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Effects of X-Irradiation on the Physicochemical Properties, and the Shelf-Lifeof Four Mango Species in Benue State, Nigeria

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Abstract:- Irradiation is an effective alternative to other preservative techniques.This study aimed at assessing the effects of Diagnostic X-rayson some physicochemical properties and the shelf life of four mango Varieties (*Broken, Dawshia, Julie,* and the *Peter* variety) grown in Benue State, Nigeria. Mango samples at the green mature stage were subjected to X-rays within the range of 60-100 kVp and stored at room temperatures (27-30 ºC). Data regarding Physicochemical properties and shelf-life were collected following laboratory guidelines. Results reveal an increase in density, moisture content, and pH with mango ripening. Ripening and increase in physicochemical properties were faster in controlled samples than in irradiated samples. Mass shrinkage was equally observed to be higher and faster in the controlled samples than in the irradiated samples. This resulted in higher shelf life (11 days) in irradiated samples than in controlled samples (7 days). Diagnostic X-rays can be used in mango preservation.

Keywords:- *X-rays, Physicochemical, shelflife, Mangoes, Benue State.*

I. INTRODUCTION

Mango (Mangifera indica L.) is a prestigious member of the Anacardiaceae family and one of the outstanding dietary fruits of the world. Its quality and nutritional attributes, the scale of production, and ability to grow in the tropical and subtropical regions enable it to be referred to as the *king of fruits*[1]–[3]. Population growth in recent yearshas increased global fruit consumption. This hasincreased the demand for fruits in both quality and quantity[4]. Because of this growing demand, there is a pressing need to enhance the quality of these produceto reduce post-harvest losses[5].Post-harvest losses of fruits like mangoes which is a global worry for both the developed and developing countries of the world[6], refers to spoilage and degradation of these fruits during transportation from the farm to consumers [7], [8].However, developing nations like Nigeria hold the highest records of postharvest losses than the developed world [9].Nigeria is known for the cultivation of fruits like pineapple, plantain, banana, guava, mango, citrus, pawpaw, among other agricultural produce which contributes to the income of persons living in both rural and urban areas, thus, serving as an important source of employment [10]. Mango has existed since the 16th century [11] but only came to Nigeria in the 20th century [2]. World rankings hold that Nigeria occupied the 8th position among the top Mango producing nations of the world in 2007 [12] and the 9th position in 2014 [13]. Benue State in Northcentral Nigeria is one of the top mango-producing states of Nigeria. This state produces a large number of mangoes with common names like the *Local mango*, *Johnbull*, *Broken*, *Peter*, *Julie*, *Dawshia*, *Hindi*, *Mummy*, *Tommy*, *Pitch*, *Palms*, and *Keith*, among other varieties of agricultural products that are taken daily in truckloads to other markets and other commercial centres across the country. Hybrid species like the *Johnbull*, *Broken*, *Peter*, *Julie*, *Dawshia* make up the commercial market of mango in Benue. However, despite Nigeria's strategic positions in mango cultivation, the country is not listed among the mango-exporting countries of the world. This hindrance is blamed on the harsh climatic conditions that catalyze spoilage, andthe lack of an effective means of preservation to increase the shelf life of these cultivars. Thishas made it difficult for farmers and vendors to convey and sell these products easily.

Food preservation refers to all processes involved in maintaining foods with the desired properties or nature for as long as possible. The physical, chemical, and sensory properties are important considerations in food preservation for acceptance. The sensory qualities reflect both the chemical and physical (physicochemical) properties of the components and how they interact during processing, preparation, and consumption[14], [15]. An understanding of these properties is necessary for scientists who haveto solve problems in food preservation, packaging, processing, storage, marketing, andconsumption[16], [17]. Literature has seen the common use of preservative methods like drying, refrigeration [18], [19], fermentation [20], canning [21], pasteurization [22], irradiation [23], among other means of preservation to increase the shelf life of food and agricultural products.

Irradiation is an invasive food preservative technique that uses ionizing radiation like X-rays, gamma-rays, and electron beams for improving the safety and shelf life of food and agricultural produce[24]. In addition to beinga good alternative to thermal treatments, the irradiation technique reduces the need for pesticides, some additives and antioxidants, and some toxic chemical treatments[25]. This preservative technique has emerged from being used for the preservation of spices and other food ingredients to perishables like meat[26], fruits [27]–[30], and other agricultural produce [31].Radiation sources for food preservation include γ-irradiation, electron beams, and X-rays. Most often, research has seen the common use of Gamma rays andX-rays due to their high penetrating powers. However, Diagnostic X-rays is rarely used.This Paper assessed the effects of diagnostic X-irradiation on the physicochemical properties and the shelf life of the *Brokin*, *Juley*, *Dawshia* and the *Peter* mango varieties.

II. MATERIALS AND METHODS

A. *Materials*

Materials and equipment used in this study include a blender, beakers, a digital pH meter, X-ray machine, a Microwave oven, a digital weighing balance, Four differenthybrid mango species (Broken, Peter, Julie, and the Dawshia mango), knife, Crucible dishes, desiccators, Potable water, and Tissue paper.

B. *Acquisition of samples*

Mango samples (*Brokin*, *Juley*, *Dawshia* and the *Peter* mango) were gotten from PE & I FOODS NIGERIA LIMITED; a fruit processing company located at KM 1 YandevKatsina-Ala road, Gboko local government area, Benue state, Nigeria. Mangoes were carefully selected at the green mature stage following the company's policy and taking into consideration some external quality factors like the maturity, healthy, and greenish nature of the samples. The selection was done in two categories; those for physicochemical properties and the others for the shelf life.

C. *Irradiation of samples*

Some samples of each mango species were kept as control (non-irradiated) while the other samples were sealed in different plastic papers and exposed to X-irradiation from an X-ray machine at a distance of 90 cm from the tube head. The rays were generated from a projectional X-ray machine of tube model number DX 4-2.9/100. The tube current and time were maintained at 32 mA and 1 second respectively while varying the tube voltage in the interval 60-100 kVp for different batches of the samples. Samples were placed on the table and the tube head adjusted to ensure that all samples were within the swipe area for each peak voltage value.

