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Research Article

Assessment of Gamma Radiation for Post-Harvest Management

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Abstract
The potential for gamma irradiation in post-harvest management was assessed by using two freshly harvested varieties of yam (*Dioscorea rotundata* L. Poir) locally known as Ogini and Fakasa yam cornels in Abuja, Nigeria and immediately transported to the Nuclear Technology Centre (NTC) of the Nigeria Atomic Energy Commission FCT Abuja, Nigeria. The cormels were stored in baskets and subjected to different doses of gamma irradiation; 0, 40, 80, 120, 150 and 180 Gy respectively. The effects of gamma irradiation on important yam parameter such as shelf-life extension; sprouting, weight loss and proximate content of stored Ogini and Fakasa yam were investigated for 12 months at two-month interval. The result showed that 100% of the un-irradiated yams, 20% of 40 Gy, 5% of 80 Gy all rotted while none of the 120 Gy and above irradiated yams rotted within the storage period. The percentage weight loss (69.79±15.49%) in the un-irradiated was significantly ($p \le 0.05$) higher than the irradiated cormels.
Keywords: Food, Gamma Irradiation, Yam Cormels, Nutrition, Postharvest Management, Sprout Inhibition.

Introduction

The food security is one of the global challenges, and it is more pronounced in developing countries. According to Martin-Shields and Stojetz (2019), global food security has been hampered as a result of different conflicts (ethno-religious and political differences); climate change and terrorism activities. While global efforts geared towards minimizing the effect of these factors, there is a need to secure the available food for all-round season provision. Hence the term post-harvest management. Adeniiji (2019) reported that most food crops are not only seasonal, but prone to microbial-induced deterioration during storage, due their chemical constituents such as high moisture content and crude protein. Hence there is a for post-harvest management to ensure all-round availability at a relatively fair cost. According to Demi (2014), yam is one of the major food crops which is consumed traditionally in Africa but has transcend to many nations including part of Europe. Yam is the second most important cormel crop in Africa next to cassava (Ferraro *et al.,* 2016), while it remains the fourth most utilized tuber crops globally (Aighewi *et al.,* 2023). In 2016, global yam production stood at 66 million metric tons (Wumbei *et al.,* 2022). The high consumption of yam is also enhanced by its ability to serve as a food in many forms such as a boiled yam with stew; pounded yam with delicious soup; yam's chips; yam flour-to produce amala, and recently being inculcated to serve as a flour for bread and confectionaries. They also serve as a source of vitamins, iron, calcium and nicotinic acid but are low in saturated fat and sodium (Obidiegwu *et al.,* 2020). This high utility has placed huge demand on the production of yam (Adejo, 2017).

The production of yam is usually seasonal, storage is necessary for its availability all year round. In developing world poor farmers and many people depend mostly on corm crops as their principal or major sources of food, nutrition and cash income. As a result, yam becomes exploited resources (Chauhan *et al.,* 2022) together with post-harvest loss which usually ranges from 25% to 60% (Abewoy 2021). Lawal *et al.,* (2011) reported that activities of yam pest and sprouting during storage left many yam seedlings spoilt and farmers are left with low yam seedling for subsequent farming process. Thus, led to the underutilization of yam formulation. Traditionally, yams are preserved inside the houses or stored outside in barns but these methods expose them to attack by pests and micro-organisms and substantial losses in weight during post-harvest period due to sprouting (Bhandari *et al.,* 2003). Yams kept in barns are bound to degrade and depreciate in size over time due to interaction with atmospheric environment (Veena *et al.,* 2021). Other conventional method involves the manual removal of the bud as soon as germination or sprouting of the tuber is noticed in the yam barn (Etudaiye *et al.,* 2020). This method is found to reduce loss in weight, moisture content and carbohydrate food content but is difficult to apply for large scale storage of yams. Storage at low temperatures, particularly at 15^0C, suppresses sprouting in yams. This temperature also reduces weight loss, moisture loss, respiration rate, and maintains good palatability of stored product. However, lack of regular supply of electricity, cost and relatively high temperature tropical weather do not encourage low temperature storage technique. Also, the use of chemical treatment in retarding sprouting which involves the use of inhibitory chemical growth regulators such as tetrachloronitro-benzene, maleic hydrazide, acetic acid, and naphthalene was reportedly effective and efficient (Gianfagna, 1995). However, chemical challenges such as inadequacy; adulterated, toxic nature and feasible chemical leaching has limited its application. Hence, the search for effective and efficient post-harvesting management of yam.

