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Physico-chemical properties of irradiated fresh tomatoes

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This study aimed to evaluate the effect of various levels of gamma irradiation on the physico-chemical composition of fresh tomatoes. Tomato samples were irradiated in a Co-60 gamma irradiator and maintained at 25 ± 2°C storage conditions. The experiment was designed with five treatments of radiation dose (0, 0.5, 0.75 1.0, 1.5, and 2 kGy). Before irradiation, the initial composition of physico-chemical properties were analyzed (pH, TSS, TTA, moisture, Vitamin-C, lycopene, and β-carotene). The repeated analysis of the physico-chemical properties of tomato fruits was done after 7, 14, 21 and 28 days. The results showed a significant difference between non-irradiated and irradiated tomatoes in vitamin-C and lycopene content. No significant differences for pH, moisture, TSS, acidity and β-carotene were noted. The observation shows that vitamin C in tomatoes is affected by irradiation dose with respect to storage time, while maintaining most of the physico-chemical composition; hence, the technology of radiation was effective in preserving the nutritional composition of tomatoes.

Key words: Physico-chemical analysis, Gamma irradiation, storage period, tomato.

INTRODUCTION

Tomato (*Lycopersicon esculentum*) is one of the most perishable crops with high postharvest losses (Arah et al., 2015). Tomatoes and tomato products provide a wide variety of nutrients and other compounds with many health benefits to the body (Gyimah et al., 2020). Tomatoes may play a preventive role against non-communicable diseases and in reducing the risk of certain cancers (Loro et al., 2018). These fruits can be consumed in many ways; salads, sandwiches, sauces, soups, and juices. Tomatoes are good source of vitamins A and C and other vitamins and minerals. It contains minerals, such as phosphorus, potassium, folate, and high levels of the antioxidants such as β-carotene and lycopene (Barrett and Lloyd, 2012). Tomato is a short-term storable crop where losses associated is mainly due to their perishability. The food irradiation using gamma rays technique is one of the preservation methods which can be used to extend the storage duration while maintaining the sensory quality of tomatoes.

The gamma technique stated earlier is used to eliminate and inactivate the spoilage and pathogenic microorganisms, without causing any adverse effect on the nutritional and sensory quality of fruit and vegetables (Ambika et al., 2019). The elimination of pests on agricultural commodities is mainly achieved by using irradiation technology, chemical fumigants, and additives

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thus reducing food losses, (Singh and Singh, 2019). The Joint Expert Committee of Food Irradiation (JECFI, 1980) convened by the Food and Agriculture Organization (FAO), the World Health Organization (WHO, 1981) and the International Atomic Energy Agency (IAEA, 2015) concluded 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. Also, JECFI (1980) studies indicated minimum losses for micronutrients as well as vitamin losses due to irradiation doses even above 10 kGy (Singh et al., 2016). Moreover, gamma irradiation has been shown to be effective in extending the shelf life of tomatoes by slowing down their rapid maturation. Mazumder and Misran (2022) review article reported that tomato cultivars "Amani," "Beto 86," and "Pusa Rubi" were purchased from a local market and irradiated at doses between 0.75 and 1.0 kGy. The shelf life of tomatoes was increased, and the spoiling microorganisms were dramatically decreased. For a very long time, it was difficult for the tomato growers in Tanzania to find in the market for their goods. The tomato fruit went bad during storage or transit, or there were no purchasers and therefore a large amount of it ended up in the garbage dump. Or the farmers would have had to undervalue their products. Several studies have been done on food irradiation, but very little information is available on the quality properties of tomato fruits treated with gamma irradiation. Therefore, this study aimed to evaluate the effect of gamma irradiation on the nutritional physicochemical properties of fresh tomatoes “Tanya” during storage.

