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The Effect of X-irradiation on the Shelf Life and Proximate Composition of Some Varieties of Tomatoes Commonly Grown in Benue State, Nigeria

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Abstract: Tomato production is a source of income to most rural producers in developing countries like Nigeria. Despite the numerous benefits from this crop, challenges of postharvest losses occasioned by lack of preservation techniques and storage facilities are making its production unprofitable in most developing countries in Africa. This research investigated the effect of X-Irradiation on the shelf life and proximate composition of some varieties of tomatoes commonly grown in Benue State. Five samples each of fully ripe Plum (Lycopersicon esculentum L.-Oval-shaped tomato of Italian origin), Juliet (Lycopersicon esculentum L.-1999 All American Selection Winner), Better Boy (Lycopersicon esculentum L. of USA origin), Giulietta F1 (Lycopersicon esculentum L. – a hybrid from France) and Cherry (Lycopersicon esculentum var. cerasiforme) tomatoes were collected from an experimental farm in Wannune, kilometer 54, Makurdi-Gboko road and exposed to X-irradiation doses of 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy using the X-ray machine (Model: 1.2UG13GN) located at Musafaha Imaging Centre Makurdi, Benue State. Results of the investigation revealed that 0.30 mGy and 0.61 mGy are adequate for extension of shelf life of Plum tomatoes by 7 days; 0.30 mGy was effective in extension of shelf life of Juliet and Better Boy tomatoes by 5 and 6 days respectively while 0.61 mGy also proved adequate for extension of shelf life of Giulietta F1 and Cherry tomatoes by 6 and 7 days respectively. Proximate analysis of X-irradiated tomatoes showed no significant changes in the ash, moisture, fat, fibre and carbohydrate contents of all varieties of tomatoes considered ($P>0.05$) except the protein contents of Juliet, Better Boy and Giulietta F1 that were significantly affected ($P<0.05$). X-irradiation doses in the range of 0.30 mGy – 0.61 mGy are effective for extension of shelf life of tomatoes commonly grown in Benue State.

Keywords: Tomato, X-irradiation, Effective Dose, Shelf Life, Proximate Composition

1. Introduction

Tomato (*Lycoperscon esculentum L.*) is one of the most widely cultivated and consumed fresh vegetable crops in the world today [1-4]. Its consumption is second only to potato as a vegetable [5]. The cultivated tomato belongs to the *Solanum* genus within the *Solanaceae* family of flowering plants. This family also known as the nightshade family includes other notable cultivated plants such as tobacco, pepper, potato and eggplant [6]. Several cultivars of tomatoes which exhibit genetic diversity in terms of shape colour and size as well as taste are found in different parts of the world [7]. Tomato is known to be excellent source of many nutrients and secondary metabolites that are very vital to human health, namely, mineral matter, vitamins, antioxidants, phenolics and organic acids [8]. Thus, consumption of tomatoes has several health benefits such as reducing the risk of certain types of cancers and chronic degenerative diseases [9-11].

Tomato production is also a source of income to most rural producers in developing countries like Nigeria [12]. Despite the numerous benefits from this crop, many challenges such as postharvest losses occasioned by the short shelf life of tomatoes are making its production unprofitable in most developing countries especially those in Africa [13]. In Benue State for instance, tomato is produced in abundance but no serious efforts have been made in providing storage facilities and effective preservation techniques to enable farmers maximize profit on their tomatoes.

Irradiation has proved to be a useful tool for the extension of shelf life of certain fruits and vegetables [14]. Food irradiation is the only technique that can maintain food quality and ensure the safety of food without significantly affecting food sensory or nutritional attributes [15]. Thus, the technology of food irradiation has been extensively employed for decontamination, disinfestation and shelf life improvement of food and agricultural products prone to rapid deterioration [16]. It is a non-thermal, non-chemical and energy-efficient food preservation technique that involves precise exposure of food and agricultural commodities to ionizing radiations such as gamma rays (cobalt-60 and caesium-137) or machine generated X-rays and high energy electrons so that a prescribed quantity of radiation is absorbed [17, 18]. These types of radiation are chosen because they produce the desired food preservative effects and do not induce radioactivity to foods or packaging materials [19, 20]. The foods exposed to ionizing radiations is either prepackaged or in bulk to reduce the risk of foodborne illness, delay or eliminate sprouting or ripening [21, 22].

Irradiation technique inactivates food spoilage organisms, including bacteria, moulds, and yeasts and is effective in lengthening the shelf-life of fresh fruits and vegetables by controlling the normal biological changes associated with ripening, maturation, sprouting, and finally aging. It also destroys disease-causing organisms, including parasitic worms and insect pests that damage food during storage [21].

This paper seeks to investigate the effect of x-irradiation on the shelf life and proximate composition of some varieties of tomatoes commonly grown in Benue State, Nigeria.

2. Materials and Methods

2.1. Materials

The following materials were used in this work: X-ray machine (Machine model: 1.2UG13GN, Tube model: R-20MC, Machine serial number: 62822815, Manufacturer: Picker International, Year: 2015), Baskets, Tomato fruits.

2.2. Sample Collection

Five varieties of fully ripe tomatoes were harvested from an experimental farm in Wannune, kilometer 54, Tarka Local Government Area of Benue State and packed in five baskets according to the varieties. The fruits were of the same maturity stage (red stage) and without blemishes, bruises or signs of infection. The fully ripe tomato fruits were used to test for extension of shelf life.

