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A Comparative Study of Ultra Violet (UV-C) and X-Ray Irradiation on the Shelf Life and Proximate Composition of Garden Egg (*Solanum aethiopicum)*

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ABSTRACT

This study assessed the effects of X-ray and UV-C irradiation on the shelf life, quality, and microbial safety of garden eggs (*Solanum aethiopicum*). Samples were exposed to X-ray doses of 30.80–87.70 µGy at 50–80 kVp for 0.4–1.0 seconds and UV-C doses of 971.64–1943.28 mJ/cm² for 15–30 minutes. X-ray irradiation significantly extended shelf life by up to 4 days, with the X4 group (87.70 µGy, 80 kVp, 1.0 s) remaining viable for 11 days. UV-C treatment showed limited effect, with the U1 group (971.64 mJ/cm², 15 min) extending shelf life by only 2 days. X-ray treatment also improved moisture retention and mineral composition while reducing fungal and bacterial contamination. In contrast, UV-C caused noticeable color changes, while X-ray-treated samples retained their original colour. Both irradiation methods kept radiation doses within internationally accepted food safety limits (ICRP 2019). No harmful radiolytic by-products or residual radioactivity were detected, and proximate analysis showed minimal nutritional alterations. Overall, X-ray irradiation was more effective than UV-C for enhancing shelf life, quality, and safety, with X4 identified as the optimal treatment. The findings demonstrate that X-ray and UV-C irradiation offer a safe, non-thermal alternative for postharvest preservation of garden eggs, supporting reduced losses and improved food security for smallholder farmers.

Keywords:
Garden egg,
UV-C irradiation,
X-ray irradiation,
Shelf life,
Proximate composition.

INTRODUCTION

Garden egg (Solanum aethiopicum), or scarlet eggplant, is a nutrient-rich vegetable widely cultivated in Nigeria and other parts of Africa for its vitamins, minerals, antioxidants, and medicinal properties. It plays a vital role in food security, nutrition, and income generation for smallholder farmers, contributing to the country's GDP and poverty reduction efforts (Akinyemi *et al.,* 2023; FAO, 2017; NPC, 2020). Beyond Solanum aethiopicum, other species such as Solanum melongena, Solanum macrocarpon, and Solanum gilo also hold culinary and medicinal value across Africa, Asia, and beyond (Oloyede, 2019; Joël *et al.,* 2024). Garden eggs offer several health benefits, including anti-inflammatory and cardiovascular support (Kaur *et al.,* 2018).

However, garden eggs are highly perishable due to their high moisture content and susceptibility to microbial spoilage, leading to postharvest losses of 30–40% of total production. Traditional preservation methods such as refrigeration, freezing, and drying have been used to extend shelf life but are limited by reduced nutritional quality, high energy costs, poor rural accessibility, and environmental concerns (Akinyemi *et al.,* 2023; EPA, 2020; Kumar *et al.,* 2020; IPCC, 2020).

In recent years, non-thermal irradiation methods have emerged as effective alternatives for food preservation. Irradiation involves exposing food to ionizing or non-ionizing radiation to inactivate microorganisms, thereby extending shelf life and improving safety (Singh *et al.,* 2018). Techniques include gamma radiation, electron beam irradiation, UV light, and X-ray irradiation. Among these, UV-C light at 254 nm and X-ray irradiation have shown great promise for extending the shelf life of garden eggs (Techavuthiporn *et al.,* 2024). While gamma and electron beam irradiation are effective, their use is constrained by high equipment costs, safety concerns, and the need for specialized facilities (Kumar *et al.,* 2020; Bhat *et al.,* 2019). In contrast, UV-C light is low cost, easy to use, and environmentally friendly, as it damages microbial DNA to prevent reproduction and spoilage (Bhat *et al.,* 2019).

Given these advantages, this study evaluates the effects of UV-C and X-ray irradiation on the nutritional quality and shelf life of Solanum aethiopicum in Nigeria.