Gamma-irradiation is a post-harvest handling technique that brings food crops in direct contact with radiations or light rays where they are ionize in order to prolong shelf life during storage (Mshelia *et al.,* 2023). According to Thomas (2020), gamma irradiation has the potential to control postharvest losses of a wide range of fresh food produce. The function of food irradiation is to control insect infestation and the numbers of pathogenic or spoilage microorganisms. It also helps to arrest or reduce ripening in fresh fruits and vegetables such as onions, potatoes, garlic and ginger; sprouting in cormels and germination that occur in bulbs as it damages the cells of the food product. Islam *et al.,* (2022) reported that the gamma irradiation process is easy, clean, and environment-friendly. The choice of Ogini and Fakasa yam cormels is because of its preferred indigenous cultivars of white yam are easily powdered, fried, boiled, cooked and pounded; and highly palatable (MTRM, ADP, 2007).

Materials and Methods

Materials Required for the Research

Distilled water, sulphuric acid (H_2SO_4), glacial acetic acid, conc. nitric acid, trichloro acetic acid, sodium hydroxide, zinc dust, acetone, petroleum ether and diethyl ether. All reagent is of analytical grade. The apparats include beaker, analytical balance, air dryer, filter paper, desiccator, hot air oven, conical flask, evaporating dish, line cloth, Kjeldahl flask, Buchi distillation unit K crucible, Soxhlet extractor, rotary evaporator, round bottom flask, thimble, oven and heating mantle, gamma irradiation facilities.

Methods

Sample Preparation

Two different species of yam (*Dioscorea rotundata)* namely; Ogini and Fakasa corms were obtained from local yam farmer at Gwagwalada, Abuja, Nigeria and identified at the Department of Agricultural Research in Nuclear Technology Centre (NTC) Sheda, Atomic Energy Commission (NAEC) Abuja. The yams were divided into six groups (ABCDEF) with ten (10) tubers making each group. The selected yam corms samples were thoroughly cleaned, and kept in a clean, moisture and dust free environment for irradiation treatment which was done in the irradiation facility.

Gamma-Irradiation Facility

The gamma irradiation of yam cormels in the gamma irradiation facility with cobalt-60 source located at Nigeria Atomic Energy Commission, Sheda, Abuja was used for the irradiation. The facility is a multipurpose semi-commercial plant designed as a research and experimentation facility as well as for industrial purposes. The irradiation was carried out in the stationary mode of operation with the possibility of varying dose rates (50–5000 Gy per hr) depending on the location and distance from the source. The prepared yam tubers were subjected to gamma irradiation effect for 2 h at the following doses; 40 Gy, 80 Gy, 120 Gy, 150 Gy and 180 Gy respectively while A was not irradiated (it served as the control).

Table 1. The amount of doses of gamma ray to different groups.

Amount of gamma radiation (Gy)	Groups
0	A
40	B
80	C
120	D
150	E
180	F

Determination of Sprouting and Decaying of Yam Corm Samples

The yam samples were marked for easy of identification and observed in an open store at ambient temperature for 12 months. Vine lengths of the sprouting tubers were measured and recorded at one (1) interval till 12 months after storage (MAS).

Determination of Weight Loss and Inhibition Efficiency of the Yam Corm Samples

The weight of each of the yam tuber was also measured and recorded at the start of the work as well as at one (1) interval till 12 months after storage (MAS) to determine weight losses of the cormels.

The weight loss is calculated using the below formula

$$\text{Weight loss, WL (g)} = (W_i - W_f)$$

Where,

W_i and W_f represents initial weight of metal sample before immersion and final weight of metal sample before immersion

Determination of Proximate Analysis of the Yam Samples

The proximate analysis was determined using the procedure described by the Association of Official Analytical Chemists (AOAC, 2005).

Figure 1. Yam samples and the peeled one for proximate determination.

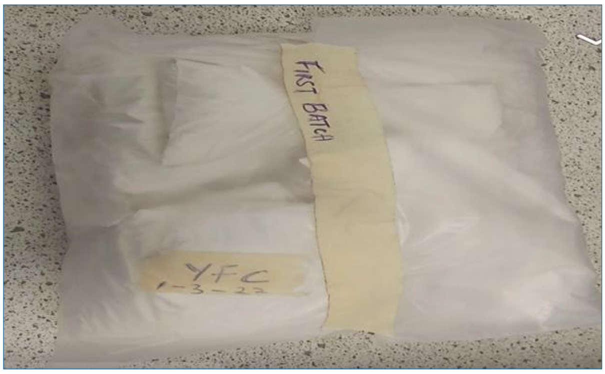

Figure 2. The yam powder sample for proximate analyses.