2.3. Sample Preparation

The fresh tomatoes were rinsed with water to remove dirt from the farm. The rinsed tomato fruits were allowed to dry for few minutes and after which each variety was subdivided into six (6) samples of thirteen fruits (13) fruits each and were labelled A, B, C, D, E and F with sample A serving as control. All the samples were packed in thirty (30) small baskets and taken to the X-ray machine for irradiation.

2.4. Irradiation Procedure

The X-irradiation of tomatoes was carried out using the single phase X-ray machine at Musafaha Imaging Centre, Makurdi, Benue State. Each tomato variety was subdivided into six samples and irradiated with X-rays of peak kilo voltages of 40 kvp, 50 kVp, 60 kVp, 70 kVp, 80 kVp and 5.00 mAs, 10.00 mAs, 15.00mAs, 20.00mAs, 25.00 mAs respectively. In order to convert these Kvp_s and mAs to doses, Edmond's Formula for a single phase X-ray machine was used [23, 24].

$$Skin\ Dose\ (\mu Gy) = \frac{418(kVp)^{1.74}(mAs)}{(SSD)^2}\left(\frac{1}{T} + 0.114\right) \quad (1)$$

Where kVp = kilo voltage peak

mAs = miliampere second SSD = Source to Skin Distance

T = Total Filtration of the X-ray machine

The total filtration (T) of the X-ray machine used in this work was 1.5 mmAl and a source to skin distance (SSD) of 100 cm was maintained throughout the exposure. The conversion arrived at the following doses: 0.00 mGy (control), 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy.

2.5. Proximate Analysis

Proximate analysis was carried out to determine the percentages of ash, moisture, crude fibre, crude protein, fat and carbohydrate using methods of analysis described by Association of Official Analytical Chemists [25].

2.5.1. Determination of Ash Content

Five grams (5 g) of sample were weighed in incinerated crucibles and then ashed in a muffle furnace at 600 °C for 4 hours. The ash content was then calculated using equation 2 [26].

$$Ash\ content\ (\%) = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad (2)$$

Where w1 is the weight of empty crucible

W_2 is the weight of crucible + food before drying W_3 is the weight of crucible + ash

2.5.2. Determination of Moisture Content

Five grams (5 g) of sample were weighed in petri dish of known weight. It was then dried in the oven at 104 ±1°C for 4 hours and later cooled in a desiccator and weighed. The moisture content was calculated using equation 3 [26].

$$Moisture\ content\ (\%) = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (3)$$

Where W_1=Weight of empty crucible

W_2=Weight of crucible + food before drying

W_3=Weight of crucible + sample after drying

2.5.3. Determination of Crude Protein

Protein content was determined using kjeldahl method, according to the procedure of Association of Official Analytical Chemists (AOAC). Concentrated H_2SO_4 (12 ml) and two tablets of selenium catalyst were dropped into a kjeldahl digestion flask containing one 1 g of the sample. The flask was placed in a digester fume cupboard, switched on and allowed to digest for 45 minutes to obtain a clear colourless solution. The digest was distilled with 4 % of boric acid, and 20 % sodium hydroxide solution until distillation was completed. The distillate was then titrated with 0.1 mol/l of HCl until a violet colour was formed, indicating the end point. A blank was run under the same condition as with the sample. Total protein was then calculated using equation 4 [26].

$$Protein\ (\%) = \frac{[titre\ value\ of\ sample - blank] \times 0.01 \times 14.007 \times 6.25}{1000 \times weight\ of\ sample} \times 100 \quad (4)$$

2.5.4. Determination of Crude Fibre

Five grams (5 g) of sample were weighed into a 500 mL Erlenmeyer flask and 100 mL trichloroacetic acid digestion reagent was added. It was brought to boiling and refluxed for exactly 40 minutes. The flask was removed from the heater, cooled and filtered through a 15.0 cm whatman paper. The residue was washed with hot water, stirred once with a spatula and transferred to a desiccator and weighed (W_1) when cool. It was then ashed in a muffle furnace at 500 °C for 6 h ours, allowed to cool, and reweighed (W_2). The percentage crude fibre was calculated by applying equation 5 [25].

$$Crude\ Fibre\ (\%) = \frac{(W_1 - W_2)}{W_0} \times 100 \quad (5)$$

Where W_1=Weight of crucible + fiber + ash

W_2=Weight of crucible + ash

W_0 = Dry weight of food sample

2.5.5. Determination of Fat Content

Two grams (2 g) of sample were weighed on a chemical balance and wrapped in a filter paper and placed in an extraction thimble. 25 mL of N-hexane was measured into the round bottom flask for fat extraction. After extraction, the flask and its contents were cooled in a desiccator and weighed for fat content. The percentage fat content was calculated using equation 6 [25].

$$Fat\ content\ (\%) = \frac{weight\ of\ fat\ extracted}{weight\ of\ food\ sample} \times 100 \quad (6)$$

2.5.6. Determination of Carbohydrate Content

Carbohydrate content was determined by difference using equation 7 [27].

$$\%\ Carbohydrates = 100\ \% - \%(protein + fat + fibre + ash + moisture\ content) \quad (7)$$

2.6. Statistical Analysis

The data obtained in this research was subjected to Analysis of Variance (ANOVA) using Standard Package for Social Sciences (SPSS) version 25.0 at 5 % (α = 0.05) level of significant difference. Duncan Multiple Test was used to separate the mean values where significant differences existed. The statistical analysis was done on the basis of the null hypothesis that X-irradiation has no significant effect on the nutrient content of tomatoes and the alternative hypothesis that X-irradiation has significant effect on the nutrient content of tomatoes commonly grown in Benue State.