D. *Physicochemical properties*

a) Moisture content

The moisture content (water content) of the samples was determined following AOAC as described by[32]. Three slices (of1 g each) cut on different parts of each mango sample were weighed accurately into weighed dry-cleaned crucible dishes and masses (of the crucible dish without the sample) M_1, and (with the sample) M_2, were measured before placing in the oven. The uncovered dishes containing the samples were placed in amicrowave oven to dry at a temperature of 110 ° C for 4 hours. After this time, the samples were removed and transferred into desiccators at room temperature to cool. After cooling, the samples were weighed for the final mass M_3. The moisture content (M.C) on a wet basis (w.b.) was calculated following equation (1).Measurements were carried out on day 1, day 3. Day 5, and day 7 where controlled samples were/almost inedible.

$$M.C(\%) = \frac{M_2 - M_3}{M_2 - M_1} \times \frac{100}{1} \quad (1)$$

b) Density measurement

The density was measured following laboratory guidelines at ambient temperatures. This was done using a beaker of known volume V, a manual juicer, and a digital balance. The weight of the dry and empty beaker M1 was measured firstly using a balance. Each mango sample was crushed using a manual juicer and the juice was collected in another beaker. The juice was filled in the beaker of known volume and the mass M2 was measured. After each procedure with a particular species, the juicer and beakers were rinsed with potable water and dried with tissue paper before taking on other species. Density was measured on 4 different days like the moisture content. Each procedure was repeated and the average value was calculated. The density of each sample was calculated following equation (2)

$$Density\ (\rho) = \frac{M_2 - M_1}{volume(V)} \quad (2)$$

c) pH measurement

the pH was measured using the Hanna pH meter at ambient temperatures and following laboratory guidelines. The protective cap was removed and the meter turned on by sliding the switch at the top.The cap was then Immersed into the crushed mango solution in a beaker up to the maximum immersion level.The solution was stirred gently until the display stabilised and the pH value recorded. After use, the pH meter was switched off, electrodes washed with clean water and the protective cap replaced. This procedure was repeated for each mango sample and the average value was calculated.

E. *Shelf life*

After the exposure process, the mango samples were stored at room temperature (27-30 °C) of Makurdi and evaluated daily by measuring the masses of the mangoes and observing their physical conditions (colour and smell of the fruits) till the overripe stage. Masses of samples were measured daily with a digital weighing balance. Once a sample was almost/inedible (passed overripe stage), it was discarded. The daily mass shrinkage and the percentage mass shrinkage was Calculatedfollowing equation (3) and (4)respectively

$$Mass\ shrinkage = M_i - M_f \quad (3)$$

$$Percentage\ Mass\ shrinkage = \frac{M_i - M_f}{M_i} \times \frac{100}{1} \quad (4)$$

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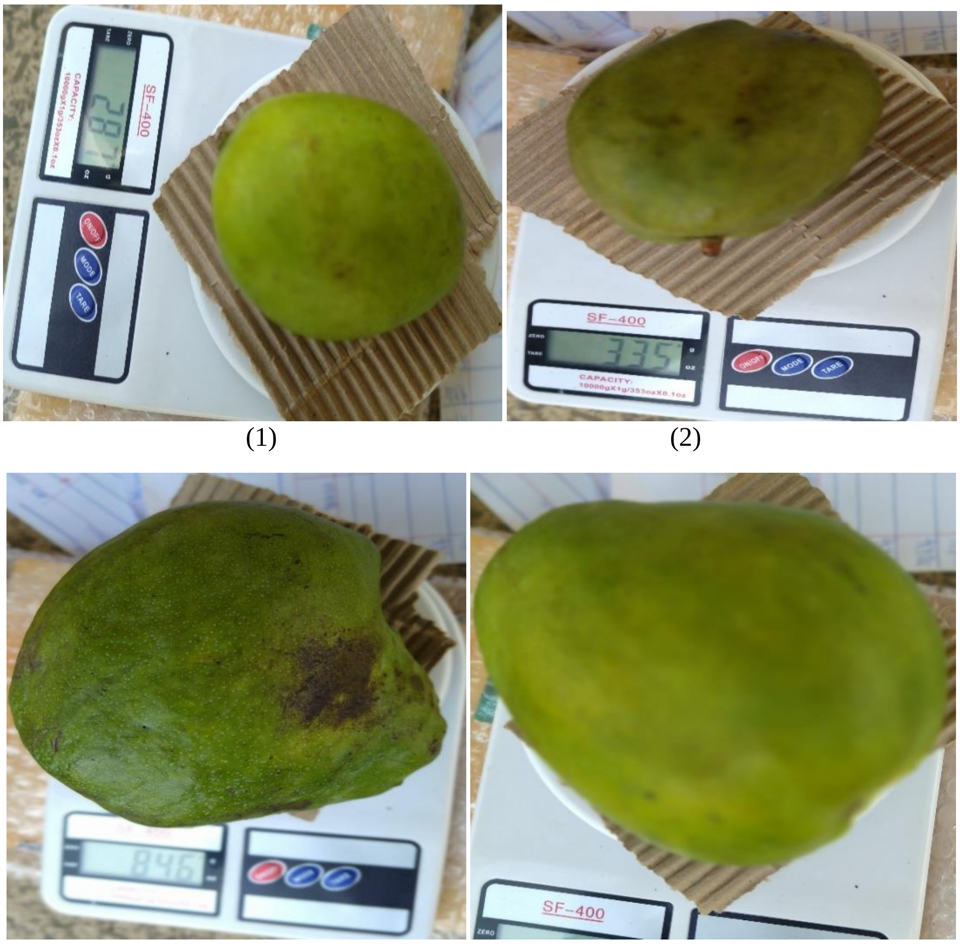


(1) (2)

(3) (4)

Fig. 1: Mass measurement of some cultivars of the Dawshia (1), Juley (2), Broken (3) and the Peter (4) mango varieties before irradiation.