MATERIALS AND METHODS

Study area

The study was conducted in Morogoro municipality and Arusha city, Tanzania. The purpose of selecting these two regions was based on the availability of key respondents at Arusha city and for Morogoro selection it was based on the convenience and availability of laboratory for experiment layout, chemical, and microbial analysis at the Sokoine University of Agriculture. Morogoro is located at Latitude -6° 49' to 15.67" S and Longitude 37° 39' to 40.39"E. Arusha urban district lies between 3°23′ to 12.93 North latitude and 36°40′ to 58.77 East longitude. The area is chosen because it is located near the head office of the Tanzania Atomic Energy Commission which is the Regulatory Authority for controlling the peaceful use of radiation which enables the researcher to access some information from the authority.

Sampling procedure

A total of 100 ripe tomatoes fruits samples of one variety (Tanya) with uniform size and no sign of physical damage or spoilage were purchased from the local market at Dar es Salaam, then cleaned with tap water to remove soil and extraneous matter. Tomatoes were randomly divided into five (5) groups, each group containing 20 tomatoes packed in polyethylene plastic then packed in a box and transported to South Africa for irradiation treatment. Each group was labeled according to the dose required and stored in the controlled room (25±2°C). The irradiation treatments were carried out at the laboratory of the Agricultural Research Council, Infruitec/ Nietvoorbij, Stellenbosch, Western Cape, South Africa. All irradiated tomato fruits were packed in a box and stored in a controlled room (25±2°C) at Agricultural Research Council, Infruitec/Nietvoorbij, Stellenbosch before being transported back to Tanzania for laboratory analysis which takes 3 h by flight to reach to Tanzania physico-chemical properties analysis was conducted at the Sokoine University of Agriculture laboratory in the Department of Food Technology, Nutrition, and Consumer Sciences.

Irradiation treatment

The irradiation treatment was carried out in a Co-60 gamma-ray source, model JS-7 400, with 23 000 Ci of activity. Geiger muller counter dosimeters were used to calibrate the irradiation area and the distribution of doses. The points of minimum radiation doses (Dmin) and maximum radiation doses (Dmax) were determined. The dose rate was measured 2 kGy/ h and used to calculate the exposure times for irradiation doses.

Tomatoes were placed in a plastic bag and the distance between the samples and the source of radiation was 20 cm. To ensure the accuracy of the radiation dose delivered, tomatoes irradiated in the plastic bags were divided into five groups with twenty fruits per bag. The plastic bags containing tomatoes were placed inside the Sadolin and then were placed on the lower conveyor of the facility at a distance of 20 cm from the Co-60 source so that the center of the Sadolin coincided with the center of the radiation source to achieve homogeneous irradiation in each treatment. The irradiator was stopped and the Sadolin was rotated 180 after half of the total exposure time for each radiation dose. The radiation doses were verified by Geiger muller counter dosimeters placed on the tomatoes.

The tomatoes of variety Tanya were distributed in five levels of radiation treatments in a complete randomized design (CRD) with three replications for each dose. The irradiation doses used for the treatment were 0.5, 0.75, 1.0, 1.5, and 2 kGy. After irradiation, the tomatoes were kept separately under an ambient temperature of 25°C ± 2 for 28 days (It is only the days in the laboratory after received back from South Africa).

Sample preparation

The tomato fruits were ground and crushed by using a blender (NFM-3003; NUC Electronics Company Limited, Korea), then squeezed to obtain the juice out of the pulp for analysis. The juice was filtered through filter papers 125 mm in diameter and clear juice was obtained for the analysis of nutritional physicochemical properties. All nutritional physicochemical property analyses described were conducted on the irradiated tomatoes as well as on the non-irradiated tomato sample (the control sample).

pH

The pH was determined by using a pH meter (Model 3305, Jenway Cole-Parmer Ltd, United Kingdom) after calibrating with a standard buffer of pH 4.00 and 7.00 as described by Obadina et al. (2018). A sample of 5 g of tomatoes and 95 ml of distilled water were blended to get 100 ml. The pH meter probe was immersed in a solution prepared to measure the pH and the value was recorded in triplicate for each sample.