3. Results and Discussion

The results of the effect X-irradiation on the shelf life of Plum (Lycopersicon esculentum L.-Oval-shaped tomato of Italian origin), Juliet (Lycopersicon esculentum L.-1999 All American Selection Winner), Better Boy (Lycopersicon esculentum L. of USA origin), Giulietta F1 (Lycopersicon esculentum L. – a hybrid from France) and Cherry (Lycopersicon esculentum var. cerasiforme) tomatoes are presented in Figures 1 - 5 respectively.

Figure 6 presents the comparative analysis of the effect of X-irradiation on the shelf life of some varieties of tomatoes.

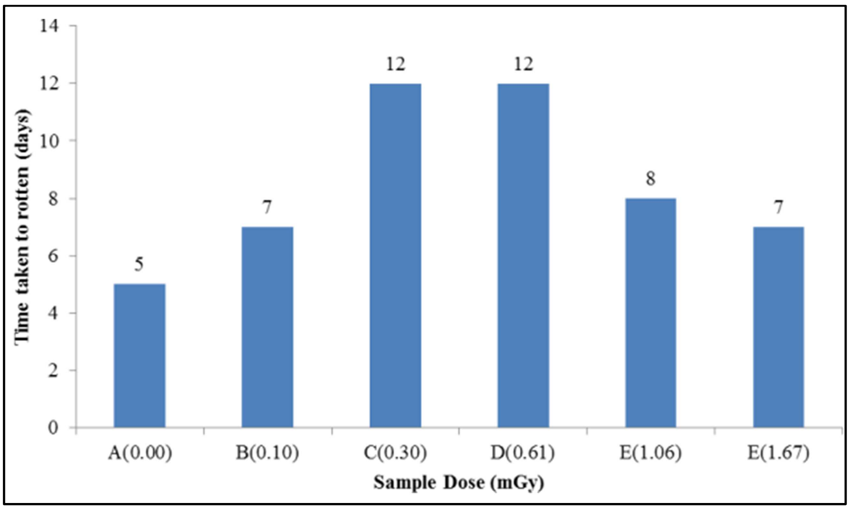

Figure 1. *Effect of X-Irradiation on the Shelf Life of fully Ripe Plum (Lycopersicon esculentum L. - Oval-shaped tomato of Italian origin) Tomatoes.*

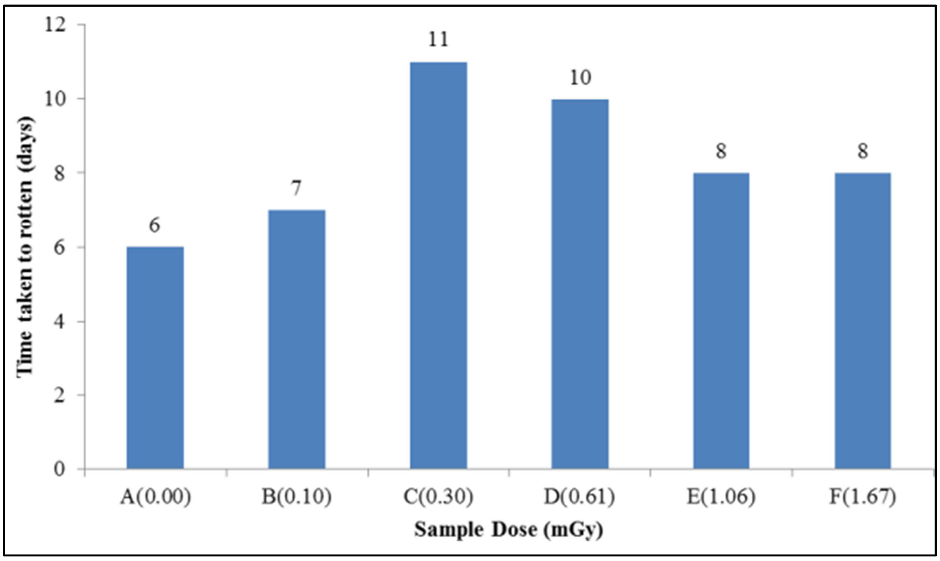

Figure 2. *Effect of X-Irradiation on the Shelf Life of fully Ripe Juliet (Lycopersicon esculentum L. - 1999 All American Selection Winner) Tomatoes.*