MATERIALS AND METHODS

The following materials were used for this work: UV-C lamp (254), UV radiometer, X-ray machine (YZ100C 100mA X-ray with X-ray tube model: DX4-2.9/100), X-ray dosimeter, Thermometer, pH meter, Oven-dry, weighing balance, crucible dish, Density bottle, spatula, foil paper, garden eggs, Distilled water, washing basin, towel, petri dish, desiccator, Kjeldahl flask, Sterile equipment (pipettes, tubes, etc.), Culture media (agar plates, broths), Incubator, Autoclave

Sample Collection

A sample of garden eggs was obtained directly from a farm in Abinsi Village, Guma Local Government Area of Benue State. This approach ensured that the garden eggs were freshly harvested and have not undergone any significant storage or handling that affected their shelf life. The initial freshness and quality of the produce were preserved, allowing for a more accurate assessment of the effects of irradiation on shelf life.

UV-C Irradiation Method

The research took place at the Physics Department laboratory at Rev. Fr. Moses Orshio Adasu University Makurdi, using a UV-C lamp with a wavelength of 254 nm. The samples were irradiated at a constant distance of 30 cm from UV-C source in the UV-C irradiator. This specific wavelength is known to be effective in inactivating microorganisms and the constant distant for irradiance uniformity for extending shelf life (Agba *et al*., 2023). The samples were exposed to a UV-C dose of 1.0-3.0 kJ/m², which is within the acceptable range for extending shelf life. To ensure uniform UV-C exposure, garden egg samples were arranged in a single layer on a sterile stainless-steel tray placed directly beneath the UV-C lamp. The samples were exposured to the UV-C light for the following exposure duration: 15, 20, 25, and 30 minutes. The garden egg samples were divided into five (5) groups, consisting of a control group with no exposure, and four treatment groups with varying exposure durations. Each group were treated in duplicate, with five (5) fruits in each subgroup, to account for any variations and ensure statistical significance. The UV-C irradiation process was monitored to ensured that the samples receive the correct doses and exposure time.

X-ray Irradiation Method

The X-ray irradiation experiment was conducted using an X-ray generator, YZ100C 100mA model with an X-ray tube model: DX4-2.9/100. Garden samples were prepared and placed in a custom-made sample holder, which was positioned at a distance of one meter from the X-ray radiation source. The X-ray generator was set to different kilovoltage peak (kVp) values of 50, 60, 70, and 80, and the corresponding radiation doses were measured using a dosimeter placed near the sample holder. Each garden egg sample was irradiated at the specified kVp values for a predetermined duration. The samples were irradiated one at a time to ensure accurate doses, and the measured radiation doses were recorded for each kVp setting. After irradiation, the samples were removed from the sample holder and stored for further analysis. The X-ray generator was calibrated before use to ensure accurate kVp output, and the dosimeter was used according to the manufacturer's instructions (Sombo *et al*., 2023). Radiation safety protocols were strictly followed to minimize exposure to personnel during the experiment.

Proximate Composition Analysis

The proximate composition was determined using the standard method of Association of Official Analytical Chemists (AOAC 2005) to determine the percentages of moisture, ash, crude fibre, crude protein, fat and carbohydrates.

Microbial Load Evaluation

The impact of irradiation on microbial populations was assessed by collecting samples from each treatment group and subjecting them to microbiological analysis. The samples were homogenized, serially diluted (10^2 and 10^4), and plated on agar using the pour plate method. Bacterial counts were determined after incubation on nutrient agar at 37°C for 24-48 hours, while fungal counts were determined after incubation on potato dextrose agar (PDA) at 25°C for 3-5 days. Colony-forming units (CFU) were counted, and microbial loads were calculated based on dilution factors, expressed in CFU/mL. Isolated colonies were subcultured and identified using biochemical tests and morphological characteristics.