III. RESULTS AND DISCUSSIONS

	pH				**Moisture content (%)**				**Density (g/cm^3)**			
Dose(kVp)	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7
0	3.5	4.2	4.9	5.4	75.94	77.55	83.25	81.27	1.06050	1.06422	1.07553	1.08590
60	3.3	3.9	4.4	4.9	73.27	75.82	81.92	82.05	1.03123	1.04651	1.07121	1.07733
70	3.8	4.0	4.5	5.1	77.13	77.50	80.42	82.33	1.03225	1.06362	1.06617	1.07062
80	3.7	3.9	4.6	4.7	74.50	75.18	79.27	81.89	1.04375	1.05756	1.06225	1.07635
90	3.4	4.0	4.3	4.9	76.63	75.80	78.63	80.45	1.03747	1.04723	1.05841	1.07874
100	3.4	3.8	4.6	5.0	74.15	75.21	78.15	80.01	1.05874	1.05572	1.05944	1.07001

Table 1: Variation in Density, Moisture content, and pH of Broken Mango with storage

	pH				**Moisture content (%)**				**Density (g/cm^3)**			
Dose(kVp)	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7
0	3.6	4.5	4.9	5.1	72.13	79.67	82.76	80.44	1.06253	1.07442	1.09157	1.10974
60	3.3	3.9	4.6	5.0	76.35	78.82	81.70	82.12	1.04351	1.06673	1.08261	1.10755
70	3.5	4.1	4.5	4.9	78.50	79.27	80.66	81.60	1.05003	1.06256	1.07942	1.0952
80	3.7	4.1	4.7	4.8	77.21	78.73	79.50	80.57	1.03125	1.05421	1.0779	1.08767
90	3.2	4.1	4.5	4.7	76.04	76.98	78.91	79.63	1.0093	1.05791	1.07211	1.07950
100	3.5	4.2	4.6	4.8	75.72	78.25	79.23	80.31	1.06425	1.06023	1.07151	1.08125

Table 2: Variation in Density, Moisture content, and pH of Dawshia Mango with storage

	pH				Moisture content (%)				Density (g/cm^3)			
Dose(kVp)	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7
0	3.9	4.6	4.9	5.0	69.25	75.67	79.87	78.64	1.04376	1.08147	1.09031	1.13622
60	3.5	4.3	4.8	4.8	73.48	73.82	79.2	78.72	1.05625	1.07611	1.08474	1.11748
70	3.8	4.0	4.4	4.6	71.31	73.50	77.42	78.13	1.06251	1.05991	1.08415	1.09761
80	3.6	4.3	4.5	4.7	67.13	75.73	78.55	79.22	1.03405	1.06855	1.07337	1.08630
90	38	4.2	4.4	4.7	74.25	75.63	76.23	76.8	1.04754	1.05367	1.06911	1.09377
100	3.8	4.5	4.5	4.6	71.04	76.98	77.63	79.06	1.04502	1.06285	1.06705	1.07950

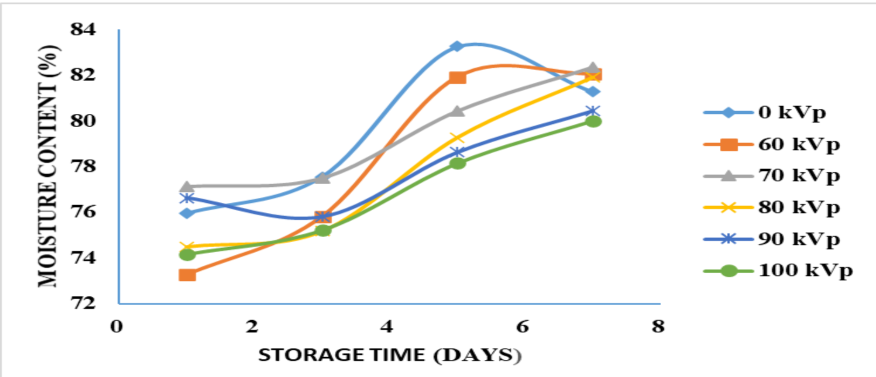
Table 3: Variation in Density, Moisture content, and pH of Juley Mango with storage

	pH				Moisture content (%)				Density (g/cm^3)			
Dose(kVp)	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7	Day 1	Day 3	Day 5	Day 7
0	3.7	4.2	4.4	4.7	68.5	77.45	84.11	83.63	1.045203	1.0644	1.07412	1.08627
60	3.4	4.0	4.2	4.4	74.33	75.2	81.25	84.25	1.02513	1.0442	1.04913	1.05125
70	3.9	4.1	4.4	4.5	63.37	76.98	79.67	82.09	1.05258	1.05916	1.06612	1.0703
80	3.8	4.0	4.3	4.5	72.15	74.65	78.35	80.33	1.01875	1.03571	1.06415	1.07705
90	3.5	3.9	4.1	4.3	77.73	76.17	79.23	80.71	1.04376	1.05272	1.05832	1.0624
100	3.4	3.9	4.0	4.2	71.98	73.19	78.51	81.20	1.0425	1.03664	1.04735	1.06117

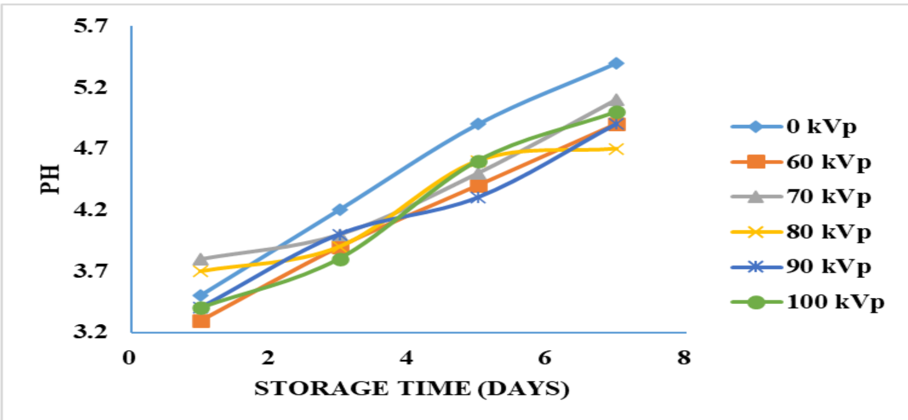
Table 4: Variation in Density, Moisture content, and pH of Peter Mango with storage