Statistical Analysis

The effect of gamma irradiation on yam samples is subjected to statistical analysis. All analyses were performed in triplicates. Means was separated according to Duncan's multiple range analysis ($P \leq 0.05$), with the help of the software SPSS 16.0. Results was expressed as means ± standard deviation. Statistical significance was established using analysis of variance (ANOVA) models to estimate the effect of gamma irradiation on nutritional and biochemical composition of Ogini and Fakasa yam cormels.

Results and Discussion

The gamma-irradiation facility with cobalt-60 source located at Nigeria Atomic Energy Commission, Nuclear Technology Centre Sheda, Abuja was used to generate and analysed the results of the effects of gamma irradiation on sprouting, nutritional and phytochemical composition of Ogini and Fakasa yam corms which are presented and discussed below.

Sprouting and Decay in Yam Corms Samples

The un-irradiated yams sprouted entirely with mean vine length of the of 83.9 cm at the end of the 3rd month after storage for both S_o and S_f yam corms sample which are Ogini and Fakasa yam corms. This mean increased to 202.7 cm and 310.1 cm at 4 months and 5 months after storage respectively. In the irradiated yam corms, 90% of the 40 Gy, and 20% of the 80 Gy sprouted within the storage period of 12 months. None of the irradiated yam corms at 120-180 Gy sprouted for S_f yam corms while for S_o corms ranging from 80-180 Gy irradiations none sprouted. The results recommend that gamma-irradiation dose range of 80–180 Gy could successfully inhibit sprouting in yam corms for 12 months. This finding agrees with Subramanian (2003) which reported that 150 Gy doses of gamma irradiation inhibit the sprouting of potatoes and onions.

Table 2. Sprouting of S_o yam species during storage.

Sample	Dose	Initial number of yams	Number sprouted per month												Total	Sprouted
S_o	(Gy)		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th		(%)
A	0	10	1	3	6	*	*	*	*	*	*	*	*	*	10	100
B	40	10	*	1	1	5	1	*	*	*	*	*	*	*	8	80
C	80	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
D	120	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
E	150	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
F	180	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 3. Sprouting of S_f yam species during storage.

Sample	Dose	Initial number of yams	Number sprouted per month												Total	Sprouted
S_f	(Gy)		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th		(%)
A	0	10	4	5	1	*	*	*	*	*	*	*	*	*	10	100
B	40	10	*	1	6	1	1	*	*	*	*	*	*	*	9	90
C	80	10	*	*	2	*	*	*	*	*	*	*	*	*	2	20
D	120	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
E	150	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
F	180	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 4. Rotting of S_o yam species during storage.

Sample	Dose	Initial number of yams	Number rotted per month												Total	Rotted
S_o	(Gy)		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th		(%)
A	0	10	*	*	2	4	2	1	1	*	*	*	*	*	10	100
B	40	10	*	*	*	*	*	*	1	2	1	1	2	1	8	80
C	80	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
D	120	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
E	150	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
F	180	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 5. Rotting of S_f yam species during storage.

Sample S_f	Dose (Gy)	Initial number of yams	Number rotted per month												Total	Rotted (%)
			1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th		
A	0	10	*	*	3	4	3	*	*	*	*	*	*	*	10	100
B	40	10	*	*	*	*	*	1	1	3	2	1	2	*	10	100
C	80	10	*	*	*	*	*	*	*	*	1	1	1	*	3	30
D	120	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
E	150	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*
F	180	10	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Determination of Weight Loss

The drying effect of the yam corms for the storage period of 12 months for the S_o and S_f yam corms are shown in Table 6. The highest weight loss (%) was observed in S_f (A) with 93.56±19.55% and S_o (A) with 90.29±19.30% respectively. This weight loss was accelerated due to high sprouting in irradiated samples. For S_o, the weight loss (%) decreases significantly ($p \leq 0.05$) from 40.83±11.21% to 13.55±5.33% as doses of radiation increase from 40 Gy to 180 Gy. Also, S_f witnessed the significantly ($p \leq 0.05$) weight loss (%) from 57.74±12.33 to 16.67±5.33 as gamma irradiation doses increases from 40 Gy to 180 Gy. These show that radiation treatment of the yam corms preserves the freshness of the corms during storage to a great extent when compared with the untreated corms used as control. Yams stored for a period of time become dehydrated, fibrous and eventually undergo physical and quality loss. This finding agrees with Sharma and Kaushal (2016) which reported 70% loss in yam variety after 12 months storage.