Determination of Shelf Life

The shelf life of garden eggs was calculated from the daily physical inspections, including visual examination for signs of spoilage, weight loss measurements, texture analysis when the fruits had no commercial value.

RESULTS AND DISCUSSION

Treatment Parameters

The treatment parameters for UV-C and X-ray irradiation are presented in Tables 1 and 2.

Table 1: Dose and Time for UV-C Treatment

Group	Exposure Time (Minutes)	Dose ($mJcm^{-2}$)
U1	15	971.640
U2	20	1295.520
U3	25	1619.400
U4	30	1943.280

Table 2: Dose and Time for X-ray Treatment

Group	kVP	Exposure time (seconds)	Dose (μGy)
X1	50	0.4	30.80
X2	60	0.6	47.90
X3	70	0.8	72.90
X4	80	1.0	87.70

The treatment parameters for UV-C and X-ray irradiation are presented in Tables 1 and 2. In Table 1, the UV-C treatment doses were calculated using the Reciprocity Law of Exposure formula given in equation 1 below.

D = E x t (Agba *et al*., 2023).   (1)

where D is the dose, E is the irradiance, and t is the exposure time.

Prior to calculation, a UVC radiometer calibrated at 254 nm was used to measure the irradiance of the UV-C source. The measured irradiance was then used in Equation 1 to calculate the UV-C doses, which ranges from 971.640 to 1943.280 mJ/cm² as shown in Table 1. This indicates a direct relationship between exposure time and UV-C dose, with longer exposure times resulting in higher doses. The different values of U (U1, U2, U3, and U4) correspond to different exposure times, ranging from 15 to 30 minutes.

In contrast, the X-ray treatment doses presented in Table 2 were directly measured using a dosimeter. The results show that as the peak kilovolt (kVp) increases from 50 to 80, the X-ray dose also increases from 30.80 to 87.70 μGy. This indicates a direct relationship between kVp and X-ray dose, with higher kVp values resulting in higher doses. The different values of X (X1, X2, X3, and X4) correspond to different kVp values, ranging from 50 to 80.

The use of dosimeters in both UV-C and X-ray irradiation ensured accurate measurement of the radiation doses, which is essential for evaluating the effects of irradiation on the samples.

Table 3: Effect of X-ray Irradiation on Proximate Composition of Garden Egg

S/N	Group	Moisture	Crude Fat	Ash	Protein	Fibre	Carbonhydrate
1	CT	64.70±0.07	5.33±0.04	8.40±0.04	3.13±0.02	6.88±0.02	11.56±0.04
2	X1	65.11±0.06	5.25±0.04	8.37±0.03	2.98±0.01	6.69±0.01	11.60±0.01
3	X2	65.16±0.06	5.23±0.04	8.43±0.02	2.95±0.01	6.72±0.01	11.51±0.01
4	X3	65.24±0.06	5.22±0.05	8.45±0.02	2.94±0.03	6.75±0.01	11.40±0.01
5	X4	65.31±0.06	5.18±0.04	8.48±0.02	2.92±0.03	6.73±0.01	11.38±0.02

Table 4: Effect of UV-C Irradiation on Proximate Composition of Garden Egg

S/N	Group	Moisture	Crude Fat	Ash	Protein	Fibre	Carbonhydrate
1	CT	64.70±0.07	5.33±0.03	8.40±0.04	3.13±0.02	6.88±0.02	11.56±0.04
2	U1	64.92±0.06	5.42±0.03	7.98±0.02	2.67±0.01	6.81±0.01	12.20±0.01
3	U2	64.98±0.05	5.42±0.01	8.11±0.02	2.65±0.02	6.76±0.01	12.08±0.02
4	U3	65.11±0.05	5.43±0.01	8.13±0.02	2.61±0.02	6.74±0.01	11.98±0.02
5	U4	65.17±0.06	5.42±0.02	8.24±0.01	2.58±0.02	6.88±0.01	11.98±0.04

