green (72 tomatoes) and red (72 tomatoes). These two groups were divided into three other groups, one control (non-irradiated) and two two others which were irradiated with a dose of 0.5 kGy and 1.0 kGy, respectively. The samples were irradiated using Gammacell ^{60}Co source (model 220 Excel - MDS Nordion - COUNTRY), with 2.629

kGy/h dose-rate, in the Laboratory of the Department of Nuclear Energy of the Federal University of Pernambuco.

After irradiation, the samples were stored in the refrigerator, at the temperature of 18° (± 1) ° C, following the methodology of Castricini et al. (2004), which allows the fruit to maintain physiological characteristics during the period of study.

For the determination of concentrations of lycopene and ß-carotene, analyses in triplicate were initiated 24 hours after irradiation, and repeated every 48 h until the 15th day after the exhibition, in the Chemical Laboratory at the Catholic University of Pernambuco.

Procedure for determination of lycopene and beta-carotene

Three tomatoes were used for the measurements of concentrations of lycopene and beta-carotene, for each day and for each stage of ripening. The procedure for the determination of concentrations of these compounds followed the methodology proposed by Rodriguez and Amaya (2004).

Considering that the tomato plant tissue contains high percentage of water and that the carotenoids are fat soluble, acetone was used as a solvent Extractor, since this is an organic solvent miscible in water.

Initially, tomatoes previously sanitized, were homogenized in a blender to yield a paste-like formation. This homogenized mass was withdrawn at a rate of 08 grams, which was stored in a beaker, where 40 mL of acetone was added. The obtained solution (acetone + tomato) was transferred to a blender and homogenized again for three minutes. Then, the second homogenized solution was passed through a vacuum filtration on Whatman filter paper number 4, with the aid of a kitassato protected with aluminum foil to avoid photo-oxidation of the pigments.

After filtering, the filtrate obtained was transferred into a volumetric flask , taking care to promote washing of the kitassato with 50 ml of acetone, to ensure that all solution have been transferred to the flask . The content of the volumetric flask was added 45 mL of hexane and waited for 20 minutes for separation to occur between the phases acetone and hexane.

After separation of the hexane from acetone, the wash of the solution was performed to remove the acetone, using 100 mL of distilled water. The solution obtained, containing hexane pigment was transferred into a 100 mL volumetric flask, and completing the volume with hexane. An aliquot of 3 ml of hexane- pigment solution was taken to the spectrophotometer CINTRA 10 UV model – Visible Spectrometer for reading of the absorbance at two wavelengths: (i) 503 nm (maximum absorption for lycopene) and 451 nm (maximum absorption for beta- carotene and close to the minimum absorption for lycopene).

The concentration values of lycopene and ß-carotene were obtained from the equations (01) and (02) (Rodriguez and Amaya, 2004):

$$C_{\text{lycopene}} = 3{,}956\ A_{451} - 0{,}805 A_{503} \qquad (01)$$

$$C_{\text{ß-carotene}} = 4{,}624 \times A_{451} - 3{,}091 \times A_{503} \qquad (02)$$

Where:

- C = concentration of lycopene (Clicopeno) or ß-carotene (carotene Cß) in microgram per gram of tomato, and
- A = Absorbance for lycopene (A_{503}) or ß-carotene (A_{451}).

Statistical analyses

For comparison between the levels of lycopene and ß-carotene, before and after irradiation, and during the observation period, it was used the multiple comparisons test of Duncan, at a significance level of 5%.

It was also used a statistical multivariate analysis technique called Principal Component Analysis (PCA), to assess which between the doses applied and the time of observation had greater influence on the levels of lycopene and ß-carotene to the green and red tomatoes.

PCA is a multivariate statistical technique that aims to transform a set of original variables to another set of variables of the same dimension called principal components. These core components have important properties, such as: each main component is a linear combination of all the original variables, are independent of each other and estimated for the purpose of holding the maximum information in terms of total variation contained in data. PCA aims to reduce the quantity of data, with the lowest possible loss of information (VARELLA, 2008).