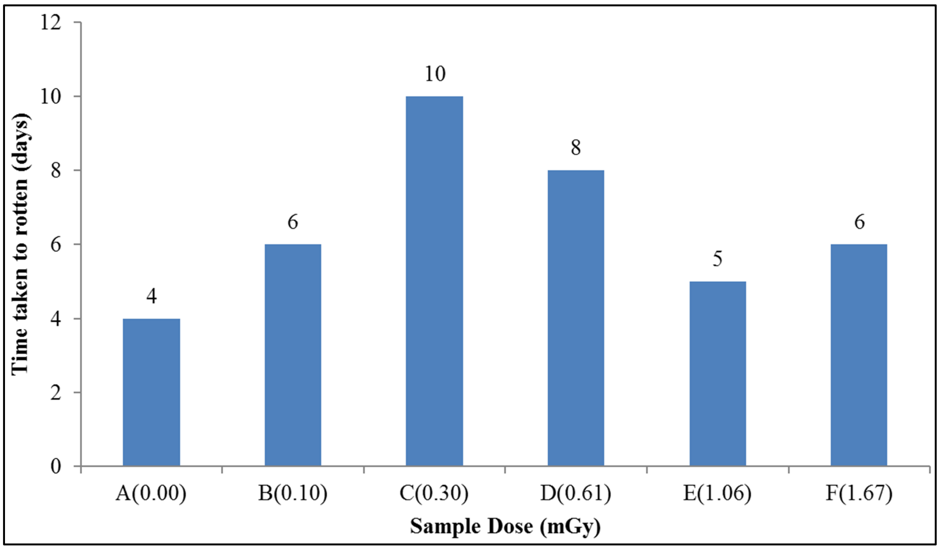

Figure 3. *Effect of X-Irradiation on the Shelf Life of fully Ripe Better Boy (Lycopersicon esculentum L. of USA origin) Tomatoes.*

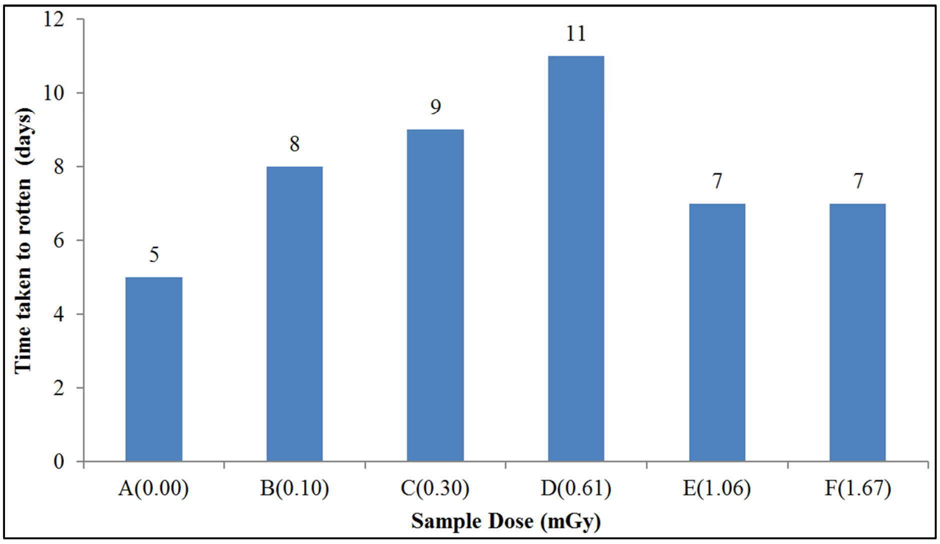

Figure 4. *Effect of X-Irradiation on the Shelf Life of fully Ripe Giulietta F1 (Lycopersicon esculentum L. – a hybrid from France) Tomatoes.*

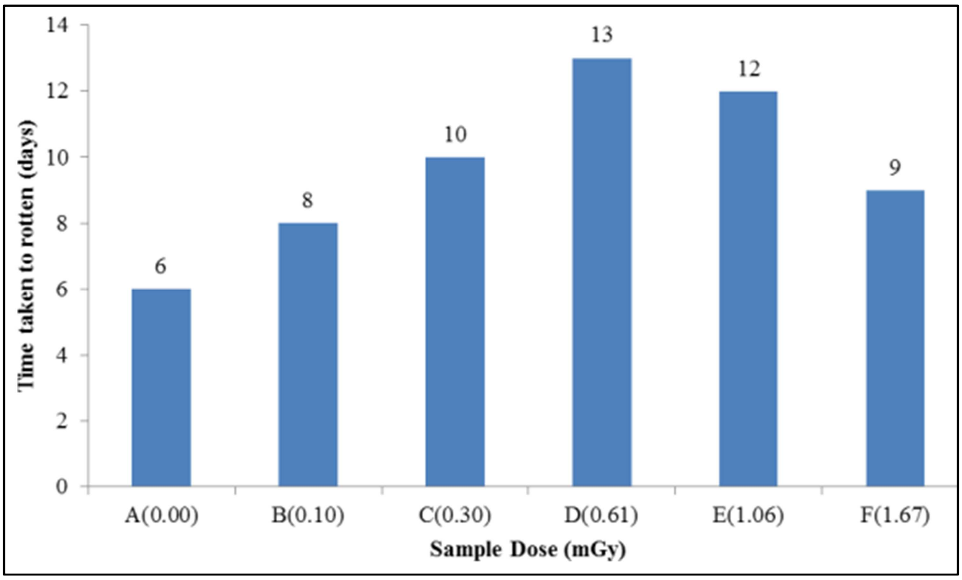

Figure 5. *Effect of X-Irradiation on the Shelf Life of fully Ripe Cherry (Lycopersicon esculentum var. cerasiforme) Tomatoes.*