Table 1 shows that X-ray irradiation significantly enhances the quality and nutritional profile of garden eggs. Notably, the moisture content increases substantially with higher doses of X-ray irradiation, while the ash content also shows a notable increase, indicating an improvement in mineral composition. Although crude fat and protein content decrease slightly, the X4 treatment group retains respectable lipid and protein contents of 5.18% and 2.92%, respectively. The fibre and carbohydrate content remain relatively stable across treatment groups, suggesting X-ray irradiation doesn't compromise these essential nutrients. This pattern aligns with Akaagerger *et al.* (2023), who reported that X-ray irradiation effectively extended the shelf life of cucumber and Irish potato in Benue State while maintaining key nutritional parameters

Table 4 shows the impact of UV-C method on the proximate composition of garden eggs, increasing moisture and lipid content, but decreasing protein content. The U1 treatment group shows a balanced proximate composition, with moderate moisture (64.92%), slight increase in lipid (5.42%), relatively higher protein (2.67%), stable fibre (6.81%), and highest carbohydrate content (12.20%).

This is consistent with Joël *et al* (2024), who observed the influenced of UV-C radiation on Solanum Macrocarpon. Both studies used timed UV-C exposure at 254 nm, confirming that shorter duration UV-C treatment can preserve structure while limiting microbial growth. ANOVA results reveal significant variations in proximate composition parameters for both X-ray and UV-C irradiation treatments, indicating changes in the nutritional profile of garden eggs.

Table 5: Effect of X-ray Irradiation on Fungal Counts of Garden Egg

Sample	10^2	10^4	Cfu/ml	Organisms
CT	40	20	3.0×10^4	Mucor Spp, Aspergillus Spp
X1	8	2	5.0×10^3	Mucor Spp
X2	6	2	4.0×10^3	Mucor Spp
X3	9	3	6.0×10^3	Aspergillus Spp, penicullium Spp
X4	5	1	3.0×10^3	Penicillium Spp

Table 6: Effect of UV-C Irradiation on Fungal Counts of Garden Egg

Sample	10^2	10^4	Cfu/ml	Organisms
U1	34	16	2.5×10^4	Penicillium Spp, Mucor Spp
U2	5	3	4.0×10^3	Penicillium Spp
U3	8	4	6.0×10^3	Penicillium Spp
U4	4	2	3.0×10^3	Mucor Spp

X-ray and UV-C irradiation significantly reduced fungal counts in garden eggs. In table 5 X-ray irradiation at 80 Kvp (X4) achieved the highest reduction, from 3.0×10^4CFU/ml (control) to 3.0×10^3CFU/ml. Similarly, in Table 6, UV-C irradiation at 30 minutes (U4) reduced fungal counts to 3.0×10^3CFU/ml. Both irradiation methods selectively affected fungal species: X-ray irradiation eliminated Mucor Spp and Aspergillus Spp, leaving Penicillium Spp in the X4 group, while UV-C irradiation altered species distribution, with Penicillium Spp dominant in U2 and U3 groups, and Mucor Spp in U4. This suggests irradiation can modify fungal ecology. This dose-dependent effect aligns with findings by Prajapati *et al* (2021), who noted the shelf-life extension of bitter gourd fruit after UV-C exposure.

Table 7: Effect of X-ray Irradiation on Bacterial Counts of Garden Egg

Sample	10^2	10^4	Cfu/ml	Organisms
Control	112	48	8.0×10^4	E. coli, Staphylococcus Spp,
X1	20	12	1.6×10^4	Staphylococcus Spp,
X2	18	8	1.3×10^4	Staphylococcus Spp
X3	22	14	1.8×10^4	E.coli
X4	16	6	1.1×10^4	Staphylococcus Spp