Species	0 kVp	60 kVp	70 kVp	80 kVp	90 kVp	100 kVp
Broken	11.1	10.9	9.7	10.03	9.96	9.80
Dawshia	7.4	6.8	6.5	6.7	6.2	6.1
Juley	14.6	13.0	13.9	13.5	13.3	13.4
Peter	8.7	8.1	7.2	7.9	7.3	7.5

Table 5: Percentage mass shrinkage of cultivars with different doses of irradiation



(a)



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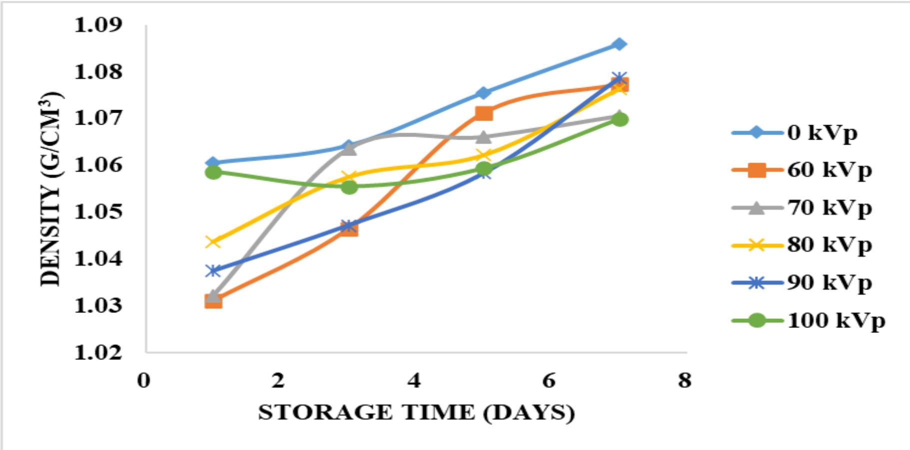
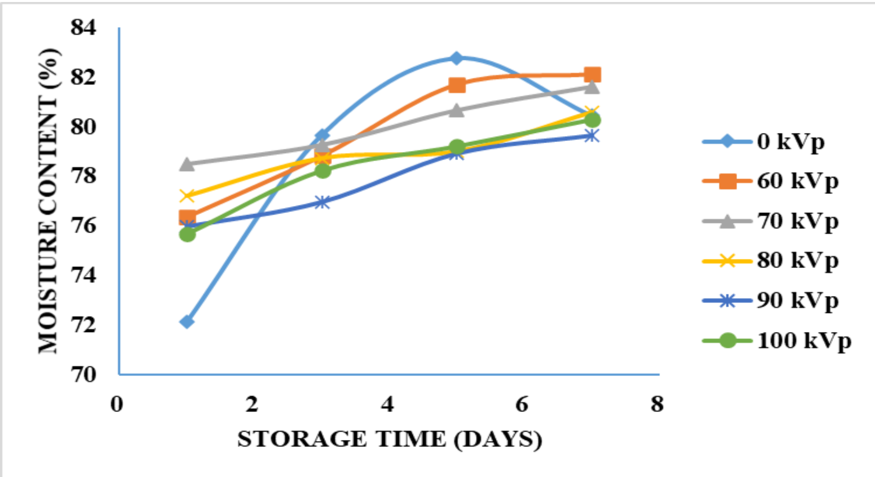
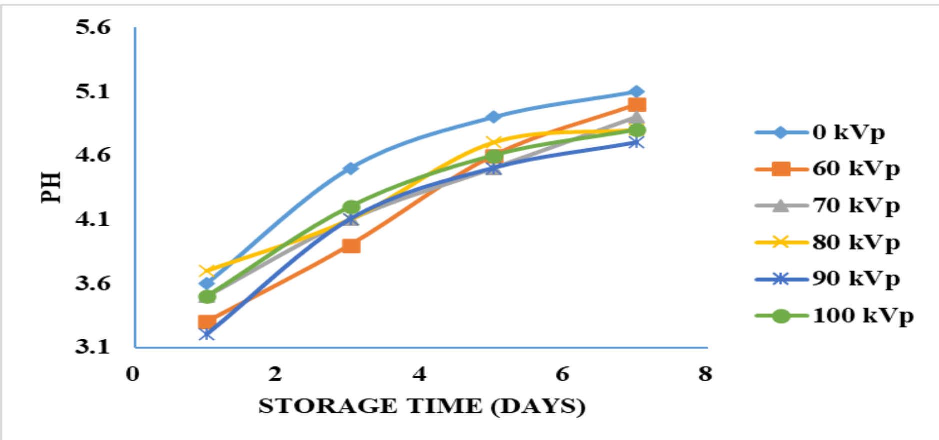


(c)

Fig. 2:Variation of moisture content (a), pH (b), and density (c) of the Broken mango with different doses of irradiation during storage.



(d)



(e)

