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Optimizing Shelf Life of *Dioscorea Rotundata* through X-Irradiation: A Review of Current Trends and Findings

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ABSTRACT

Dioscorea rotundata, is a staple food crop in many tropical regions. Despite its importance, the crop is highly perishable, leading to significant post-harvest losses. This review aims to provide an overview of the effects of X-irradiation on the microbial load, nutritional quality, and shelf life of *Dioscorea rotundata*. A key finding of this review is the relationship between X-irradiation and the physical properties of Dioscorea rotundata. Notably, a consistent inverse relationship is observed between attenuation and thickness across the tubers, indicating that as the thickness of the tuber increases, attenuation decreases. Conversely, attenuation is found to increase with density. This understanding is important for optimizing the X-irradiation process to achieve the desired preservation effects. Furthermore, the application of X-irradiation has been shown from current findings to have a profound impact on the preservation of *Dioscorea rotundata*. It is noted that all variants of the crop experience a reduction in both sprouting and rot as the absorbed doses of irradiation increase. Several findings suggest that X-irradiation can be an effective method for extending the shelf life of *Dioscorea rotundata* and has also shown to significantly diminish the microbial colony count in *Dioscorea rotundata*, with a reduction of approximately 90% following X-irradiation. The substantial decrease in microbial load contributes to the extended shelf life and improved food safety of the crop. By reducing the microbial load, X-irradiation holds promise to minimize the risk of spoilage and contamination, leading to a reduction in post-harvest losses. Overall, this review highlights the potential of X-irradiation as a preservation technique for *Dioscorea rotundata*, offering a promising solution to reduce post-harvest losses and improve food security.

Keywords: X-irradiation, Absorbed dose, *Dioscorea rotundata*, shelf life and Microbial

INTRODUCTION

Dioscorea Rotundata, (DR) which is more commonly referred to as white yams, represents a significant category of tubers that are scientifically classified within the expansive *Dioscorea genus*, a taxonomic group that encompasses more than 600 distinct and diverse species, each varying in characteristics and uses (Adomėnienė & Venskutonis, 2022). These tubers, which are a type of underground storage organ for plants, are native to diverse geographic regions including various parts of Africa, Asia, and the Americans. They are primarily associated with and thrive in tropical climates characterized by warm temperatures and significant rainfall. *Dioscorea Rotundata* play an essential and significant role in the culinary traditions and practices of numerous cultures around the world, especially in West Africa, where they are not only regarded as a staple food item but also hold immense cultural importance, serving as a fundamental source of sustenance and nourishment for the local populations (Syombua, *et al.*, 2021). Yams are not only significant for their nutritional value but also play a crucial role in the economies of many West African countries, supporting millions of livelihoods.

Yams, with their rich nutritional profile and economic importance, are increasingly recognized for their potential in sustainable agricultural systems and food security initiatives. Culturally, yams possess considerable significance within numerous African communities, frequently being intertwined with harvest celebrations and rituals. For instance, the New Yam Festival in Nigeria represents a lively commemoration that signifies the conclusion of the harvest season, encompassing offerings, traditional dances, and communal feasting. Moreover, yams are acknowledged in traditional medicinal practices for their potential health-promoting properties (Obidiegwu, *et al*., 2020).

The exploration of innovative preservation techniques is vital for maintaining yam quality and extending shelf life, particularly in regions with challenging storage conditions (Wu, 2012). It is also optimal to store cut yams within airtight containers or wrapped in plastic to avert desiccation (over dryness). By employing these methodologies, yams can be preserved, thereby enabling consumers to avail themselves of their nutritional advantages for sometime (Yu, *et al*., 2016). In as much as the aforementioned methods offers some benefits, there are more superior methods which include Gamma irradiation and X-irradiation that has shown promise in extending the shelf life in species of yams by effectively reducing microbial load while maintaining their nutritional quality (Gómez-Contreras, *et al.*, 2021; Chun, *et al.*, 2013). Figure 1 below is an illustration of *Dioscorea Rotundata* seedlings.

Figure 1: Dioscorea Rotundata seeds

REVIEW METHODOLOGY

The literature review captured 17 important articles that met the inclusion criteria from Scopus, PubMed, Science Direct, Web of Science, research gate and google scholar databases. Research studies were carried out in Nigeria, India, Egypt, Indonesia, China and Brazil. Of the review carried out, 6 articles were conducted in Nigeria and the rest in other regions of the world. All the studies included in the review illustrate the effects of gamma radiation on shelf life and quality of different food products.