Titratable acidity (TTA)

Titratable acidity (TTA) was conducted according to the procedure described by Maul et al. (2000). Ten milliliters of extracted tomato juice was mixed thoroughly with 50 ml of distilled water in a 100 ml conical flask and titrated against 0.1 N NaOH with three drops of phenolphthalein indicator. This continued until a pH of 8.1 was attained. Since citric acid is the most abundant organic acid in tomatoes, the titratable acidity was expressed in the percentage of citric acid. The milli-equivalent weight of citric acid used was 0.06404 and values were recorded in triplicate (AOAC, 2005). The acidity of the samples was calculated according to Equation 1.

$$\text{Citric acid }\% = \frac{\text{Volume of NaOH (mls)} \times 0.1\text{N} \times 0.064\text{g} \times 100}{\text{Volume of sample (mls)}} \tag{1}$$

Ascorbic acid

Ascorbic acid (Vitamin-C) was determined according to the method described by AOAC (2005) number 967.21, which is based on the reduction of 2, 6-dichlorophenol-indophenol (DCPIP) by ascorbic acid. About 10 g of tomato were placed in a conical flask containing 50 ml of 1% oxalic acid. The contents were filtered into a 25 ml flask, completed to volume with oxalic acid, and 10 ml titrated with a 0.2 % solution of 2, 6-dichlorophenol-indophenol until the appearance of a pink color endpoint. The results were expressed in milligrams of ascorbic acid per 100 g of sample (mg 100 g-1).

Moisture content

The moisture content of the fresh tomatoes was determined by oven method number 934.01 (AOAC, 2000). Three grams of fresh tomatoes were placed in a dry dish of known weight. The dishes with samples were placed in an oven preset at 105°C. After 4 h the dishes were removed from the oven and placed in a desiccator to cool for taking the weight of the dry sample. The moisture content of each sample was calculated by the following formula:

$$\%\text{Moisture} = \frac{W_1 - W_2}{W_1} \times 100 \tag{2}$$

where W1 is the weight of the sample (g) before drying and W2 is the weight of the sample (g) after drying.

Lycopene

Lycopene content was determined according to Eletr et al. (2017) and Owureku-Asare et al. (2014). A sample of 2 g was weighed and 50 ml of petroleum ether extract was introduced in each bottle. The mixture was shaken vigorously by using an orbital shaker (KS501 digital IKALABORTECHNIK, Japan) at 150 rpm for 20 min and 10 g of anhydrous Sodium Sulphate was added then filtered through filter papers (125 mm Diameter × 100 Circles 4 Whatman). The wavelength of the extract was read at 470 nm ultraviolet-visible spectrophotometer (Model X-ma 3 000 series, Human Corporation, South Korea). The total lycopene content was calculated using the formula Equation 3 and expressed in mg/100 g of fresh weight (FW).

$$\text{Total lycopene content}\left(\frac{\mu g}{g}\right) = A \times V(ml) \times \frac{10^4}{A1\%_{1cm}} \times \textit{sample weight}\ (g) \tag{3}$$

where A = absorbance at 470 nm, V = total volume of tomato extract (50 ml), and $^{A1\%}{}_{1cm}$ = absorption coefficient of lycopene in PE (3450).

The result was multiplied by 0.1 to get the total lycopene content in (mg/100 g) of fresh weight (FW).

Total soluble solids

Tomato fruit samples were selected, washed, sliced, blended, and filtered through filter papers 125 mm in diameter and clear juice was obtained for the analysis of TSS according to the procedure described by Maul et al. (2000). The total soluble solid was measured from the already extracted tomato juice using a portable digital refractometer (PAL-1 model Cat. No.3810, made by ATAGO Company Limited, Tokyo, Japan). The readings were recorded in triplicate and results were expressed in % Brix.