Table 8: Effect of UV-C Irradiation on Bacterial Counts of Garden Egg

Sample	10^2	10^4	Cfu/ml	Organisms
Control	112	48	8.0×10^4	E. coli, Staphylococcus Spp,
U1	30	14	2.2×10^4	E.coli
U2	26	12	1.9×10^4	E.coli
U3	23	9	1.6×10^4	Staphylococcus Spp
U4	18	6	1.2×10^4	Staphylococcus Spp

X-ray and UV-C irradiation significantly reduced bacterial counts in garden eggs. X-ray irradiation at 80 Kvp (X4) achieved the highest reduction, from 8.0×10^4 CFU/ml (control) to 1.1×10^4CFU/ml. Similarly, UV-C irradiation for 30 minutes (U4) reduced bacterial counts to 1.2×10^4CFU/ml. Both irradiation methods selectively affected bacterial species: X-ray irradiation eliminated E. coli in X4, leaving only Staphylococcus Spp, while UV-C irradiation shifted species distribution from E. coli (U1-U2) to Staphylococcus Spp (U3-U4), indicating a potential selective pressure on bacterial ecology. The changes in bacterial species suggest irradiation can influence microbial composition, potentially impacting garden egg safety and quality.

Table 9: Observed Shelf-life for UV-C Treatment Group

S/N	Group	Shelf Life (Days)	Extended Shelf Life (Days)
1	CT	7	-
2	U1	9	2
3	U2	8	1
4	U3	7	0
5	U4	6	-1

Table 10: Observed Shelf-life for X-ray Treatment Group

S/N	Group	Shelf Life (Days)	Extended Shelf Life (Days)
1	CT	7	-
2	X1	9	2
3	X2	10	3
4	X3	10	3
5	X4	11	4

Table 10 shows that X-ray irradiation significantly extended garden egg shelf-life, with the X4 treatment (80 Kvp) showing the most pronounced effect, lasting 11 days compared to 7 days for the control group. The X-ray treated samples exhibited slower firmness loss, with X4 remaining slightly soft, whereas the control group became mushy by Day 7. Additionally, X-ray irradiation reduced mass loss, with X4 showing the lowest average mass loss (~6.9 g/day).

Table 9 shows that UV-C irradiation had mixed outcomes. U1 (15 minutes UV-C) extended shelf-life to 9 days, while higher doses (U3 and U4) accelerated spoilage, with U4 lasting only 6 days. UV-C treated samples also exhibited noticeable colour changes due to pigment breakdown and oxidative stress. Overall, X-ray treatment, particularly X4, is a promising method for improving garden egg storage and handling.

These findings are consistent with previous studies showing that X-ray irradiation can enhance postharvest quality and storage stability and storage stability of fresh produce, while UV-C effects vary with dose and exposure time (Yissah *et al* 2016; Yoon *et al* 2024; Singh *et al 2020;* Zhao *et al* 2022).

CONCLUSION

This study demonstrated that both X-ray and UV-C irradiation are effective methods for improving the shelf-life, quality, and safety of garden eggs. X-ray treatment significantly extended the shelf-life of garden eggs by 3-4 days, with the X4 treatment group (87.70 µGy) showing the most substantial extension. X-ray irradiation also enhanced the moisture content and mineral composition of garden eggs, with the X4 treatment group exhibiting an impressive 65.31% moisture level. Additionally, X-ray irradiation was effective in reducing microbial contamination, with significant reductions in fungal and bacterial counts.

In contrast, UV-C treatment showed varying degrees of shelf-life extension, with the U1 treatment group (971.640 mJ/cm²) showing an extension of 2 days. UV-C irradiation also had a notable impact on the proximate composition of garden eggs, but the protein content decreased with higher doses, raising concerns about potential nutrient loss.

Overall, the study suggests that X-ray irradiation is a more effective method for improving the shelf-life, quality, and safety of garden eggs compared to UV-C irradiation. The X4 treatment group demonstrated the most promising results, with enhanced moisture content, improved mineral composition, and significant reductions in microbial contamination.

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