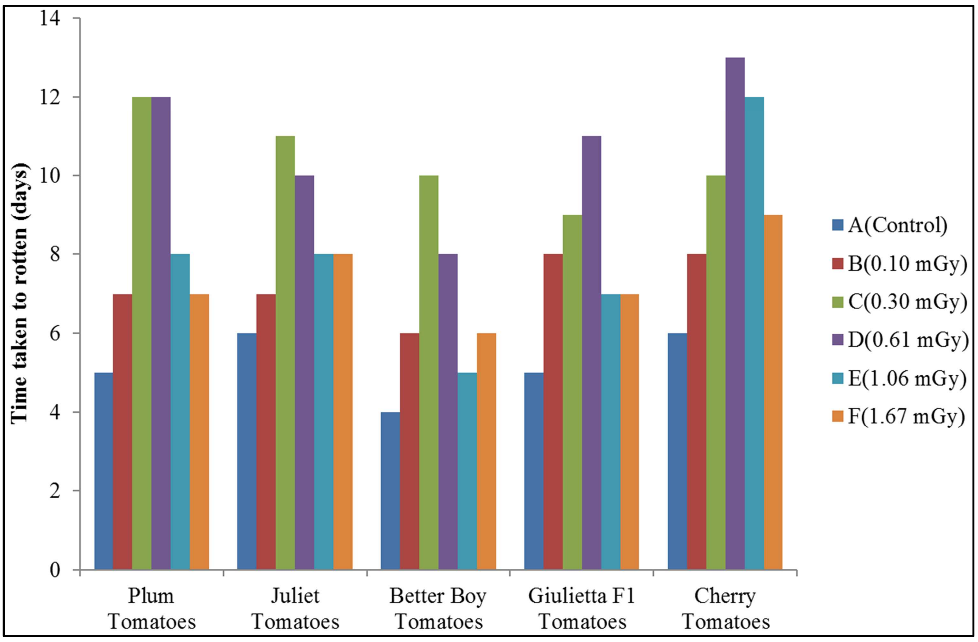

Figure 6. *Comparative Analysis of the Effect of X-irradiation on the Shelf Life Some Varieties of Tomatoes.*

The effect of X-irradiation on the proximate compositions of Plum, Juliet, Better Boy, Giulitta F1 and Cherry tomatoes are presented in Tables 1, 2, 3, 4 and 5 respectively.

Table 1. *Proximate Composition of the Control (Non-Irradiated) and X-Irradiated Plum (Lycopersicon esculentum L. - Oval-shaped tomato of Italian origin) Tomatoes.*

Sample Dose (mGy)	Ash (%)	Moisture (%)	Fat (%)	Protein (%)	Fibre (%)	Carbohydrate (%)
A(0.00)	0.800±0.000^{a}	93.500±0.707^{a}	0.001±0.002^{a}	0.075±0.012^{b}	0.500±0.000^{a}	5.123±0.720^{a}
B(0.10)	0.900±0.707^{a}	92.250±1.060^{a}	0.001±0.000^{a}	0.067±0.000^{ab}	0.500±0.000^{a}	6.283±0.353^{a}
C(0.30)	0.600±0.282^{a}	92.750±1.767^{a}	0.002±0.000^{a}	0.059±0.000^{ab}	0.250±0.353^{a}	6.339±1.697^{a}
D(0.61)	1.200±1.131^{a}	92.250±1.060^{a}	0.001±0.002^{a}	0.072±0.006^{b}	0.500±0.353^{a}	5.977±2.199^{a}
E(1.06)	0.900±0.424^{a}	92.500±0.707^{a}	0.001±0.001^{a}	0.063±0.006^{ab}	0.500±0.353^{a}	6.036±1.135^{a}
F(1.67)	0.500±0.141^{a}	92.250±2.474^{a}	0.002±0.000^{a}	0.051±0.012^{a}	0.500±0.000^{a}	6.697±2.321^{a}
P-value	0.859	0.935	0.434	0.130	0.489	0.953

Values are of mean ± standard deviation of duplicate

Values with same superscript are not significantly different ($P > 0.05$) at $\alpha = 0.05$ (Duncan multiple range test)

Table 2. *Proximate Composition of Non-Irradiated and X-Irradiated Juliet (Lycopersicon esculentum L. - 1999 All American Selection Winner) Tomatoes.*

Sample Dose (mGy)	Ash (%)	Moisture (%)	Fat (%)	Protein (%)	Fibre (%)	Carbohydrate (%)
A(0.00)	$1.300{\pm}0.141^{a}$	$89.250{\pm}4.596^{a}$	$0.001{\pm}0.002^{a}$	$0.084{\pm}0.000^{b}$	$0.500{\pm}0.000^{a}$	$8.865{\pm}4.453^{a}$
B(0.10)	$1.700{\pm}0.141^{ab}$	$92.750{\pm}1.060^{a}$	$0.002{\pm}0.000^{a}$	$0.072{\pm}0.006^{a}$	$0.500{\pm}0.000^{a}$	$4.976{\pm}0.925^{a}$
C(0.30)	$1.900{\pm}0.141^{ab}$	$91.250{\pm}1.767^{a}$	$0.001{\pm}0.002^{a}$	$0.063{\pm}0.006^{a}$	$0.250{\pm}0.353^{a}$	$6.536{\pm}2.258^{a}$
D(0.61)	$2.400{\pm}0.282^{b}$	$88.750{\pm}3.181^{a}$	$0.001{\pm}0.000^{a}$	$0.059{\pm}0.000^{a}$	$0.250{\pm}0.353^{a}$	$8.541{\pm}3.111^{a}$
E(1.06)	$1.800{\pm}0.282^{ab}$	$91.750{\pm}1.767^{a}$	$0.001{\pm}0.002^{a}$	$0.072{\pm}0.006^{a}$	$0.259{\pm}0.353^{a}$	$6.127{\pm}1.126^{a}$
F(1.67)	$2.500{\pm}0.707^{b}$	$86.750{\pm}0.353^{a}$	$0.002{\pm}0.000^{a}$	$0.063{\pm}0.006^{a}$	$0.500{\pm}0.000^{a}$	$10.185{\pm}1.055^{a}$
P-value	0.085	0.306	0.434	0.019	0.704	0.400