β-carotene

β-carotene content was determined according to Eletr et al. (2017) and Owureku-Asare et al. (2014). A sample of 2 g was weighed and 50 ml of petroleum ether extract was introduced in each bottle. The mixture was shaken vigorously by using an orbital shaker (KS501 digital IKALABORTECHNIK, Japan) at 150 rpm for 20 min and 10 g of anhydrous Sodium Sulphate was added then filtered through filter papers (125 mm Diameter × 100 Circles 4 Whatman). The wavelength of the extract was read at 470 nm ultraviolet-visible spectrophotometer (Model X-ma 3 000 series, Human Corporation, South Korea). The β-carotene content was calculated using the formula Equation 4 and expressed in mg/100 g of fresh weight (FW).

$$\text{Total }\beta-\text{carotene content}\left(\frac{\mu g}{g}\right) = A \times V(ml) \times \frac{10^4}{A1\%_{1cm}} \times \textit{sample weight}\ (g) \tag{4}$$

where A = Absorbance at 550 nm; V = Total volume of tomato extract (50 ml); $^{A1\%}{}_{1cm}$ = absorption coefficient of lycopene in PE (3450).

The result was multiplied by 0.1 to get the total β-carotene content in (mg/100 g) of fresh weight (FW).

Statistical analysis

The Analysis of Variance (ANOVA) was used to test the significance of treatment effects on physico-chemical properties content as parameters for nutritional quality ($P < 0.05$) and a comparison of treatment means were done by Duncan New Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Effects of radiation dose on physicochemical properties

A total of 100 tomato fruit were irradiated and stored in a controlled room environment at 25 ± 2°C. From five groups of samples, one tomato fruit was chosen at random for analysis among those which were suitable for consumption. The physicochemical analyses were carried out for all treatments for the three storage times. The properties analyzed were pH, total soluble solids (TSS), total treatable acidity (TTA), moisture content, ascorbic acid, β- carotene, and lycopene. The results on the physicochemical parameter are shown in each storage time (pH, moisture content, β-carotene, lycopene, Vitamin C, pH, titratable acidity, and Total Soluble solids). The results were compared with non-irradiated tomatoes to see the impact of irradiation on physicochemical properties.

pH

The results show radiation dose has no significant effect on tomato pH for each storage time (0, 7, 14, and 28 days) Table 1. Exceptional was observed after 21 days of storage whereby there was a slight difference between control samples and tomato samples treated with 0.5 kGy radiation dose (Table 1). Similar results were reported by Sing et al. (2016), that there is a slight difference in pH value after irradiation. The pH of fresh tomatoes from this study was is in the range of 3 to 4.9. Akusu et al. (2016), highlighted that the pH range for fruits and vegetables was in the range of 3 to 5. According to Loro et al. (2018), the maturity processes a slight increase in pH values with the maturing process, because their ability to synthesize organic acids became less than the consumption of these substances. This observation contributed to the high acidity present in tomatoes. A similar finding was reported by Akusu et al. (2016) and Rodriguez-Lafuente et al. (2010) that irradiated fruit and vegetable fruits stored under ambient temperature conditions have no effects on pH. Moreover, the same results were observed by Gyimah et al. (2020) that storage time has no significant effect on tomatoes' pH.

Acidity

The result shows that the TTA of the non-irradiated (control sample) was 0.46% and irradiated tomatoes ranged from 0.35 to 0.43%. However, no significant difference was observed in TTA between treatments ($P < 0.05$) (Table 1). Unrelated findings were reported in the study done by Castricini et al. (2004), where the difference was detected for 0.5 and 1.5 kGy. Moreover, De Castro et al. (2006) observed the TTA decreased in the 7 days storage period. Studies highlighted that this decrease during maturity because organic acids are substrates of respiration, hence acids are converted into salts and sugars by enzymes (Singh et al., 2016).

Moreover, during ripening, all tomatoes increase short at the breaker stage and a continuous decrease subsequently of TAA was reported by Adam et al. (2014).