Table 1: Summary of the reviewed articles

S/No	**Food products**	**location**	**Dose(Gy)**	**Effects detected**	**References**
1.	Yam	Nigeria	15-20 Gy	Good inhibition of sprouting, little effect on nutritional composition at the optimal doses	Adetunji *et a*l., 2018
2.	Irish Potato	Nigeria	10-50 Gy	inhibition of sprouting, postponed senescence, and prolonged storage life without any serious loss in quality	Basirat *et al.*, 2020
3.	Sweet Potato	India	5-15 Gy	Reduced sprouting, slight changes in moisture content; high doses caused texture degradation	Behera *et al.*, 2019
4.	Cassava	Nigeria	5–10 Gy	Successful as an anti-sprouting agent; has succeeded in preserving starch quantity and exhibit few negative effects	Oluwatosin *et al.*, 2017

5.	Taro	Nigeria	10–20 Gy	Reduced sprouting, maintained taste and texture at lower doses; higher dose s caused discoloration	Akinyele *et al*., 2016
6.	Cocoyam (*Colocasia esculenta*)	Nigeria	5-20 Gy	Gamma ray with low doses will effectively delay sprouting but higher doses can also have an adverse effect on growth and yield.	Eze & Ogu, 2016
7.	Potato Tubers	India	150 & 500(Gy)	radiation was found to be detrimental for the tubers as discolouration of the tubers kept under ambient condition was observed within two weeks of the treatment. Considerable weight loss, significant loss in firmness, change in specific gravity and loss of ascorbic acid along with rapid discoloration was observed.	Dhali *et al*., 2018
8.	Potato Soft Rot	Egypt	0.0, 0.5, 1.0, 1.5, 2.0 & 2.5 kGy	Complete inhibition occurred at doses 2.5 and 2.0 KGy for high densities (Approximately $4.0\ x10^9$ CFU/ml) of *P. at rosepticum and P. carotovorum subsp. brasiliense*, respectively. The D_{10} value of gamma irradiation was 0.24 KGy for *P. atrosepticum* and 0.20 KGy for *P. carotovorum subsp. brasiliense*. Irradiation of artificially infected tubers with soft rot bacteria using the two mentioned D_{10} doses for the two bacterial species increased the shelf life of tuber s kept under ambient temperature.	H. Abd El-Ghany, *et al*., 2017
9.	Cassava (*Manihot esculenta Crantz.*)	Indonesia	0, 15, 30, 45, and 60(Gy)	Gamma irradiation induced some morphological changes and variability in yield. Several irradiated plants showed root fresh weight, which potentially developed new cassava variants with higher yield	Nurul Khumaida *et al*., 2015
10.	Mushrooms	China	2 kGy	2 kGy gamma radiation led to a reduction in sugar content while the antioxidant activity of *Arenania montana* L was significantly decreased.	Agbaka, and Ibrahim, 2020
11.	*Kufri Jyoti* Variety of Potato	India	100 & 200 (Gy)	There were changes in the various physical quality parameters (weight, specific gravity, texture and colour) after five months of	Pranay and Sidhant, 2020

				storage. Untreated samples kept in ambient showed very high weight loss of 27.4% and sprout wright of 4.23%. 200 Gy radiation was found to be detrimental for the tubers as discolouration in tubers was observed. The sample treated with 100 Gy radiation dose after 30 days of harvest and store d at 15°C temperature showed best results	
12.	*Sphenostyli s stenocara (Hoechst. ex. A. Rich.) Harms.*	Nigeria	25Gy/h, 50 G y/h, 100 Gy/150 Gy/h, 200 Gy/h and 250 Gy/h	The two varieties responded differently to the doses of the treatment. The muta gen stimulated the germination percentage in both varieties. The highest germ ination percentage was observed at 20 0 Gy for Tss86 while for Tss10 it was observed at 25 Gy.	Eze *et al.*, 2021
13	Wheat	Egypt	0, 1.5, 2, 2.5, 3, 5, 7 and 10 krad (i.e 0, 15, 20, 25, 30, 50, 70 and 100 Gray)	The results acquired revealed that, a significant increment in germination rate, height and root length were acquired at 2.5 krad treatment	El-Kameesy *et al.*, 2019
14	Potato growing under salt stress	Egypt	20 Gy	It demonstrated a considerable increase of fresh weight (250 percent more than the untreated). Irradiation of potato callus with 20 Gy of gamma rays was presumed as one of the most effective processes leading to salt resistance.	Mohamed *et al.*, 2021
15	Jerusalem artichoke (*Helianthus tuberosus*) tubers	Egypt	0, 2.5, 5 and 10(Gy)	The obtained results show that gamma irradiation at dose rate 5 Gy gave the best results of plant height, number of branches, shoot fresh and dry weight compared with treatments exposed to gamma irradiation at dose rate 2.5 and 10 Gy and also higher photosynthetic pigments such as chlorophyll a, b, a + b and carotenoids than	Mounir *et al.*, 2022
16	carioca beans (*Phaseolus vulgaris*, L)	Brazil	1, 5 and 10 (kGy)	The study establishes that ionizing radiations of 1, 5 and 10 kGy did not have significant effects on the nutritive aspects of the cooked beans. Such findings imply that insects and microorganisms can be controlled during grains storage	Dâmaris *et al.*, 2018