Table 6. Weight loss during storage.

Sample	Dose (Gy)	S_o mean initial weight (kg)	S_f mean initial weight (kg)	12 months after storage					
				S_o mean final weight (Kg)	S_f mean final weight (Kg)	S_o weight loss (Kg)	S_f weight loss (Kg)	S_o weight loss (%)	S_f weight loss (%)
A	0	2.06±0.20	2.02±0.42	0.20±0.14	0.13±0.10	1.86±0.06	1.89±0.32	90.29±19.30	93.56±19.55
B	40	2.40±0.28	3.10±0.99	1.42±0.40	1.31±0.04	0.98±0.12	1.79±0.95	40.83±11.21	57.74±12.33
C	80	2.21±0.42	2.80±0.84	1.54±0.51	1.32±0.08	0.67±0.09	1.48±0.76	30.32±7.53	52.86±9.31
D	120	2.00±0.71	1.90±0.14	1.52±0.33	1.35±0.34	0.48±0.38	0.55±0.20	24.00±7.33	28.95±6.33
E	150	2.06±0.76	2.40±0.85	1.71±0.47	1.94±0.20	0.35±0.29	0.46±0.65	16.99±5.67	19.17±5.33
F	180	2.09±0.79	2.40±0.99	1.80±0.74	2.00±0.20	0.29±0.05	0.40±0.79	13.55± 5.33	15.77±5.33

Note: S_o mean Ogini yam sample; S_f mean Fakasa yam sample

Proximate Analysis

This nutritional quality analysis was conducted on the yam samples immediately after irradiation then at 12 months as shown in Figure 3 and 4.

The percentage carbohydrate content, moisture content, ash content, crude lipid content, crude fibre content, and crude protein content of yam (*Dioscorea rotundata* L. Poir) corms immediately after irradiation, and 12 months of storage compared to assess the effect of gamma radiation on the proximate content of the yam species. For the S_o, the moisture content observed after irradiation (S_oA_o) was very higher when compared to moisture content of I80 Gy doses (S_oF_{12}) after 12 months of storage.

The moisture contents of the yam corms ranged between 62.86±0.06 to 68.67±0.30% for Ogini and 60.37±0.60 to 67.95±0.10 for Fakasa corms and 63.84±0.02 and 67.90±0.09 as control for both species immediately after irradiation and between * to 55.59±0.27 for Ogini and * to 54.23±2.75 for Fakasa in the irradiated corms after 12 months of storage as compared to * in the control as * represents totally rotted yam corms. Although it has been observed that corm moisture content varies considerably among species, harvest date and length of storage species which were recorded by Osagie (1992) for comparison with the results obtained in this research, it is evident from this work that radiation retains to a large extent the moisture content of the yam corm during storage. This is an indication that radiation processing of yam corms could preserve the qualities, such as, freshness from the observed high moisture content of irradiated yam corms after twelve months of storage.

The ash content, which is linked with mineral content in yam corms remain almost un-affected by radiation processing as recorded immediately after irradiation with a range of 1.93±0.02 to 2.81±0.05% for Ogini and 2.25±0.01 to 3.08±0.07 for Fakasa then 2.02±0.03 and 2.02±0.03 being their control and slightly higher after eight months of storage with values ranging between 2.50±0.07 to 2.65±0.20% for Ogini and 2.45±0.14 to 2.62±0.10 for Fakasa corms when compared with 2.18±0.13 and 2.19±0.12 in the control but by twelve months after storage only the 180 Gy yam corms of 2.15±0.16% for Ogini and 2.05±0.10% for Fakasa and * for control as its totally rotted. The irradiation processing does not affect the mineral composition of irradiated yam corms while losses were recorded in the control during storage possibly due to other activities and sprouting.