Vitamin C

In the control sample, the level of vitamin C is significantly ($P <0.05$) high compared to the level of irradiated tomatoes and this was observed in all days of storage and with respect to their dose. Before extending the storage time (day 0) there is about a 9% significant decrease in vitamin C when 2 kGy was applied to fresh tomatoes. Similar trends were observed after 7, 14, 21, and 28 days of storage. The results indicate that after 14 days of storage vitamin C decreased significance with dose, as the dose increased the level of vitamin C decreases from 12.06 to 11.46 mg/100 g before the extent of the storage time when 2 kGy radiation dose was applied (Table 1). Related results reported by Kirthy (2012), showed that the reduction of vitamin C in tomatoes is affected by both levels of irradiation and storage time. The same result was reported by Adam et al. (2014) who found decreases in vitamin C in irradiated tomatoes in all irradiation treatments from day 0 to day 24 of the storage period. Also, the reduction of the content of vitamin C is attributed to the biochemical process leading to the spoilage of fruits. Adam et al. (2014) uphold that the loss in vitamin C content during storage is attributed to the increase in ascorbate oxidase activity. Further, the destruction of vitamin C is a consequence of the alteration of fruit’s metabolic oxidation pathways by radiation, which converts vitamin C into dehydroascorbic acid and still is metabolized as vitamin C (Adam et al., 2014).

According to Fernandes et al. (2018), all forms of food processing affect nutritional and organoleptic properties for example cooking, canning, pasteurizing, or blanching the same as the irradiation process some of these nutrients can be lost. Vitamin loss is the largest nutritional concern associated with food irradiation. Shea et al. (2000) reports that water-soluble vitamins, such as B vitamins and vitamin C are the most affected because these vitamins are oxidized during irradiation, although the loss of vitamins with irradiation is not considered greater than that with conventional heat processing. Unrelated findings were reported by Iqbal et al. (2016), that no significant change in vitamin C when 6 kGy was applied.

Moisture content

Table 1 present the effect of gamma radiation doses (kGy) on the moisture content of tomato fruits stored at ambient temperature (25±20C). Tomato fruits irradiated at 1.5 kGy recorded slightly higher percentage moisture content on days 0 and 14, which were 96.45% and 96.58% than those treated with 0.5 and 2 kGy which were 95.18 and 95.49% respectively.

This result concurred with the findings of Wilkerson et al. (2013) who found that the percentage of moisture in tomatoes in the control was 91.87 in 0.25 kGy dosage and decreased insignificantly from 92.7 to91.13 at 0.75 kGy. The results show that the percentage of moisture

Table 1. Effect of radiation doses on Physical chemical properties of Tomatoes (After 0 -28 Days)