				through irradiation technology without altering the nutritional characteristics.	
17	Yam (*Dioscorea Rotundata* varieties)	Nigeria	0.64kGy-0.86kGy	Reduces decay and sprouting in *Dioscorea rotundata* varieties.	Alumuku *et al.*, 2026

Food Groupings and Topographical Distribution

The countries where a large part of these studies were carried out include Nigeria, India, Egypt, and there seems to be an interest in the use of gamma irradiation in postharvest preservation especially in the developing nations which experience huge postharvest losses. Most irradiated commodities included tuber crops (potato, yam, cassava, cocoyam), legumes and certain fruits and vegetables

Gamma Irradiation: An Advanced Preservation Technique

Gamma irradiation has emerged as a highly effective method for significantly reducing microbial contamination, which not only extend shelf life but also ensures the retention of essential nutrients and flavour characteristics Chun, *et al.*, 2013). This innovative approach, when combined with traditional preservation techniques, presents a formidable solution for enhancing both the safety and longevity of products in the marketplace (Gómez-Contreras, *et al.*, 2021). At its core, gamma irradiation utilizes a specific type of ionizing radiation, namely gamma rays, to target and eliminate a wide array of harmful microorganisms, including bacteria, parasites, and pathogens that can compromise food safety. A schematic diagram of Gamma irradiation is shown in Figure 2

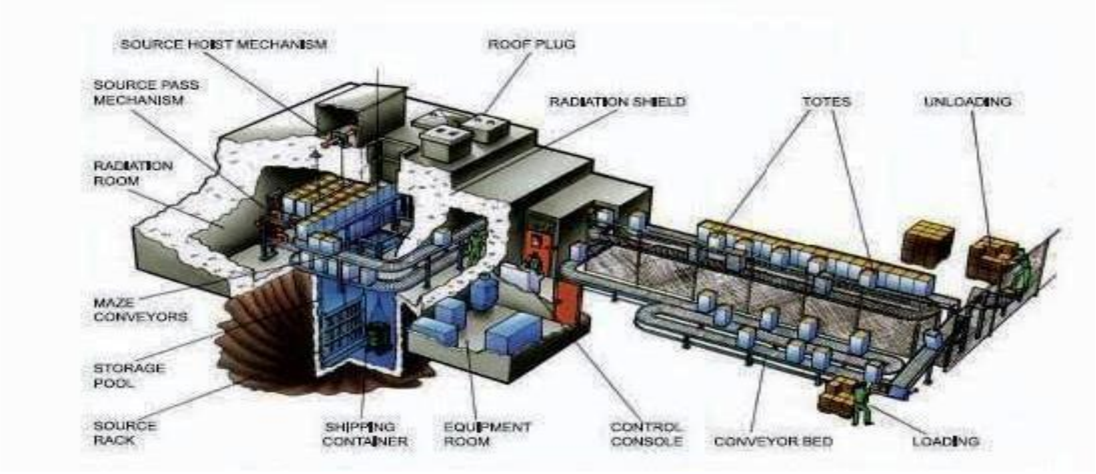

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Figure 2: Schematic diagram of gamma irradiator (Wu, 2012)