Values are of mean ± standard deviation of duplicate
Values with same superscript within a column are not significantly different ($P > 0.05$) at $\alpha = 0.05$ (Duncan multiple range test)

Table 3. *Proximate Composition of Non-Irradiated and X-Irradiated Better Boy (Lycopersicon esculentum L. of USA origin) Tomatoes.*

Sample Dose (mGy)	Ash (%)	Moisture (%)	Fat (%)	Protein (%)	Fibre (%)	Carbohydrate (%)
A(0.00)	$1.000{\pm}0.000^{a}$	$92.500{\pm}0.707^{a}$	$0.001{\pm}0.001^{a}$	$0.067{\pm}0.000^{c}$	$0.500{\pm}0.000^{a}$	$5.932{\pm}0.705^{a}$
B(0.10)	$0.900{\pm}0.141^{a}$	$91.300{\pm}0.424^{a}$	$0.002{\pm}0.000^{a}$	$0.059{\pm}0.000^{bc}$	$0.250{\pm}0.353^{a}$	$7.539{\pm}0.848^{a}$
C(0.30)	$1.000{\pm}0.848^{a}$	$89.750{\pm}0.353^{a}$	$0.001{\pm}0.001^{a}$	$0.059{\pm}0.000^{bc}$	$0.250{\pm}0.353^{a}$	$8.940{\pm}1.554^{a}$
D(0.61)	$0.400{\pm}0.282^{a}$	$92.500{\pm}0.707^{a}$	$0.002{\pm}0.000^{a}$	$0.055{\pm}0.006^{ab}$	$0.500{\pm}0.000^{a}$	$6.543{\pm}0.417^{a}$
E(1.06)	$0.700{\pm}0.141^{a}$	$94.750{\pm}5.303^{a}$	$0.001{\pm}0.002^{a}$	$0.050{\pm}0.000^{bc}$	$0.250{\pm}0.353^{a}$	$4.548{\pm}6.224^{a}$
F(1.67)	$0.700{\pm}0.141^{a}$	$92.500{\pm}2.828^{a}$	$0.001{\pm}0.002^{a}$	$0.046{\pm}0.006^{a}$	$0.500{\pm}0.000^{a}$	$6.253{\pm}2.679^{a}$
P- value	0.616	0.551	0.833	0.009	0.704	0.179

Values are of mean ± standard deviation of duplicate
Values with same superscript within a column are not significantly different ($P > 0.05$) at $\alpha = 0.05$ (Duncan multiple range test)

Table 4. *Proximate Composition of Non-Irradiated and X-Irradiated Giulietta F1 (Lycopersicon esculentum L. – a hybrid from France) Tomatoes.*

Sample Dose (mGy)	Ash (%)	Moisture (%)	Fat (%)	Protein (%)	Fibre (%)	Carbohydrate (%)
A(0.00)	$2.200{\pm}0.848^{abc}$	$89.250{\pm}1.767^{a}$	$0.002{\pm}0.000^{a}$	$0.034{\pm}0.000^{b}$	$0.250{\pm}0.353^{a}$	$7.962{\pm}2.262^{ab}$
B(0.10)	$1.100{\pm}0.424^{a}$	$91.000{\pm}1.414^{b}$	$0.001{\pm}0.001^{a}$	$0.021{\pm}0.006^{a}$	$0.250{\pm}0.353^{a}$	$6.514{\pm}1.178^{a}$
C(0.30)	$2.800{\pm}0.565^{bc}$	$90.250{\pm}3.181^{a}$	$0.002{\pm}0.000^{a}$	$0.017{\pm}0.000^{a}$	$0.500{\pm}0.000^{a}$	$6.432{\pm}3.747^{ab}$
D(0.61)	$1.600{\pm}0.000^{ab}$	$92.750{\pm}0.353^{ab}$	$0.001{\pm}0.001^{a}$	$0.025{\pm}0.000^{a}$	$0.500{\pm}0.000^{a}$	$5.124{\pm}0.354^{ab}$
E(1.06)	$2.900{\pm}0.141^{c}$	$86.250{\pm}4.596^{a}$	$0.002{\pm}0.000^{a}$	$0.017{\pm}0.000^{a}$	$0.500{\pm}0.000^{a}$	$10.334{\pm}4.449^{b}$
F(1.67)	$2.200{\pm}0.282^{abc}$	$91.750{\pm}1.767^{ab}$	$0.001{\pm}0.001^{a}$	$0.022{\pm}0.006^{a}$	$0.250{\pm}0.353^{a}$	$5.778{\pm}1.842^{ab}$
P-value	0.051	0.062	0.704	0.010	0.704	0.160

Values are of mean ± standard deviation of duplicate
Values with same superscript within a column are not significantly different ($P > 0.05$) at $\alpha = 0.05$ (Duncan multiple range test)