Radiation (kGy)	Physical chemical properties of Tomatoes							
	storage period (Days)	PH	TA (%)	Vitamin C (mg/100g)	Moisture	Lycopene (mg/100g)	TSS	β-carotene (mg/100 g)
	0	$3.99^{a} \pm 1.15$	$0.46^{a} \pm 0.04$	$11.54^{b} \pm 0.23$	$95.06^{a} \pm 0.2$	$3.40^{a} \pm 0.3$	$3.38^{a} \pm 2.1$	$0.31^{ab} \pm 0.1$
Control	7	$4.90^{a} \pm 0.15$	$0.48^{a} \pm 0.1$	$11.67^{a} \pm 0.3$	$94.95^{a} \pm 0.1$	$3.04^{a} \pm 0.01$	$4.57^{a} \pm 1.3$	$0.28^{a} \pm 0.1$
	14	$4.37^{a} \pm 1.13$	$0.41^{a} \pm 0.1$	$12.46^{ab} \pm 0.3$	$94.97^{a} \pm 0.7$	$3.58^{a} \pm 0.2$	$5.73^{a} \pm 1.2$	$0.32^{a} \pm 0.33$
	21	$4.37^{a} \pm 1.13$	$0.41^{a} \pm 0.1$	$12.46^{ab} \pm 0.3$	$94.97^{a} \pm 0.7$	$3.58^{a} \pm 0.2$	$5.73^{a} \pm 1.2$	$0.32^{a} \pm 0.33$
	28	$3.67^{a} \pm 0.1$	$0.40^{a} \pm 0.12$	$12.79^{a} \pm 1.5$	95 .1$^{a} \pm 0.2$	$3.86^{a} \pm 0.2$	$5.73^{a} \pm 0.5$	$0.34^{a} \pm 0.9$
	0	$4.23^{a} \pm 0.20$	$0.48^{a} \pm 1.10$	$10.97^{ab} \pm 1.0$	$95.18^{a} \pm 1.0$	$2.87^{a} \pm 0.4$	$3.28^{ab} \pm 1.0$	$0.31^{ab} \pm 0.3$
0.5	7	$3.66^{a} \pm 0.17$	$0.39^{a} \pm 0.05$	$11.27^{ab} \pm 0.5$	$94.81^{a} \pm 0.1$	$2.96^{a} \pm 1.5$	$4.47^{a} \pm 3.0$	$0.33^{a} \pm 0.05$
	14	$4.38^{a} \pm 0.17$	$0.42^{a} \pm 0.06$	$12.57^{ab} \pm 1.2$	$94.81^{a} \pm 1.3$	$3.38^{a} \pm 0.1$	$4.90^{a} \pm 1.2$	$0.34^{a} \pm 0.05$
	21	$4.38^{a} \pm 0.17$	$0.42^{a} \pm 0.06$	$12.57^{ab} \pm 1.2$	$94.81^{a} \pm 1.3$	$3.38^{a} \pm 0.1$	$4.90^{a} \pm 1.2$	$0.34^{a} \pm 0.05$
	28	$3.49^{a} \pm 0.34$	$0.43^{ab} \pm 0.10$	$12.80^{ab} \pm 1.0$	$96.1^{a} \pm 0.3$	$4.01^{a} \pm 0.1$	$5.56^{a} \pm 0.3$	$0.38^{b} \pm 0.9$
	0	$3.90^{a} \pm 1.36$	$0.47^{a} \pm 0.05$	$11.40^{b} \pm 0.1$	$94.89^{a} \pm 0.5$	$3.09^{a} \pm 0.4$	$3.97^{ab} \pm 0.9$	$0.27^{a} \pm 0.1$
0.75	7	$4.39^{a} \pm 0.15$	$0.47^{a} \pm 0.1$	$11.25^{ab} \pm 0.1$	$95.31^{a} \pm 0.9$	$3.25^{ab} \pm 0.4$	$4.23^{a} \pm 0.2$	$0.27^{a} \pm 0.1$
	14	$4.38^{a} \pm 1.15$	$0.37^{a} \pm 0.12$	12.32a±1.1	$95.31^{a} \pm 0.1$	$3.05^{a} \pm 0.1$	$5.50^{a} \pm 1.2$	$0.29^{b} \pm 0.1$
	21	$4.38^{a} \pm 1.15$	$0.37^{a} \pm 0.12$	$12.32^{a} \pm 1.1$	$95.31^{a} \pm 0.1$	$3.05^{ab} \pm 0.1$	$5.50^{a} \pm 1.2$	$0.29^{b} \pm 0.1$