This process is particularly beneficial to many agricultural products that are susceptible to spoilage due to microbial growth. In addition to its antimicrobial properties, gamma irradiation plays a crucial role in inhibiting the sprouting of yams and delaying their ripening process (Role of Gamma Irradiation in the Preservation of Fruits and Vegetables, 2023). This dual functionality not only helps to maintain the visual appeal and texture of the yams but also contributes to preserving their nutritional value over extended periods. By effectively managing both microbial contamination and physiological changes, gamma irradiation is seen as a versatile preservation method that can be relied upon to deliver high-quality products to consumers eliminating pathogens and spoilage microorganisms from food products, thereby substantially reducing the incidence of food borne diseases (Zhang & Zhou, 2022). This characteristic renders it particularly advantageous for perishable commodities. By instigating disruptions in the DNA of microorganisms, gamma irradiation can thwart the spoilage processes of food, thereby prolonging shelf life and facilitating safer storage and transportation

(Reduction of the Microbial Load of Food by Processing and Modified Atmosphere Packaging, 2023) (Alfarobbi & Anggraini, 2018)

Overview of X-Irradiation Technology.

The technique that is widely recognized and referred to as X- irradiation technology, functions as a sophisticated and multifaceted method for the preservation of yam products, as it effectively utilizes high-energy X-rays to both eliminate and significantly reduce the presence of harmful pathogens, spoilage-causing microorganisms, and various types of insects that can infest food items ("The Effect of X-Ray on Food," 2022). This cutting-edge and innovative technology is increasingly being embraced and adopted by a growing number of industries as a practical and effective alternative to traditional irradiation methods, which include a variety of other food preservation strategies that are currently being developed and implemented (Zhang & Zhou, 2022).

X- irradiation involves the careful utilization of X-rays, which are classified as a distinct type of electromagnetic radiation characterized by their ability to penetrate various materials as seen in Figure 3, to effectively permeate and treat food products for safety and preservation. The energy that is emitted by these X-rays has the profound capability to disrupt and damage the intricate molecular structure of the DNA found within microorganisms and insects, thereby rendering them incapable of reproduction or causing deterioration and spoilage in the treated food items (Application of Irradiation in the Food Industry, 2023). This technology finds its use across various food categories, including fruits, vegetables, grains, and meats, hence, boosting food safety and lengthening shelf life (Chang, 2023)

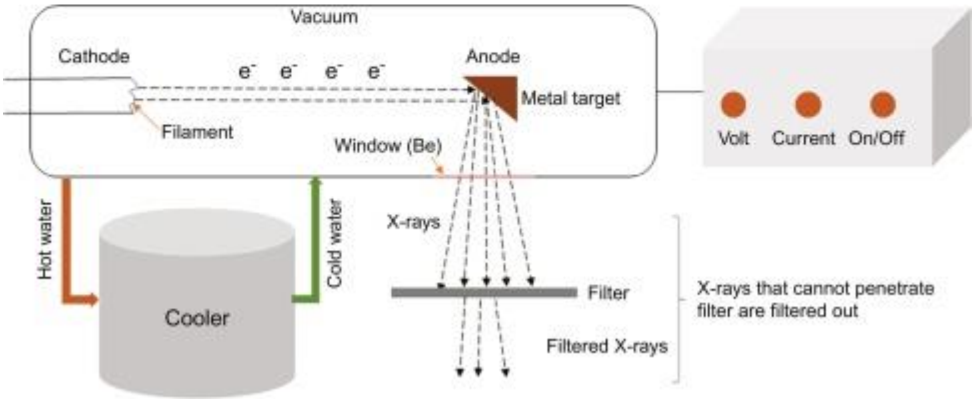

Figure 2: Schematic of X-irradiation

X-irradiation technology has emerged as a promising alternative to gamma irradiation, offering effective microbial control while potentially addressing some consumer concerns regarding traditional preservation methods. While both gamma and X-irradiation offer significant benefits for food preservation, ongoing research is essential to optimize their applications and address consumer concerns regarding safety and nutritional integrity (Chang, 2023).