After twelve months of storage it was observed that the lipid and protein contents were slightly higher in the irradiated yam corms than the control. The lipid content ranged between 0.42±0.05 to 1.00±0.07% for Ogini and 0.41±0.07 to 0.52±0.05% for Fakasa then 1.64±0.05 and 0.65±0.31% being their control immediately after irradiation and between 0.79±0.22 to 0.58±0.56% for Ogini and 0.51±0.29 to 0.63±0.59 % for Fakasa then * and 0.62±0.29% being their control after 8 months of storage while the value after 12 months was 0.21±0.21% and 0.17±0.07% for Ogini and Fakasa yam corms at 180 Gy as all others were represented as * which is totally rotted. Similarly, the protein contents were higher in the irradiated yam corms after twelve months of storage than the control that no longer exist.

The protein content ranged between 3.50±0.07 to 4.52±0.00% for Ogini and 5.63±0.00 to 6.32 ±0.00% for Fakasa then 4.68±0.07 and 5.01±0.00% being their control immediately after irradiation and between 2.36±0.09 to 7.73±0.3% for Ogini and 13.58±0.17 to 6.84±0.00% for Fakasa then * and 3.03±0.02% being their control after 8 months of storage while the value after twelve months was 0.34±0.27% and 0.36±2.75% for Ogini and Fakasa yam corms at 180 Gy as all others were represented as * which is totally rotted. This is an indication that radiation processing preserves the lipid and protein contents in the irradiated corms when yam sprouts in storage, it utilizes stored food to support the sprouting. The result is increase in metabolic activity which leads to increase in respiration and loss of quality.

There was no observed significant difference in the crude fibre content of the water yam after seven months of storage. It ranged between 2.92±0.02 to 3.28±0.20% for Ogini and 2.25±0.01 to 4.60±0.25% for Fakasa then 3.75±0.23 and 4.14 ±0.09% being their control immediately after irradiation and between 0.37±0.07 to 0.48±0.17% for Ogini and 0.31±0.23 to 0.89±0.07% for Fakasa then * and 0.42±0.23% being their control after 8 months of storage while the value after 12 months was 0.21±0.21 and 0.17±0.07% for Ogini and Fakasa yam corms at 180 Gy as all others were represented as * which is totally rotted.

The carbohydrate contents ranged between 28.37±1.52 to 19.72±2.70% for Ogini and 28.20±1.62 to 17.53±2.80% for Fakasa then 24.07±1.32 and 20.28±1.31% being their control immediately after irradiation and between 32.85±1.51 to 24.44±2.90% for Ogini and 35.73±1.60 to 29.42±2.92% for Fakasa then * and

41.61±1.24% being their control after 8 months of storage while the value after 12 months was 4.35±0.20 and 3.73±0.31% for Ogini and Fakasa yam corms at 180 Gy as all others were represented as * which is totally rotted. There were no significant differences ($p \leq 0.05$) in the average values of the lipid, protein and carbohydrates content of the irradiated and un-irradiated yam corms.