RESULTS AND DISCUSSION

Table 1 shows the values of lycopene contents obtained from samples of green and red color tomatoes, samples without irradiation and exposed to 0.5 and 1.0 kGy radiation doses. These results suggest that radiation caused a decrease in lycopene content, both for green tomatoes as red, which are statistically significant different at the 5% level.

One can see that, regardless of the treatment, the lycopene contents were increased during the observation period, with statistically significant differences at 5%. Both tomatoes green color as red coloration reached the highest lycopene levels on the 15th day of storage. However, all lycopene values differ significantly in all observation days ($p < 0.05$), in agreement with similar results obtained by Villegas et al. (1972).

Table 1: values of lycopene in tomatoes ripe and green during 15 days of storage, refrigerated, in three different treatments (non-irradiated and irradiated at 0.5 and 1.0 kGy).

Day	GREEN TOMATOES			RED TOMATOES		
	Control (non-irradiated)	0.5 kGy	1.0 kGy	Control (non-irradiated)	0.5 kGy	1.0 kGy
1	$0,191^{Bb} \pm 0.003$	$0,219^{Ae} \pm 0.002$	$0,044^{Cf} \pm 0.007$	$1,104^{Ab} \pm 0.002$	$0,156^{Cb} \pm 0.005$	$0,408^{Bb} \pm 0.001$
3	$0,965^{Af} \pm 0.003$	$0,413^{Bc} \pm 0.003$	$0,108^{Ce} \pm 0.002$	$2,947^{Af} \pm 0.002$	$0,924^{Bf} \pm 0.002$	$0,687^{Ce} \pm 0.002$
5	$0,788^{Ag} \pm 0.001$	$0,261^{Bf} \pm 0.001$	$0,109^{Ce} \pm 0.001$	$2,261^{Ae} \pm 0.001$	$0,811^{Ce} \pm 0.002$	$1,489^{Bc} \pm 0.001$
7	$1,464^{Ae} \pm 0.001$	$0,265^{Cf} \pm 0.002$	$0,284^{Bc} \pm 0.001$	$5,196^{Ae} \pm 0.002$	$1,204^{Ce} \pm 0.001$	$1,475^{Bf} \pm 0.001$
9	$1,964^{Ad} \pm 0.003$	$0,289^{Bc} \pm 0.002$	$0,273^{Cd} \pm 0.001$	$5,584^{Ad} \pm 0.001$	$1,213^{Cd} \pm 0.002$	$1,501^{Bd} \pm 0.002$
11	$2,534^{Ac} \pm 0.002$	$0,315^{Bd} \pm 0.001$	$0,318^{Bb} \pm 0.002$	$7,356^{Ac} \pm 0.002$	$1,435^{Cc} \pm 0.002$	$1,541^{Bc} \pm 0.001$
13	$3,031^{Ab} \pm 0.003$	$0,480^{Bb} \pm 0.001$	$0,403^{Ca} \pm 0.002$	$8,488^{Ab} \pm 0.001$	$1,635^{Cb} \pm 0.001$	$1,685^{Bb} \pm 0.002$
15	$3,688^{Aa} \pm 0.001$	$0,503^{Ba} \pm 0.002$	$0,285^{Ce} \pm 0.002$	$10,317^{Aa} \pm 0.015$	$1,937^{Ba} \pm 0.003$	$1,803^{Ca} \pm 0.002$

Uppercase (ABC) different horizontally in the same color and different treatments differ; and lowercase letters (abc) vertically different in the same color and the same treatment differ. Statistical analyss were performed using test of Duncan at 5% level of significance

It can be seen that, in general, there is a decrease of lycopene contents after irradiation, which is statistically proven at 5% (Table 2). Variations in decreases in lycopene content were very significant after exposure to radiation during the storage period, namely:

(i) Green tomatoes, irradiated to 0.5 kGy: ranging from 0% to 99.9%, compared to the control. To this dose, ionizing radiation at a dose of 0.5 kGy inhibited

approximately 67% lycopene content until the fifth day. From this, the inhibition was almost total, reaching 99.9%

(ii) Green tomatoes, irradiated at 1.0 kGy: variation from 77% to 99.99%. At 1.0 kGy the behavior is repeated; however, the losses in the first 5 days were more marked, ranging from 77% to 86%

(iii) Red tomatoes, irradiated to 0.5 kGy: variation of 76.83% to 99.98%. For this dosage, the reduction was almost total in the first five days. However, there was a tendency to increase the production of lycopene from the seventh day.

(iv) Red tomatoes irradiated at 1.0 kGy: variation of 34.14% to 99.98%. For this dosage, the reduction was almost total in the first three days. However, there was a tendency to increase the production of lycopene from the fifth day.

Reductions of lycopene content may indicate a possible inhibition of the synthesis of this compound, or the oxidation due to irradiation (Lima et al., 2004). As increased lycopene content is related to the ripening of tomato, inhibiting its synthesis will result in increased shelf life of the fruit. The tomato ripening begins with the decomposition process of chlorophyll through chemical and enzymatic changes, and initially this degradation process is initiated by external factors. According to Heaton, Lencki and Marangoni (1996) these factors are water stress, light, thermal changes, increased levels of ethylene or a combination of these.

With the decomposition of chlorophyll breakdown initially occurs at the oxigenolítica the macrocicloporfirínico the feoforbídeo followed by a reduction in fluorescent intensity catabolite chlorophyll. This process occurs due to the action of the enzyme oxigenase which is found only during senescence and reductase enzyme which its path depends on ferrodopina. The oxigenasse acts in the degradation of chlorophyll, while the carotenoid levels in leaf cells and fruit keps relatively constant until the beginning of senescência. When the amount of chlorophyll begins to decrease, the other colors begin to protrude (PRUZINSKÁ et al., 2003). Chlorophyll ($C_{55}H_72O_5N_4Mg$) differs from Lycopene as its molecular structure is composed of carbon, hydrogen, oxygen, nitrogen, and magnesium. When compared to other carotenoids, lycopene is a hydrocarbon that stands out for having a higher capacity to sequestrate the singlet oxygen, since it has eleven conjugated double bonds and two non-conjugated, provided this soluble molecule that has greater reactivity (ANGUELOVA & WARTHESEN, 2000).

According to Seravalli and Ribeiro (2004), the effect of light, temperature and oxidation play an important role in the degradation of carotenoids. During exposure to radiation may occur increasing temperature, beyond which, when interacting with the medium the radiation produces free radicals that promote the oxidation of the material. Thus, radiation may be causing the degradation of the carotenoids present in the irradiated tomatoes, which may explain the decrease of the lycopene content in the irradiated samples obtained in the present study (Table 2).

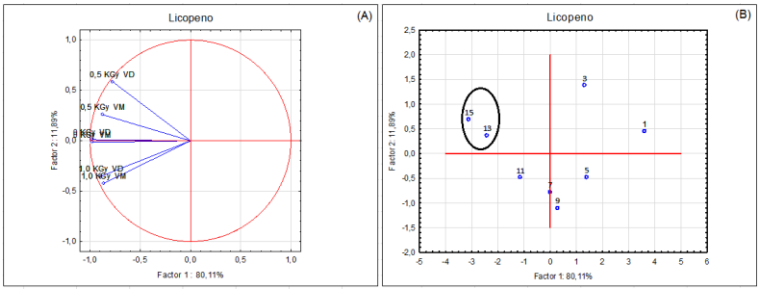
Coseteng and Lee (1987), in their studies, found that after irradiated, the respiration rate of tomatoes studied increased about twice, while the ethylene production rate was almost half that observed during the ripening of non-irradiated fruits. Villegas et al. (1972) state that the irradiation usually slows the carotenogenesis process, causing greater effects in high doses of radiation and less mature fruit. This is consistent with the results observed in this study, where it can be seen that the lycopene content in the tomatoes for the green color are smaller than those in the red

color and lycopene content in the dose of 1.0 kGy, when compared with the control, were significantly smaller for the green tomatoes (Table 1)