	28	$3.38^{a} \pm 0.92$	$0.30^{ab} \pm 0.12$	$11.68^{ab} \pm 0.1$	$96.07^{a} \pm 1.0$	$3.72^{a} \pm 0.5$	$4.33^{a} \pm 1.9$	$0.34^{a} \pm 1.2$
	0	$3.76^{a} \pm 0.21$	$0.43^{ab} \pm 0.10$	$10.92^{ab} \pm 2.0$	$95.04^{a} \pm 1.0$	3.16 $^{a} \pm 0.2$	$2.94^{a} \pm 1.0$	$0.26^{a} \pm 0.3$
1	7	$4.93^{a} \pm 0.25$	$0.46^{a} \pm 0.0$	$11.37^{ab} \pm 1.7$	$95.71^{a} \pm 1.2$	$3.49^{b} \pm 0.7$	$4.36^{a} \pm 0.5$	$0.31^{a} \pm 0.0$
	14	$4.43^{a} \pm 0.33$	$0.37^{a} \pm 0.1$	$12.40^{ab} \pm 0.5$	$95.71^{a} \pm 0.3$	$3.46^{a} \pm 0.2$	4.97a±1.2	$0.34^{ab} \pm 0.0$
	21	$4.43^{a} \pm 0.33$	$0.37^{a} \pm 0.1$	$12.40^{ab} \pm 0.5$	$95.71^{a} \pm 0.3$	$3.46^{ab} \pm 0.2$	$4.97^{a} \pm 1.2$	$0.34^{ab} \pm 0.0$
	28	$4.15^{a} \pm 0.17$	$0.37^{a} \pm 0.10$	$13.23^{ab} \pm 1.5$	$95.46^{a} \pm 0.2$	$3.8^{a} \pm 0.8$	$4.27^{a} \pm 0.7$	$0.35^{abc} \pm 0.3$
	0	$3.90^{a} \pm 0.30$	$0.39^{ab} \pm 0.04$	$10.96^{ab} \pm 1.5$	$96.45^{a} \pm 0.4$	$2.93^{a} \pm 1.3$	$3.78^{ab} \pm 0.3$	$0.29^{ab} \pm 0.4$
1.5	7	$4.11^{a} \pm 0.20$	$0.39^{a} \pm 0.02$	$11.26^{ab} \pm 1.5$	$95.98^{a} \pm 2.0$	$3.39^{ab} \pm 2.1$	$4.60^{a} \pm 1.4$	$0.32^{a} \pm 0.02$
	14	$3.16^{a} \pm 0.17$	$0.35^{a} \pm 0.10$	$12.06^{b} \pm 0.4$	$96.58^{a} \pm 1.0$	$3.49^{a} \pm 0.1$	$5.46^{a} \pm 1.2$	$0.34^{ab} \pm 0.3$
	21	$3.16^{a} \pm 0.17$	$0.35^{a} \pm 0.10$	$12.06^{b} \pm 0.4$	$96.58^{a} \pm 1.0$	$3.49^{ab} \pm 0.1$	$5.46^{a} \pm 1.2$	$0.34^{ab} \pm 0.3$
	28	$3.58^{a} \pm 0.1$	$0.37^{ab} \pm 0.11$	$12.83^{ab} \pm 1.9$	$95.46^{a} \pm 1.6$	$3.73^{a} \pm 0.8$	$5.07^{a} \pm 0.6$	$0.40^{ab} \pm 0.3$
	0	$4.18^{a} \pm 0.70$	$0.38^{a} \pm 0.01$	$10.49^{a} \pm 2.0$	$96.14^{a} \pm 0.3$	$2.49^{a} \pm 0.1$	$4.08^{ab} \pm 1.2$	$0.34^{b} \pm 0.7$
2	7	$3.79^{a} \pm 0.49$	$0.34^{a} \pm 0.0$	$11.06^{b} \pm 0.1$	$95.49^{a} \pm 1.0$	$2.89^{a} \pm 0.1$	$4.61^{a} \pm 0.7$	$0.33^{a} \pm 0.0$
	14	$4.36^{a} \pm 0.52$	$0.36^{a} \pm 0.20$	$11.46^{c} \pm 0.23$	$95.49^{a} \pm 1.1$	$3.39^{a} \pm 0.0$	$4.93^{a} \pm 12$	$0.42^{c} \pm 0.6$
	21	$4.36^{a} \pm 0.52$	$0.36^{a} \pm 0.20$	$11.46^{c} \pm 0.23$	$95.49^{a} \pm 1.1$	$2.99^{b} \pm 0.0$	$4.93^{a} \pm 1.2$	$0.42^{c} \pm 0.6$
	28	$3.77^{a} \pm 0.1$	$0.40^{a} \pm 0.12$	$12.79^{a} \pm 1.5$	95 .1$^{a} \pm 0.2$	$3.86^{a} \pm 0.2$	$5.733^{a} \pm 0.5$	$0.34^{a} \pm 0.9$