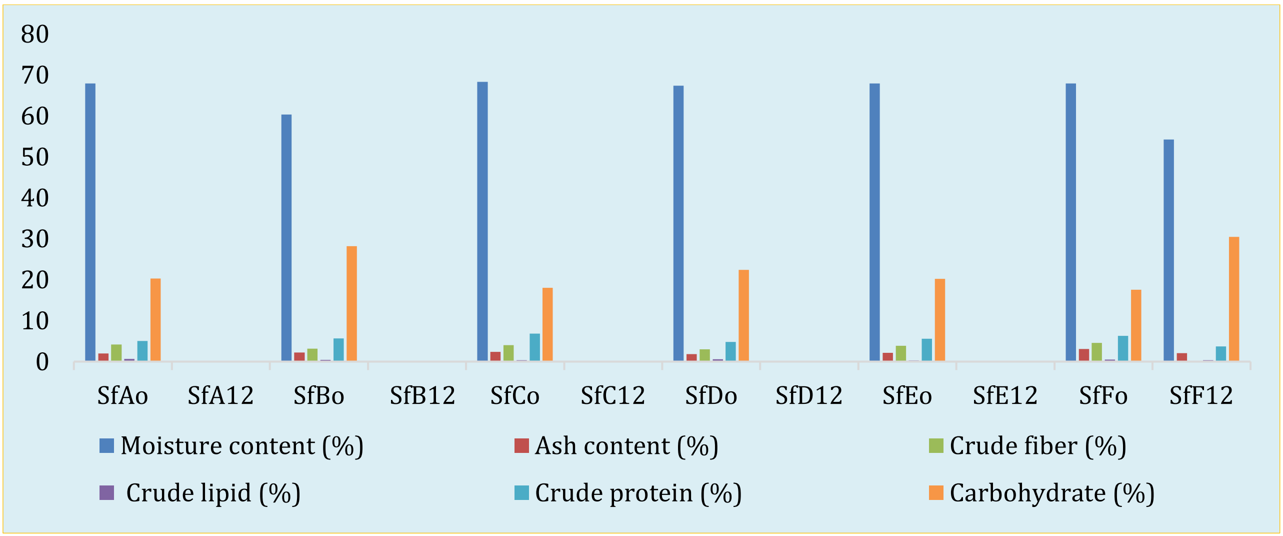

Figure 3. Comparison of proximate content of S_f (at different gamma doses) immediately after irradiation (0 month) and 12 months after irradiation (12).

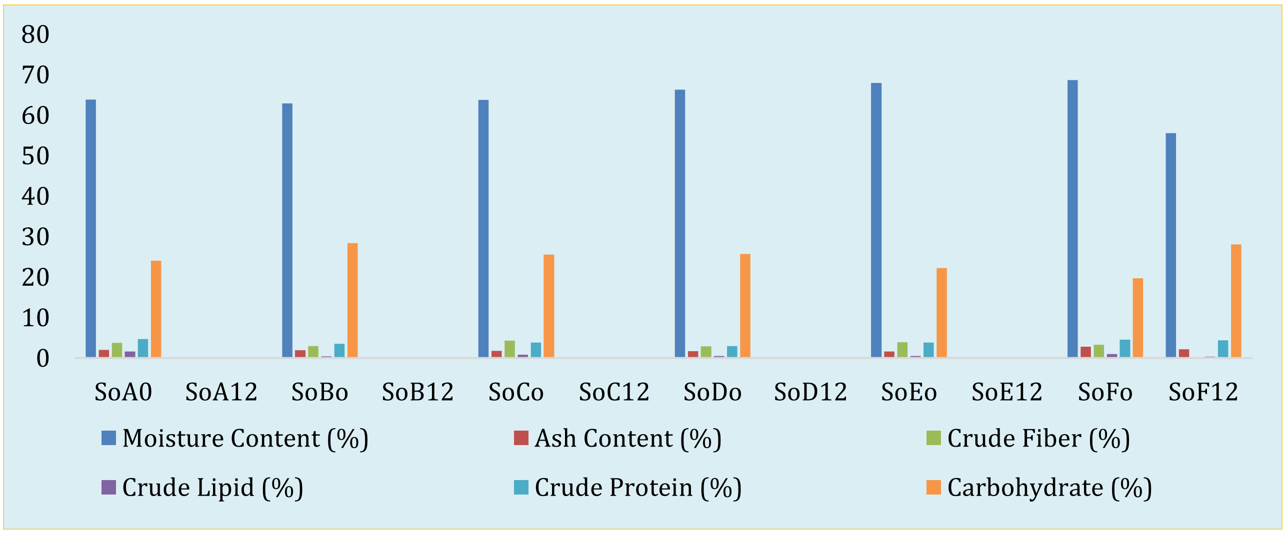

Figure 4. Comparison of proximate content of S_o (at different gamma doses) immediately after irradiation (o) and 12 months after irradiation (12).

Conclusion

The study demonstrated that gamma irradiation at the dose of 80 Gy and above completely prevents sprouting in Ogini yam and 120 Gy and above for Fakasa yam (*D. rotundata*) corms. This also shows that Ogini yam corms are better corms than Fakasa from all the results reported. The application of radiation at a dose of (120-180) Gy inhibited sprouting in yam without affecting its physicochemical and nutritional qualities. Test marketing of yam corms showed that the consumers will buy irradiated food. The irradiation of yam and maize become economical when the products are sold within the peak period and the through put is high. Irradiation of yam becomes economical if yams are marketed within 6 months of storage.

The irradiation processing at doses of 80 Gy above preserved the quality of the yam corms through sprout inhibition, preservation of food values such as lipid and protein while carbohydrate and reduction of weight losses of yam corms. The findings on the yam corms indicate that gamma-irradiation effectively enhances the storage life as in shelf life of yam corms by reducing decay and stopping sprouting. The overall benefits suggest that irradiation could be a viable method for post-harvest management of yam corms and food crops sustainability for SDG1; zero hunger and SDG 7.

Declarations

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Author Contributions: OYE, EO and AOL conceptualise the research, ECC and SN assisted in bench work, EEI and OYE assisted in write up, GJA reviewed the writeup.

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