Damayanti, et al. (1992) studied pineapples from the "Queen" cultivar submitted to doses ranging from 0.05 kGy to 0.25 kGy kept at a temperature of 25 ° C ± 3 and obtained results similar to those presented in this work, which disclosed that gamma radiation is effective to lengthen the post-harvest storage period. Neves et al. (2002) in order to evaluate the behavior of gamma radiation in postharvest nectarine cv. "Sunred", a kind of Chinese origin peach fruit subjected to doses of 0.2 kGy, 0.4 kGy, 0.6 kGy and 0.8 kGy and stored in a cold room at 0° C temperature. The authors observed that irradiated fruits extended their shelf life and after 28 days of storage the fruits submitted to the dose of 0.4 kGy presented the best visual appearance, smaller loss of weight, and greater firmness.

The Principal Component Analysis (PCA) allowed to assess how radiation doses and observation period influenced in lycopene content. The results are summarized in Figure 1.

Figure 1 PCA applied to lycopene levels for green tomatoes (RV) and red (VM), and the influence of parameters: (A) Radiation Dose; (B) evaluation period.



The results presented in Figure 1 allow to see that both the control samples (non-irradiated), as they had similar amounts in irradiated composition of the variance (factor 1:80.11%) associated with the determination of the levels of lycopene from red and green tomatoes. Lines that represent the doses approach the line that represents the unit circle, which delimits the variables that best represent the factor. The positions of the lines of 0.5 and 1.0 kGy for tomatoes, green and red indicate that decreases the levels of lycopene were proportional to dose, the dose of 0.5 kGy, for the green tomatoes, and the dose of 1.0 kGy, for the red tomatoes, which presented the smallest loads factorials, those that least affect the levels of lycopene.

The results in Figure 1A show that both the control samples (not irradiated) and the irradiated had similar importance in the composition of variance (Factor 1: 80.11%), associated with the determination of lycopene content of green and red tomatoes. The straight lines which represent the doses approach the line which represents the unit circle, which defines the most significant variables of the factor. The positions of the lines for 0.5 and 1.0 kGy, for the green and red tomatoes, indicate that decreases in lycopene contents were proportional to the dose. Also, the dose of 0.5 kGy for green tomatoes, and the dose 1.0 kGy, for red tomatoes, are the ones which had the lowest factor loadings, i.e. the ones that least affected the lycopene content.

Referring to Figure 1B, the position of the reference points for the 13th and 15th days of observation, which are most distant from the 0 vertical line relating to Factor 1, indicate that lycopene concentrations were the most representative for forming the major component in these days , independent of dose, both for green tomatoes as well as red.

Table 2 shows the values of ß-carotene contents obtained from samples of green and red color tomatoes, before and after exposure to 0.5 and 1.0 kGy radiation doses. It is noticed that the radiation caused a decrease in ß-carotene concentrations for both green tomatoes as for red, which are statistically significant different at the 5% level.

As has occurred for lycopene, the levels of ß-carotene increased throughout the observation period, being statistically significant different at the level of 5%, regardless of the treatment applied. Both the green tomatoes as the red reached the highest levels of ß-carotene on the 15th day of storage. However, all the ß-carotene values differed significantly from each other in every day of observation ($p < 0.05$), with the exception of irradiated red tomatoes at 1.0 kGy which showed similar levels of ß-carotene on the 1st, 11th and 13th days of storage.