Table 5. *Proximate Composition of Non-Irradiated and X-Irradiated Cherry (Lycopersicon esculentum var. cerasiforme) Tomatoes.*

Sample Dose (mGy)	Ash (%)	Moisture (%)	Fat (%)	Protein (%)	Fibre (%)	Carbohydrate (%)
A(0.00)	$0.800{\pm}0.282^{a}$	$92.000{\pm}2.828^{ab}$	$0.002{\pm}0.000^{a}$	$0.030{\pm}0.006^{b}$	$0.250{\pm}0.353^{a}$	$6.919{\pm}2.186^{a}$
B(0.10)	$0.900{\pm}0.141^{a}$	$91.250{\pm}0.353^{ab}$	$0.002{\pm}0.000^{a}$	$0.021{\pm}0.006^{ab}$	$0.500{\pm}0.000^{a}$	$7.327{\pm}0.206^{ab}$
C(0.30)	$0.500{\pm}0.424^{a}$	$91.500{\pm}0.707^{ab}$	$0.002{\pm}0.000^{a}$	$0.017{\pm}0.000^{a}$	$0.500{\pm}0.000^{a}$	$7.481{\pm}0.283^{ab}$
D(0.61)	$1.000{\pm}0.565^{a}$	$88.750{\pm}2.474^{a}$	$0.002{\pm}0.000^{a}$	$0.017{\pm}0.000^{a}$	$0.250{\pm}0.353^{a}$	$9.981{\pm}1.556^{b}$
E(1.06)	$0.800{\pm}0.282^{a}$	$93.500{\pm}0.707^{b}$	$0.001{\pm}0.001^{a}$	$0.017{\pm}0.000^{a}$	$0.250{\pm}0.353^{a}$	$5.432{\pm}0.638^{a}$
F(1.67)	$0.900{\pm}0.424^{a}$	$88.500{\pm}0.000^{a}$	$0.002{\pm}0.000^{a}$	$0.021{\pm}0.006^{ab}$	$0.500{\pm}0.000^{a}$	$10.077{\pm}0.419^{b}$
P-value	0.824	0.109	0.489	0.128	0.704	0.037

Values are of mean ± standard deviation of duplicate
Values with same superscript within a column are not significantly different ($P > 0.05$) at $\alpha = 0.05$ (Duncan multiple range test)

3.1. The Effect of X-irradiation on the Shelf Life of Tomatoes

The result presented in Figure 1 shows that the control and other samples of Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin) tomatoes X-irradiated with 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy took 5, 7, 12, 12, 8 and 7 days to rotten respectively. This implies that X-irradiation doses of 0.30 mGy and 0.61 mGy were most effective in extending the shelf life Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin) tomatoes by 7 days. In the same vein, Figure 2 shows that it took 6 days for the control (non-irradiated) sample of Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner) while samples X-irradiated with 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy took 7, 11, 10, 8 and 8 days to rotten respectively. This implies that doses of 0.30 mGy and 0.61 mGy were adequate for extension of shelf life of Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner) tomatoes. More so, Figure 3 shows that the control and samples of Better Boy (*Lycopersicon esculentum L.* of USA origin) tomatoes X-irradiated with 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy took 4, 6, 10, 8, 5 and 6 days respectively to rotten completely. This also implies that X-irradiation doses of 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy extended the shelf life of Better Boy (*Lycopersicon esculentum L.* of USA origin) tomatoes by 2, 6, 4, 1 and 2 days respectively when compared to the control sample. A dose of 0.3 mGy which enhanced the shelf life by 6 days is therefore the most effective dose for extension of shelf life of Better Boy tomatoes. Figure 4 shows the effect of X-irradiation on the shelf life of Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) tomatoes. It was observed that the control sample and samples X-irradiated with 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy took 5, 8, 9, 11, 7 and 7 days respectively to rotten completely. A dose of 0.61 mGy which extended the shelf life of Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) tomatoes by 6 days is thus the most effective dose. Nevertheless, the effect of X-irradiation on the shelf life Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes as presented in Figure 5 shows that the control (non-irradiated) and samples exposed to X-irradiation doses of 0.10 mGy, 0.30 mGy, 0.61 mGy, 1.06 mGy and 1.67 mGy respectively took 6, 8, 10, 13, 12 and 9 days respectively to rotten completely. This implies that X-irradiation dose of 0.61 mGy extended the shelf life of cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes by 7 days and is the most effective dose. Figure 6 shows a comparative analysis of the effect of X-irradiation on the shelf life of Plum, Juliet, Better Boy, Giulietta F1 and Cherry tomatoes respectively. According to this Figure, X-irradiation doses in the range of 0.30 – 0.61 mGy are adequate for extension of shelf life of these varieties of tomatoes considered.

This research is in accordance with the work of Sombo *et al.* [28] who carried out a preliminary investigation of the effect of X-rays on the ripening and shelf life of locally grown Caynne, Roccoto and Annahein pepper in Benue State found that peak tube voltage in the range of 50 – 55 kvp was effective in extending the shelf life of pepper. Yissah *et al.* [29] also found that the shelf life of Okra was greatly enhanced when X-irradiated with 0.05 Gy. Similarly, Ricciardi *et al.* [30] in their work on X-ray irradiation as a valid technique to prolong the shelf life of Ricotta cheese revealed that the artisanal Ricotta irradiated with 2 kGy and 3 kGy remained acceptable for more than 20 days whereas the control became unacceptable after 3 days while the industrial Ricotta x-irradiated at 0.5 kGy, 2 kGy and 3 kGy showed significant shelf life extension up to 84 days compared to the control which only lasted for 40 days. Other researchers such as Lacivita *et al.* [31] and Mahmoud *et al.* [32] also discovered that X-irradiation extends the shelf life of various fruits and other foods they investigated using different doses.