Advantages of X- Irradiation Over Gamma Irradiation

X-ray irradiation utilizes X-rays produced by machines to achieve its effects, distinguishing it from gamma irradiation, which relies on the emission of radiation from radioactive isotopes like cobalt- 60 or cesium-137. This fundamental difference not only highlights the technological advancement of X-ray systems but also mitigates concerns surrounding the management and disposal of radioactive materials that are typically associated with gamma irradiation.

i. One of the key advantages of X-ray irradiation lies in its higher linear energy transfer (LET) value. This parameter is critical as it indicates the energy deposited by radiation per unit length of tissue, which in turn enhances the process's efficacy in inactivating microbial pathogens. The superior LET of X-ray irradiation translates to a more effective disruption of microbial cellular structures, making it a highly attractive method for food preservation. By effectively targeting and neutralizing harmful microorganisms, X-ray irradiation not only extends the shelf life of food products but also enhances food safety, positioning it as a compelling alternative to gamma irradiation (Zhang & Zhou, 2022).

ii. X-ray machines provide an exceptional level of careful regulation concerning both the amount of radiation administered during the treatment process and the length of time that this treatment is applied, thereby enabling highly specialized applications that not only enhance the effectiveness of the treatment but also work simultaneously to significantly reduce any possible negative impacts that could occur to the food product being treated.

iii. X-ray irradiation has shown effective results in reducing microbial loads in various food products, thus enhancing their safety and prolonging shelf life (Moosekian, *et al.*, 2012; Zehi, *et al.*, 2020). For penetrative efficacy, empirical evidence suggests that X-rays demonstrate a superior performance in comparison to gamma rays, particularly in relation to thicker and denser substrates that present considerable obstacles to radiation penetration. This unique property of X-rays, characterized by their enhanced capacity to permeate such materials, enables the proficient and effective processing of larger and more substantial food items, while safeguarding the value and quality of the products throughout the entirety of the treatment process (Zehi, *et al*., 2020).

Following the successful and thorough completion of the intricate irradiation process, it has been observed that various types of foods which have undergone treatment utilizing X-ray technology exhibit a remarkably lower likelihood of retaining any form of residual radiation when this is compared to those specific foods that have been subjected to the alternative method of gamma irradiation, a fact that ultimately serves to significantly enhance the overall safety and well-being of consumers who are planning to consume these food items in the near future (“The Effect of X-Ray on Food,” 2022; Figueroa, 2022).

Comparison of X-irradiation with other shelf-life extension methods

X-irradiation's advantages extend beyond microbial reduction, as it also minimizes the risk of residual radiation in treated foods, enhancing consumer safety and acceptance compared to gamma irradiation (Moosekian, *et al.*, 2012). Moreover, its superior penetration capabilities allow for effective treatment of denser food products, ensuring quality preservation during processing (Zehi, *et al*., 2020).

i. Thermal methods: While it is true that thermal methods, such as the widely known process of pasteurization, can effectively eliminate harmful microorganisms and pathogens present in certain foods (Sonar, *et al.*, 2023), it is equally important to acknowledge that these same methods may have a detrimental effect on the sensory attributes. This may include flavour and aroma, as well as the nutritional quality, such as the loss of vitamins and minerals, of various food items. Conversely, it should be noted that X-irradiation, which represents a non-thermal method of food preservation, is characterized by its ability to maintain and even enhance the delicate balance of taste, the pleasing texture, and the essential nutrients found in food making (Bisht, *et al.,* 2021).

ii. Chemical preservation: While it is true that the utilization of various chemical agents can significantly extend the shelf life of food products, it is also important to acknowledge that these substances may inadvertently introduce a range of potential health risks and consequently provoke a strong aversion among consumers who are increasingly concerned about their dietary choices and overall well-being (Öztürk & Ceylan, 2023). On the other hand, when the alternative method of X irradiation is considered, it becomes evident that this technique effectively alleviates many of the safety concerns that are typically associated with the use of chemical preservatives, thereby providing a safer option for extending the longevity of food items without compromising consumer health (Zhang & Zhou, 2022).

iii. Modified atmosphere packaging (MAP): Although it is true that Modified Atmosphere Packaging, (MAP), possesses the capability to significantly prolong the shelf life of various food products by altering the composition of gases present within the packaging environment, it is important to note that this process does not effectively eliminate or eradicate harmful pathogens that may be present (McMillin, 2020). Conversely, X irradiation, a method that involves the application of ionizing radiation, directly works to reduce the microbial load found in food items (Arapcheska, *et al*., 2020).