Villegas et al. (1972) observed that the largest changes in the levels of ß-carotene occurred for the largest doses. However, in this study, the dose of 0.5 kGy promotes a decrease of these contents, but the 1.0 kGy dose promoted a greater production of ß-carotene (after the initial decrease with 0.5 kGy), mainly in the last 5 days of storage for the green tomatoes and since the first day of observation for the red tomatoes, which suggests that this dose would be more efficient to keep the red tomatoes after harvesting, since it decreases more markedly the levels of lycopene and less markedly the levels of ß-carotene.

Table 2: values of β-carotene in green and ripe tomatoes during 15 days of refrigerated storage in three different treatments (non-irradiated and irradiated at 0.5 and 1.0 kGy)

Assessment day	GREEN TOMATOES			RED TOMATOES		
	Control (non-irradiated)	0,5 kGy		Control (non-irradiated)	0,5 kGy	
1	$0,242^{Ah} \pm 0.0006$	$0,042^{Bh} \pm 0.0006$	$0,032^{Ch} \pm 0.0006$	$1,242^{Ae} \pm 0.0598$	$0,590^{Be} \pm 0.0021$	$1,308^{Ae} \pm 0.0006$
3	$0,998^{Af} \pm 0.0017$	$0,256^{Bg} \pm 0.0011$	$0,088^{Cg} \pm 0.0017$	$3,327^{Af} \pm 0.0012$	$0,804^{Bf} \pm 0.0001$	$1,419^{Be} \pm 0.0017$
5	$0,803^{Ag} \pm 0.0001$	$0,192^{Bg} \pm 0.0015$	$0,130^{Cf} \pm 0.0010$	$4,682^{Ab} \pm 0.0015$	$0,368^{Bh} \pm 0.0006$	$1,224^{Cg} \pm 0.0010$
7	$1,353^{Ae} \pm 0.0015$	$0,203^{Bg} \pm 0.0020$	$0,211^{Cd} \pm 0.0021$	$5,784^{Aa} \pm 0.0006$	$0,878^{Be} \pm 0.0017$	$1,218^{Cg} \pm 0.0001$
9	$1,551^{Ad} \pm 0.0036$	$0,293^{Bd} \pm 0.0017$	$0,174^{Ce} \pm 0.0001$	$6,312^{Ad} \pm 0.0010$	$0,935^{Bd} \pm 0.0010$	$1,254^{Cd} \pm 0.0015$
11	$1,745^{Ac} \pm 0.0015$	$0,327^{Bc} \pm 0.0006$	$1,130^{Cc} \pm 0.0017$	$7,502^{Ac} \pm 0.0010$	$1,045^{Bc} \pm 0.0006$	$1,305^{Cc} \pm 0.0026$
13	$2,016^{Ab} \pm 0.0010$	$0,471^{Bb} \pm 0.0010$	$1,536^{Cb} \pm 0.0006$	$8,138^{Ab} \pm 0.0006$	$1,132^{Bb} \pm 0.0010$	$1,317^{Cc} \pm 0.0006$
15	$2,452^{Aa} \pm 0.0006$	$0,602^{Ba} \pm 0.0020$	$1,853^{Ca} \pm 0.0010$	$9,271^{Aa} \pm 0.0015$	$1,316^{Bb} \pm 0.0025$	$1,345^{Cb} \pm 0.0015$

Uppercase (ABC) different horizontally in the same color and different treatments differ; and lowercase letters (abc) vertically different in the same color and the same treatment differ. Statistical analyses were performed using statistical test of Duncan at 5% level of significance.

In general, there is a decrease levels of ß - carotene with the radiation exposure, which is statistically proven at 5% (Table 2). Variations in decreases in ß-carotene concentrations were very significant after exposure to radiation during the storage period, namely:

(i) green tomatoes irradiated to 0.5 kGy: variation of 74.3% to 99.9%, compared to the control. To this dose, ionizing radiation inhibited from 74.3% to 82.6% of ß-carotene content by the fifth day. Thereafter tomatoes showed inhibition in the production of this compound.

(ii) green tomatoes irradiated at 1.0 kGy: variation of 24.4% to 99.9%. To this dose, inhibiting the production of ß-carotene was more pronounced until the ninth day. From there on the tomatoes began to produce ß-carotene.