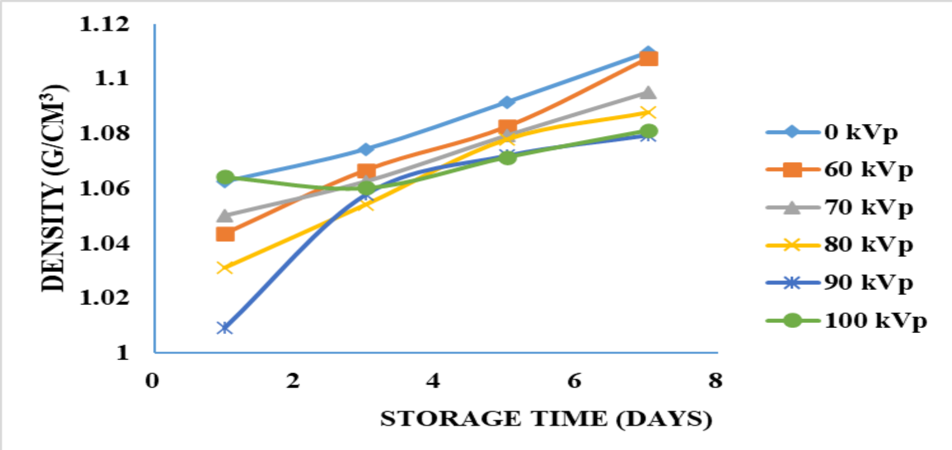
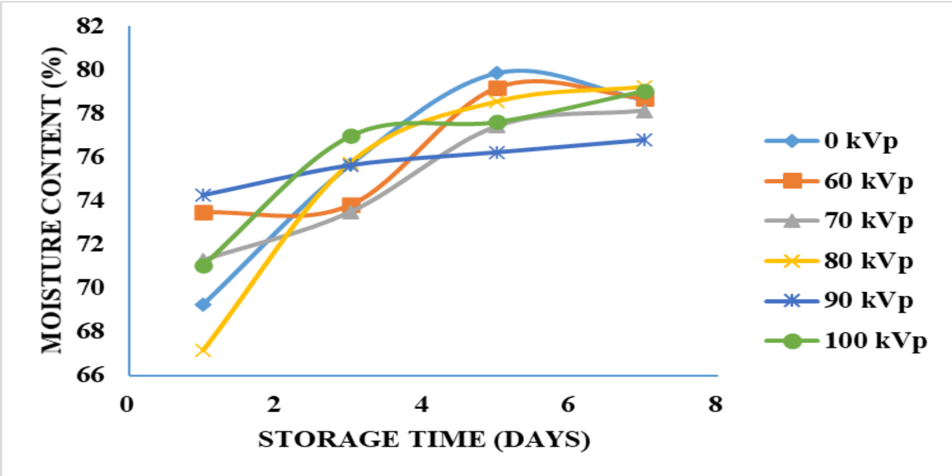
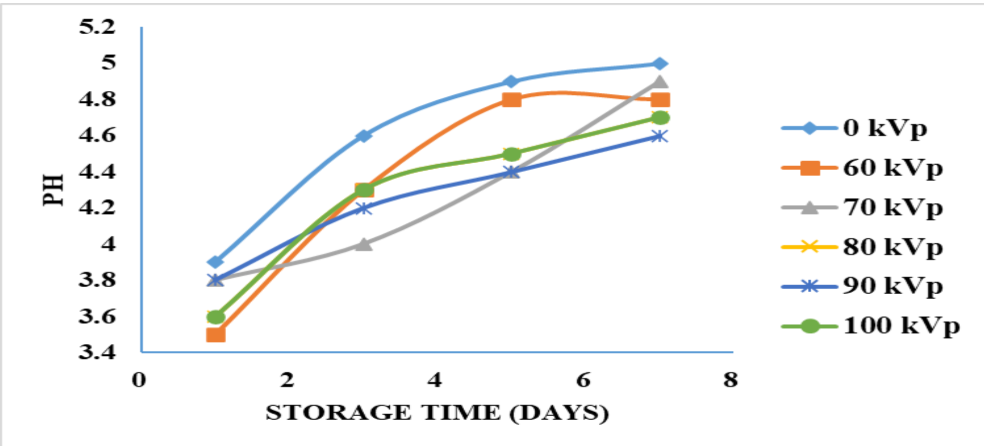


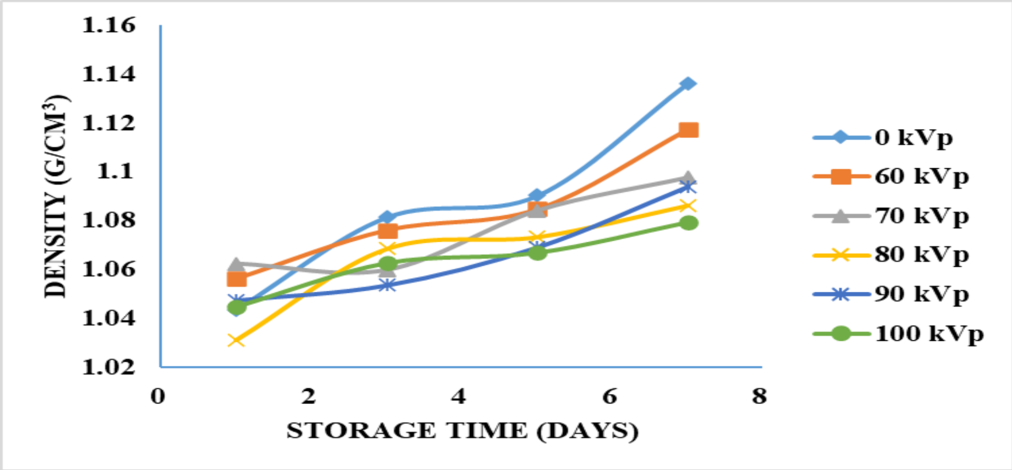
Fig. 3: Variation of moisture content (d), pH (e), and density (f) of the Dawshia mango with different doses of irradiation during storage



(p)

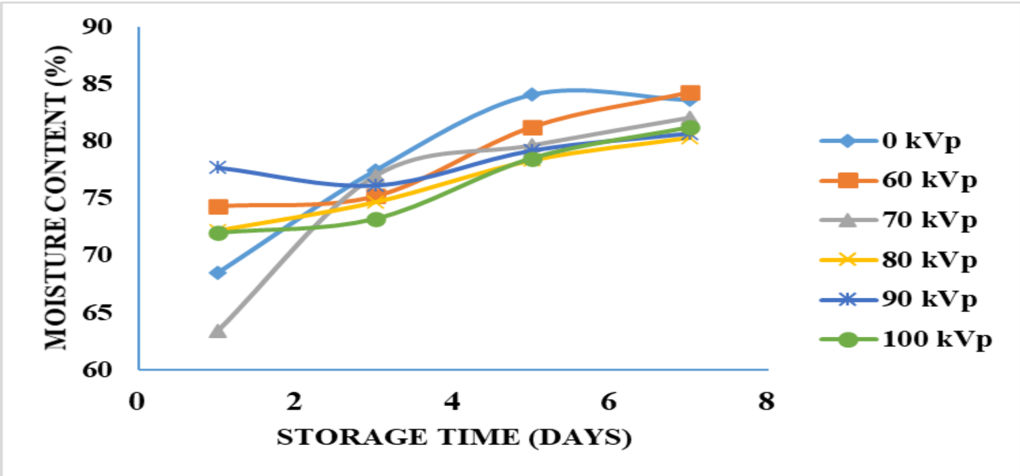


(q)