3.2. The Effect of X-irradiation on the Proximate Composition of Tomatoes

Tables 1, 2, 3, 4 and 5 reveal that percentage ash content of the control and the X-irradiated samples of Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin), Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner), Better Boy (*Lycopersicon esculentum L.* of USA origin), Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) and Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes had p-values of 0.895, 0.085, 0.616, 0.051 and 0.824 respectively. No significant difference between the control and x-irradiated samples was observed at 5 % (α=0.05) level of significance. Similarly, the effect of X-irradiation on moisture content of Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin), Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner), Better Boy (*Lycopersicon esculentum L.* of USA origin), Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) and Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes is presented in Tables 1, 2, 3, 4 and 5 show p-values of 0.935, 0.306, 0.551, 0.062 and 0.109 respectively. These p-values provide strong support for the null hypothesis that X-irradiation as no significant effect on the moisture content of these tomatoes mentioned above. In the same vein, the fat content of the control (non-irradiated) and X-irradiated Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin), Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner), Better Boy (*Lycopersicon esculentum L.* of USA origin), Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) and Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes were not significantly affected as observed in the respective p-values of 0.434, 0.434, 0.833, 0.704 and 0.489. Furthermore, Analysis of Variance (ANOVA) carried out to determine the effect of X-irradiation on the protein content of Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin), Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner), Better Boy (*Lycopersicon esculentum L.* of USA origin), Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) and Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes presented in Tables 1, 2, 3, 4 and 5 produced p-values of 0.130, 0.019, 0.009, 0.010 and 0.128 respectively. These p-values imply that the protein contents of Juliet, Better Boy and Giulietta F1 were significantly decreased ($P<0.05$) while that of Plum and Cherry tomatoes were not significantly affected ($P>0.05$). The variations in protein content may be associated to aggregation or cross-linking as a consequence of X-irradiation affecting nitrogen solubility. The significant changes ($P<0.05$) in protein may also be due to free radicals that might be formed in association with splitting of the peptide bonds, deamination and decarboxylation reactions of amino acids followed by chains of chemical reactions forming other new radicals [33]. More so, the effect of X-irradiation on the fibre content of Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin), Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner), Better Boy (*Lycopersicon esculentum L.* of USA origin), Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) and Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes presented in Tables 1, 2, 3, 4 and 5 yielded P-values values of 0.489, 0.704, 0.704, 0.704 and 0.704 respectively. Meanwhile, the p-values of the carbohydrate contents of the control and X-irradiated samples of Plum (*Lycopersicon esculentum L.* - Oval-shaped tomato of Italian origin), Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner), Better Boy (*Lycopersicon esculentum L.* of USA origin), Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) and Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes shown in Tables 1, 2, 3, 4 and 5 were 0.953, 0.400, 0.179, 0.160 and 0.037 respectively. This means that X-irradiation has no significant effect ($P>0.05$) on the carbohydrate contents of these tomatoes. However, a slight (insignificant) increase was observed in all irradiated samples of plum tomatoes when compared to the control. This agrees with the work of Lima *et al.* [34] who reported that carbohydrates are less sensitive and relatively stable when exposed to radiation doses not more than 10 kGy.

In a nutshell, it was discovered that X-irradiation had no significant effect on the proximate composition of Plum, Juliet, Better Boy, Giulietta F1 and Cherry tomatoes.

4. Conclusion

The results of this research show that X-irradiation doses of 0.30 mGy and 0.61 mGy are adequate for extension of shelf life of Plum (*Lycopersicon esculentum L.* - Oval- shaped tomato of Italian origin) tomatoes by 7 days. 0.30 mGy is effective in extending the shelf life of Juliet (*Lycopersicon esculentum L.* - 1999 All American Selection Winner) and Better Boy (*Lycopersicon esculentum L.* of USA origin) tomatoes by 5 and 6 days respectively while 0.61 mGy is effective in extending the shelf life Giulietta F1 (*Lycopersicon esculentum L.* – a hybrid from France) and Cherry (*Lycopersicon esculentum var. cerasiforme*) tomatoes by 6 and 7 days respectively. X-irradiation had no significant effect on the proximate composition of tomatoes ($p>0.05$) commonly grown in Benue state. Therefore, X-irradiation doses in the range of 0.30 mGy – 0.61 mGy are adequate for extension of shelf life of tomatoes commonly grown in Benue State without significantly affecting the proximate composition.

5. Recommendations

The present research reveals that X-irradiation doses in the range of 0.30 mGy – 0.61 mGy are adequate for extension of shelf life of some varieties of tomatoes without significantly affecting the proximate composition. However, future research should be carried out to determine the effect of X-irradiation on vitamins, minerals, antioxidants, phenolics and organic acid content of tomatoes. We also recommend that further research should be carried out on the effect of X-irradiation on the shelf life and proximate composition of some varieties of tomatoes using higher doses of X-irradiation and other types of irradiation.

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