Mean values bearing different superscripts in each column are significantly different ($P < 0.05$) according to Duncan's Multiple Range Test
Source: Author

content on days 14 and 21 are similar at doses of 0, 0.5, 0.75, and 1.5 kGy when compared to other storage days (Table 1).

However, the moisture content of tomatoes is influenced by the variety and storage condition of the tomatoes. Also, it was observed by Dionesio (2009) that the changes in metabolic activities may result in changes in moisture content during the storage period of fresh fruits. In addition, Munir et al. (2018) also point out that the effect on moisture contents of products caused by increased respiration rates and senescence processes may result in weight loss of fresh produce during storage.

Lycopene

Table 1 presents the means of lycopene content, which did not show significant differences between treatments within 14 days, however after 21 days of storage, a slight difference in lycopene content was observed. The findings are consistent with the findings of Singh and Singh (2019), who observed that irradiated tomatoes contain lycopene levels ranging from 26 to 31 micro g g-1 (3.86 mg/100 g). However, according to Kumar et al. (2014), the lowest lycopene contents increased in irradiated tomatoes and untreated fruits during storage. Related results were reported by Loro et al. (2018), who report similar trends with those of Kumar et al. (2014). A significant difference was observed for other storage times (0 days, 7 days, 21, and 28 days) between different irradiation treatments. The low level of lycopene could be contributed to tomatoes that are not well ripened since the red color of tomatoes attributed to high lycopene content (Ilahy et al., 2011; Loro et al. 2018). Further, the results show an increase in lycopene contents from 2.13 to 3.56 mg/100g for day 21 and from 3.42 to 4.2 mg/100g for samples stored for 28 days. The increase in Lycopene may be due to storage time; as a general rule, the longer the storage time, the more red the tomatoes and the higher the lycopene content.

TSS

The results of this study were similar tothe study done by Mendes et al. (2020), Akter and Khan (2012), who reported that irradiation of cherry tomatoes, has no significant effect on soluble solids. The results showed that there is a slight increase in TSS as storage time is extended; this phenomenon could be due to an increase in water-soluble pectin from cellulose (insoluble). In addition, the content of soluble solids in tomatoes was influenced by the amount of sugar present in tomatoes (Prassana et al., 2007). While the total sugar content of the non-irradiated tomato (control) sample was 3.38-5.73°Brix after 28 days of storage (Table 1). The results obtained were similar to those reported by Loro et al. (2018) that the °Brix values of fresh tomatoes ranged from 3.8 to 4.0 after being treated with different radiation doses. The results of this study were in agreement with Costa-Rodrigues (2018), who found that over the course of storage periods, the ratio values gradually increased until the last day of evaluation, which was 30 days after storage.

B-carotene

As presented in Table 1, results showed no significant difference in -carotene content between irradiated tomotes ($P< 0.05$) over the entire 28-day storage period. The amount of -carotene in the control sample was low after 14 days, which could be attributed to unripe fruits. The low level of beta-carotene could be attributed to unripe tomatoes, as the red color of tomatoes contributes to their highβ-carotene content (Ilahy et al., 2011). Furthermore, for samples stored for 21 and 28 days, the results show an increase in beta-carotene content. Kumar et al. (2014) found an increase in -carotene content in irradiated tomatoes stored for seven to fourteen days in a similar study.

CONCLUSION AND RECOMMENDATION

Tomato radiated with various radiation dosages maintain and impair some of the physico-chemical properties of tomatoes. The dose of up to 2 kGy may show positive results in prolonging the shelf life with minimal effects on the quality of tomatoes. Irradiation presents advantages over other existing technologies because it does not affect the raw character of the fresh product such as moisture content, pH, B-carotene, and lycopene contents except for vitamin C which showed a decrease in all treatment and storage time. This study has provided appropriate and effective means of preserving fresh tomato fruits, specifically the 'Tanya 'cultivar of Tanzania to prevent post-harvest losses without compromising on physicochemical and nutritional properties of importance in developing countries such as Tanzania and the greater SADC region.

To ensure optimal quality, further research should be conducted on understanding the mechanisms by which irradiation alters the physicochemical attributes of foods for a dose above 2 kGy.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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