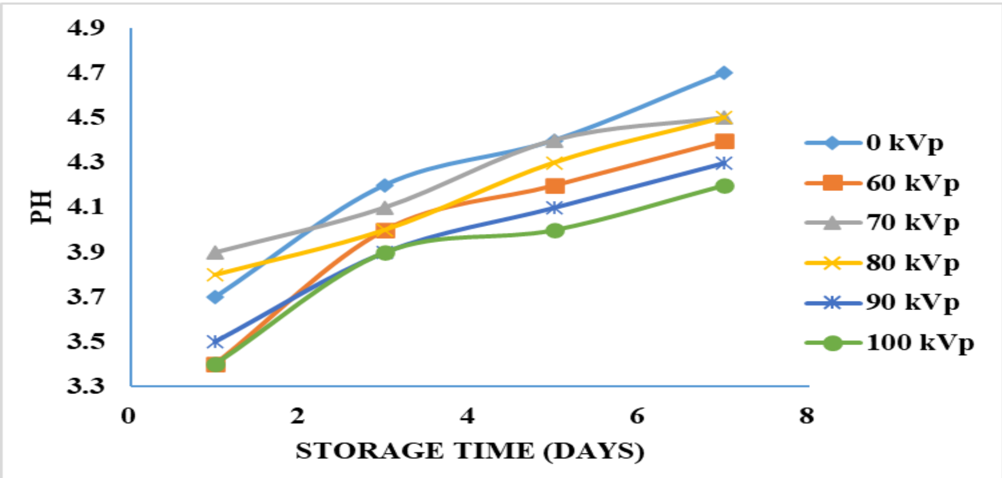


(r)

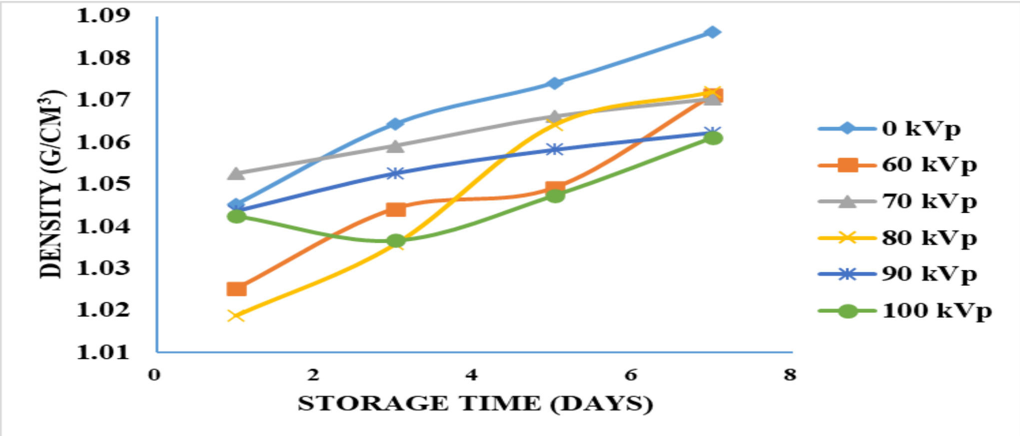
Fig. 4: Variation of moisture content (p), pH (q), and density (r) of the Juley mango with different doses of irradiation during storage



(x)



(y)



(z)

Fig. 5: Variation of moisture content (x), pH (y), and density (z) of the Peter mango with different doses of irradiation during storage

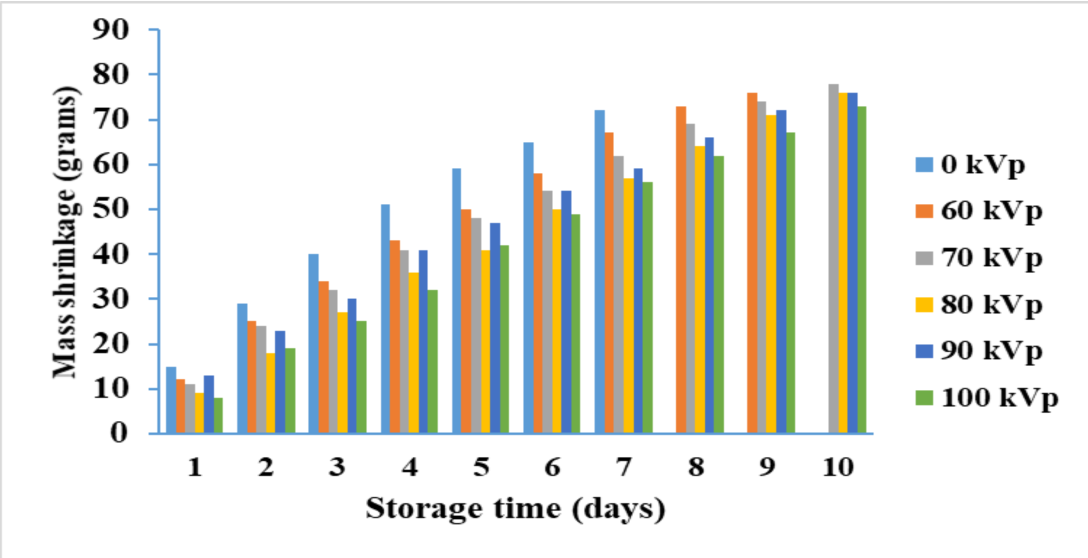


Fig. 6: Bar chart representation for Mass shrinkage of the Broken mango with different doses of irradiation during storage