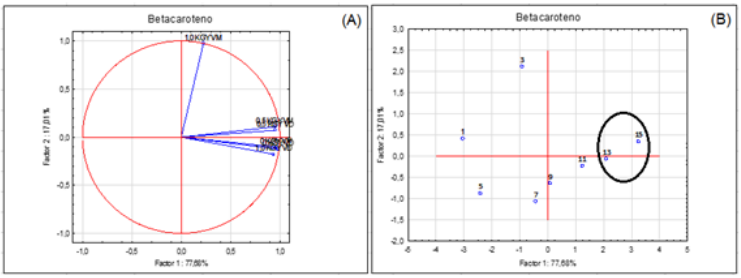
(iii) red tomatoes irradiated to 0.5 kGy: variation of 85.8% to 99.9%. To this dose inhibiting the production of ß-carotene was almost complete until the ninth day, and from there it is noticed a tendency to produce this compound.

(iv) red tomatoes irradiated at 1.0 kGy: variation from 0% to 85.5%. To this dose there was no inhibition on the production of ß-carotene on the first day of observation. From the third day, the inhibition was 57% and it was increased up to 85.5% on the last day of observation.

Lima et al. (2011) evaluated the levels of carotenoids and ascorbic acid in fruit irradiated with doses of 0.5 kGy 1.0 kGy and verified that the dose of 1.0 kGy showed a reduction in levels of ß - carotene. Taipina and Mast (2003), studied the influence of gamma radiation on the levels of vitamin A and ß - carotene in marketed animal foods, in particular fresh beef liver and pork like "gras pâté. They found that for these samples there was a complete retention in the content of these compounds for a dose of 3 kGy and there was a loss of about 60% ß - carotene when the dose was 30 kGy.

Figure 2 presents the PCA results applied to assess how the radiation doses and the observation period influenced in ß-carotene content.

Figure 2: PCA applied to β-carotene levels for green tomatoes (VD) and red (VM), evaluating the influence of parameter: (A) radiation dose; (B) evaluation period



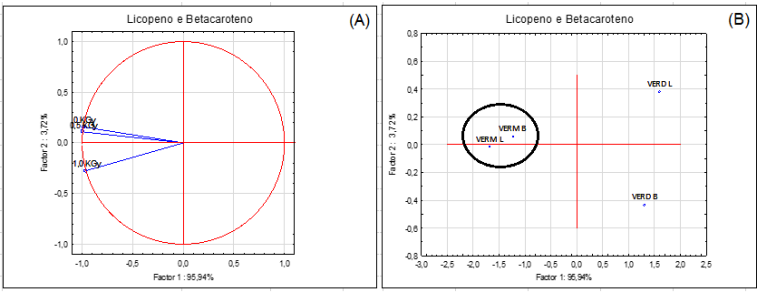
From Figure 2A, it is possible to observe the behavior of radiation doses. The figures indicate that both the control as well as radiation doses contributed equally to the composition of the variance (factor 1: 77.66%) in the determination of ß-carotene content of green and red tomatoes. The straight lines represent the doses approaching the line which represents the unit circle, which defines the most significant variables for the factor. The positions of the lines 0.5 kGy and 1.0 kGy for the green and red tomatoes (Figure 2A), indicate that the dose of 1.0 kGy to red tomatoes, showed the lowest load factor, ie less affected ß-carotene levels for these tomatoes.

In Figure 2B, the placement of points for the 13th and 15th days of observation, which are more distant from the 0 of the vertical line for factor 1, indicate that ß-carotene concentrations were higher in these days, regardless of the dose, for red and green tomatoes.

Figure 3 presents the results of the PCA, which allowed verifying which, among the levels of lycopene and ß-carotene was more influenced by doses of radiation. As discussed above, it appears that the control and the doses had equal importance in

the composition of the variances of the factors analyzed. However, it becomes more evident that the red tomatoes were the most affected by radiation with respect to variations of the levels of ß-carotene and lycopene (Figure 3B).