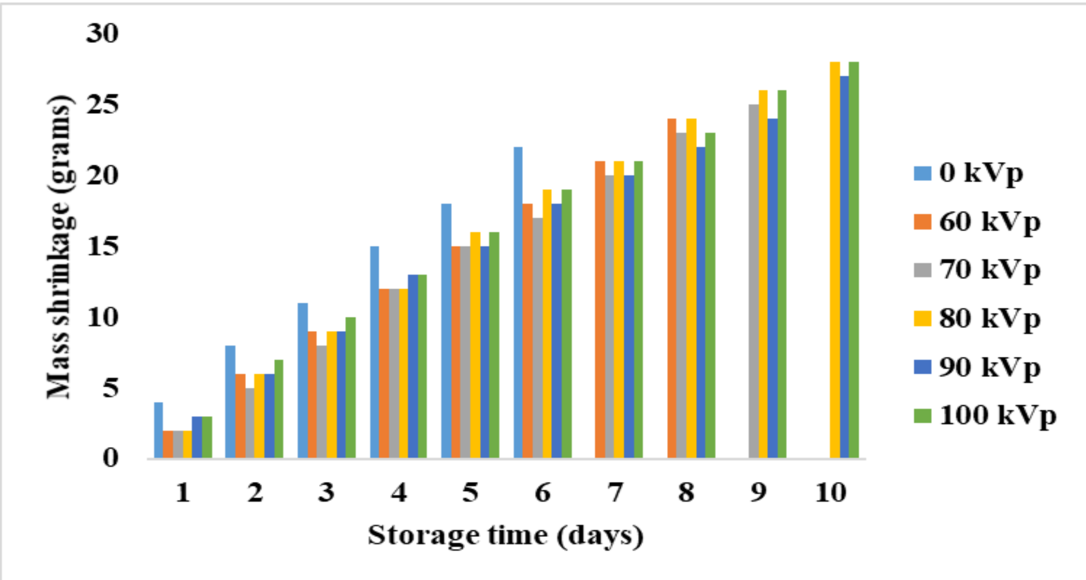


Fig. 7: Bar chart representation for Mass shrinkage of the Dawshia mango with different doses of irradiation during storage

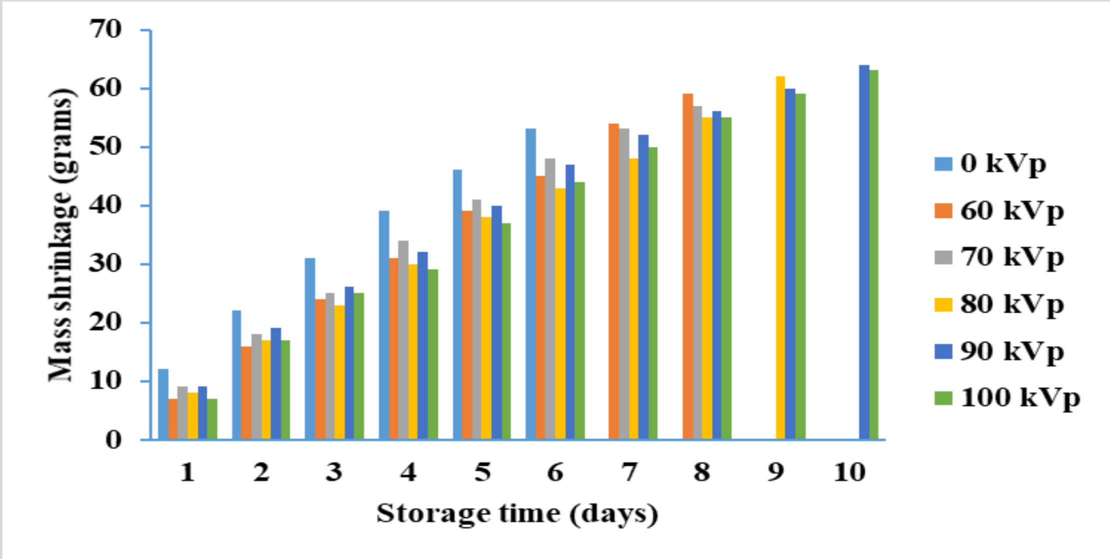


Fig. 8: Bar chart representation for Mass shrinkage of the Juley mango with different doses of irradiation during storage

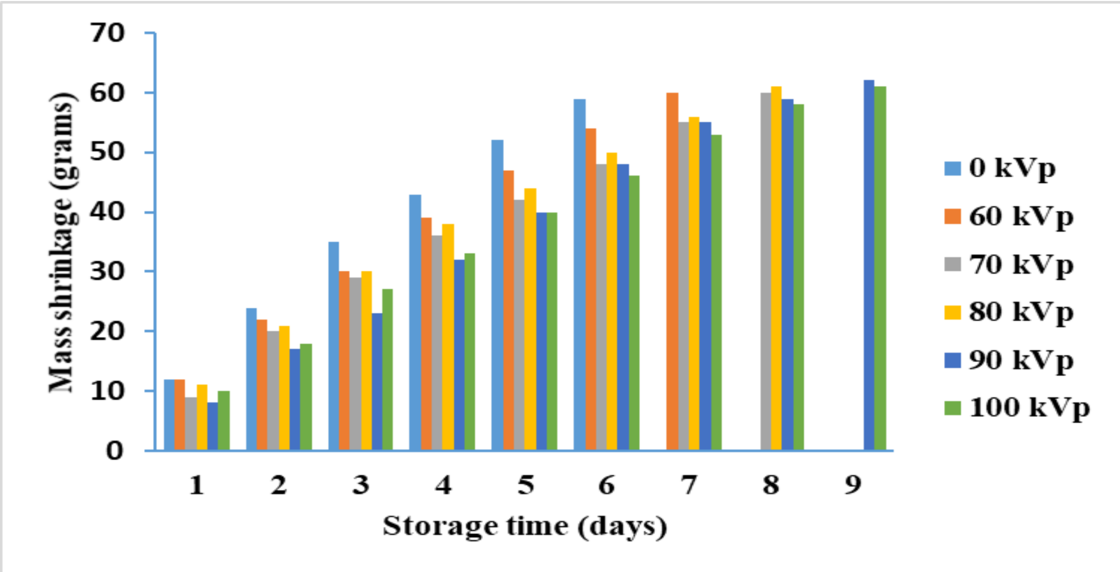


Fig. 9: Bar chart representation for Mass shrinkage of the Peter mango with different doses of irradiation during storage