Figure 3: (A) radiation dose Influence on the lycopene and β - carotene contents (B) tomatoes most affected by the radiation dose from the Principal Component Analysis (PCA). VERD L and VERD B and REDL and RED B, refer to the determination of lycopene and β-carotene



The results show that radiation doses caused inhibition of lycopene and ß - carotene in tomatoes, but acted differently between the green and red tomatoes. At a dose of 0.5 kGy green tomatoes underwent a less marked decrease of lycopene until the fifth day. Thereafter inhibition was almost total, reaching 99.9%. As for red tomatoes, lycopene was immediately inhibited and was produced from the fifth day of storage, but in low amounts. This inhibition of lycopene content and ß - carotene are possibly linked to the fact that radiation is inhibiting the fruit ripening process, ie, extend shelf life, which from an economic point of view it is feasible to avoid, for example, loss during transport. For the ß - carotene at a dose of 0.5 kGy the results showed that radiation promoted the inhibition of this compound in green tomatoes until the fifth day, but this inhibition became almost complete from the seventh day. For red tomatoes, it was observed an almost complete inhibition until the ninth day, and thereafter there was a tendency for the production of such compound, but in low concentrations.

At a dose of 1.0 kGy, green tomatoes underwent more intensive inhibition in lycopene content until the fifth day than the dose of 0.5 kGy. From there the inhibition was almost total, reaching 99.9%. As for red tomatoes, lycopene was immediately inhibited until the first three days of storage, but started to be produced from the fifth day of storage, but in low concentrations.

On the ß-carotene, for 1.0 kGy, the results showed that the inhibition of this compound promoted radiation in green tomatoes until the ninth day, but kept the same not being produced in significant quantities from the eleventh day to the red tomatoes, it was observed that there was no change in the levels of ß-carotene on the first day of evaluation. However, these levels were decreasing gradually, 85.5% on the fifteenth day of storage.

For ß-carotene at the dose of 1.0 kGy, the results showed that radiation promoted the inhibition of this compound in green tomatoes until the ninth day, but did not prevent the production in significant quantities from the eleventh day on. For red tomatoes, there was no change in ß-carotene content in the first day of evaluation. However, these levels were decreasing steadily, reaching 85.5% in the fifteenth day of storage.

It is worth noting, as highlights Von Elbe (2000), that the pH interferes with the decomposition of tomatoes and at a basic pH (9.0) chlorophyll becomes more stable to heat when compared to acid pH (3.0). As carotenoids accumulate in chloroplast of all green plants, when the molecule of chlorophyll is broken gives rise to ß-carotene and lycopene, which allow the tomatoes to acquire the colors orange and red, related to tomato ripening and mature, respectively.

By analyzing the concentration of ß - carotene in tangerine and pineapple after they received a dose of 2.45 kGy, Who (1994) noted that they did not show significant changes in their levels. Kilcast (1992) observed that exposure of mangos to a 2.0 kGy radiation did not change the concentration of ß-carotene, while Cia et al. (2000) recommend doses of radiation ranging from 0.5 to 2.0 kGy in the control of Botritiscinerea in grape of the type named 'Italy'.

A study by Germano et al. (1996), with avocados of the cultivar ' Fortune ', subjected to radiation doses showed that the doses of 0.08 kGy and 0.1 kGy promote an increase in the period of storage under refrigeration. Control samples remained firm for seven days as that irradiated obtained four and eight days more respectively for each dose.

CONCLUSION

Irradiation of tomatoes, both in green as red, resulted in decreased levels of lycopene and ß-carotene, significantly improving the shelf life of this fruit. Furthermore, multivariate analysis of principal components (PCA) emphasized that the green tomatoes were the specimen that provided the better results after irradiation, as well as 1.0 kGy is the dose level the most effective for conservation of tomatoes.

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