IV. DISCUSSION

A. *Ripening of mango samples*

Ripening occured within 2-5 days in control samples and 4-8 days in irradiated samples. Ripening began in the peter mango, followed by the *Juley* and *Broken*, then the *Dawshia* mango. This was indicated by the yellowish colour and good smell of fruits. According to [33], the ripening process is associated with the conversion of chloroplast to chromoplast and the hydrolyses of starch into fructose and glucose marked by an increase in enzymatic activity [34], [35].These processes were faster in the control samples than in the irradiated samples indicating a delay in ripening with exposure to radiation from X-rays within the diagnostic range. Though the *Broken* mango ripped first before the *Dawshia*variety, the *Broken* was able to resist spoilage more than the *Dawshia* variety. Ripening was fastest in the *Peter* mango as most of its controlled samples were fully ripe as early as the 4th day and could barely reach day 7. The *Juley* variety was also quick to ripe but was very resistant to spoilage as compared with the Peter species. On average, the *Dawshia*and *Broken* species did better during the storage time than the *Peter* and *Juley* species. Results also reveal that samples irradiated at 80-100 kVp showed more resistance to ripening and spoilage than the controlled and 60-70 kVp values indicating higher chances of preservation at higher doses of irradiation. This is a possible indication that the dose range of 80-100 kVp was more effective in stopping the growth of microorganisms that serves as a catalyst for mango spoilage. These results conform with the works of [35] who carried out a similar study on bananas (*Musa acuminata*) at ambient temperatures.

B. *The pH of samples*

Results show an increase in pH with the ripening of samples up to the overripe stage. Similar results were obtained by [36].Increase in pH values with ripening is associated with the oxidation of citric acid as mango ripens, resulting in higher values of pH [37]. This increase was remarkable in the controlled samples. The lowest pH values were observed for unripe samples on day one (immediately after irradiation) while the highest values were observed in riped controlled samples for all varieties on the 7th day.This closely follows results obtained by [38] and [39].No effect of X-rays on pH was observed on the first day of irradiation. Higher pH values observed in controlled samples indicate that the ability of diagnostic X-rays to delay ripening in mangoes results in a delay in the progress of the pH values.Differences in pH ranges may be associated with the genetic dissimilarity of varieties [40].

C. The moisture content

Moisture content followed a similar trend to the pH (Table 1-4, Figure 2-5). The moisture increases as mango ripen with higher values in non-irradiated samples. However, a decrease was observed from the ripe to the overripe stage of the mango samples. This is evident in results obtained by [41].Values of moisture content range within 63-84%. This also follows results documented by [36], [42].Following the results, the *Peter* variety has the highest moisture content, followed by the *Broken*, *Dawshia*, then the *Juley* variety.During ripening, as starch gets converted in unripe mangoes to sugars,this increases the transfer of moisture from peel topulp via osmosis, leading to an increase in the moisture content[43].The *Broken* variety has a higher moisture content than the *Juley* variety but spoilage in the *Juley* variety occur first. This can be attributed to other factors like the water activity of the two samples [44]. Lower values of moisture content in irradiated samples are evident that the X-irradiated samples were more preserved. Hence, diagnostic X-rays is capable of delaying ripening which in turn affects the moisture content of mangoes at ambient temperatures.

D. The density

The density of samples increased as mango ripens within the range 1.00930-1.13622 g/cm^3. Similar findings were documented by [41] and [45] who reported an increase in the density of mango with ripening up to a maximum at the overripe stage. Like the pH and moisture content, higher values of densities were observed in the control samples as compared to the irradiated samples indicating that diagnostic irradiation has an indirect effect on the density of mango samples at ambient temperatures. Results also show that the Juley variety is denser than all other samples, followed by the *Dawshia*, *Peter*, then the *Broken* variety in that order.Lower density values were also obtained in the irradiated samples as compared with the controlled samples.

E. Mass shrinkage and shelf life

The decrease in starch content during ripening results in the shrinkage of the mass. The mass shrinkage was higher and faster in the controlled samples than in the irradiated samples. The changes were not consistent in the irradiated samples (Figure 6-9). This is confirmatory with results obtained by[46], and [35]who observed smaller mass shrinkages in the ripening of bananas treated with X-rays within the range of 50-90 kVp. The delay in mass shrinkage in the irradiated samples resulted in higher shelf life (11 days) than in the controlled samples (7 days). This is because X-rays reduced the risk of food-borne diseases by killing microorganisms that catalyze fruit spoilage [47]. The higher percentage mass shrinkages in the controlled (Table 5) samples imply that the they were less preserved. Different percentage mass shrinkage ranges in different species are mostly associated with the mass range and nature of the cultivars. No significant variation in the mass shrinkage was observed for the irradiated samples of a particular species. This agrees with the works of[48]. The shelf life of the non-irradiated mangoes was generally 7 days for all species except for the controlled samples of the peter species that barely reached the 7th day. Diseases were also dominant in the peter species. This can be attributed to the nature of the Peter mango. The Broken mango proved to be more resistant to spoilage than all the other varieties. This was closely followed by the *Dawshia* andthe *Juley* varieties. Results show that without irradiation, some of these mangoes could stay for 5-7 days at most and still be edible at temperatures of 27-30 °C. However, Irradiation in the range 60-100 kVp proved to be able to extend the shelf life of these varieties for 4days as samples exposed to X-rays were able to last up to 11 days at the ambient temperatures of Makurdi. Results obtained by [38] reveal that Irradiated mango could be preserved for more than 28 days at 10-14°C. Similar studies have equally revealed that irradiation is capable of preserving without change in quality [49].

V. CONCLUSIONS

The study reveals an increase in the shelf life of samples with irradiation, especially for samples irradiated with X-rays in the range of 80-100 kVp. These irradiated samples were seen to last for 4 more days after the controlled samples were discarded, indicating that diagnostic X-rays affect shelf life, and hence, the physicochemical properties of mangoes at ambient temperatures. Thus, irradiation technology (80-100 kVp) can make a significant impact in extending the shelf-life of mango and in controlling mango diseases in Benue state as it has proven to be able to delay ripening in mangoes at ambient temperatures. These effects were however short-lived due to the said temperatures (27-30 °C), so, we recommend further studies in the use of higher doses of X-rays, and at controlled temperatures to better improve the shelf life of these species.

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CONFLICT OF INTEREST

Authors declare no conflict of interest

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