Dosimetry in X-irradiation

Dosimetry analysis, which takes place during the process of X-irradiation holds significant importance for a multitude of reasons (Denadi, *et al*., 2022), the most crucial of which is to confirm that the radiation dose that is being administered is not only effective in achieving the intended results, such as enhancing the plant's ability to withstand potential threats from pests or diseases, but is also within safe limits, thereby reducing the likelihood of any adverse effects that could compromise the structural value of the plant's cellular makeup (Dowlath, *et al.*, 2021). Several critical components of dosimetry analysis encompass various factors that must be carefully considered (Bayat, 2022)**.**

Types of Dosimetry

Effective dosimetry plays a good role in the field of food preservation, this process not only aims to prolong the shelf life of crops but also seeks to maintain their nutritional quality and ensure consumer safety. By optimizing the radiation levels used in this procedure, we can achieve a delicate balance that maximizes preservation benefits while minimizing any potential adverse effects on the food. Dosimetry, the science of measuring ionizing radiation doses, can be divided into several distinct categories, each tailored for specific applications and environments. Some of which includes:

Thermoluminescent Dosimeters (TLDs): TLDs are designed to measure and quantify the total amount of radiation absorbed during their exposure to X-rays. These dosimeters operate on the principle of thermoluminescence, where certain materials store energy from ionizing radiation and release it as light when heated (Montanha, *et al*., 2023).

i. This characteristic allows TLDs as shown in Figure 4, to provide precise and reliable measurements of radiation doses, which is essential for ensuring that the levels applied are both effective for preservation and safe for consumption.

Figure 3: Thermoluminescent Dosimeters Chips

Incorporating TLDs into the dosimetry process allows researchers and food technologists to monitor and adjust radiation levels, ensuring that the crops receive the optimal dose required for effective preservation. This careful calibration not only enhances the longevity of the yams but also protects their inherent nutritional properties and safety, leading to a better product for consumers (Murthy, 2013). TLDs have the unique capability to be strategically positioned either alongside or even within the treatment zone, allowing for the collection and yield of highly precise measurements that are crucial for effective radiation monitoring and assessment of *Dioscorea rotundata* (Dahoud & Mustafa, 2014).

ii. Ionization Chambers: These sophisticated instruments, which are specifically designed to assess and evaluate the ionization levels of air or a variety of different gases in the presence of various forms of radiation, play a crucial role in numerous scientific and medical applications (DeWerd & Smith, 2021). Their predominant usage is found within clinical environments where they are essential for ensuring safety and accuracy, and they can also be effectively adapted for a wide range of applications in agricultural research, thus demonstrating their versatility and importance across multiple fields.

iii. Film Dosimetry: This particular method involves the intricate utilization of film emulsion, which serves as a medium through which the distribution of radiation dose can be visually evaluated and assessed in a detailed manner. After the film has been exposed to radiation, it undergoes a processing procedure, during which the changes in density that occur as a result of exposure are carefully correlated with the specific radiation dose that was received, allowing for precise measurements and analysis of radiation levels (Ju, *et al.*, 2002).

Dose Distribution: Gaining a comprehensive understanding of how X-ray doses are distributed throughout the entire crop is of utmost importance and significance in various applications. It is essential to recognize that different areas within tubers may demonstrate varied levels of radiation absorption, which can be attributed to several factors including the density of the tissues, the moisture content present, and the specific anatomical characteristics that define each region of the yam (Hedreen, 2022). The process of spatially mapping the distribution of these doses proves to be a crucial tool in pinpointing specific locations that may either receive insufficient amounts of radiation or, conversely, be exposed to excessive doses (Ebert, *et al.*, 2021), thereby ensuring optimal treatment outcomes.

The sensitivity to X-irradiation can vary among the various cultivars of *Dioscorea rotundata*, which means that different strains of this particular plant species respond in unique ways to exposure to X-rays, leading to a range of effects that can significantly influence both their development and overall health (Tan, *et al.*, 2023). Dosimetry analysis must account for cultivar-specific responses to accurately evaluate treatment efficacy (Denadi, *et al.*, 2022).

Implication of X-irradiation on *Dioscorea Rotundata*

As the application of X-irradiation technology gains more attention as a promising approach for controlling microbial populations (Cha & Ha, 2022), it becomes imperative to conduct an in-depth examination of its effects on *Dioscorea Rotundata* (Zare, *et al.*, 2023). Irradiation utilizes high-energy radiation to reduce microbial contamination; the process may yield varying outcomes depending on the nutritional status and physiological responses of the crops involved. Understanding how X-irradiation interacts with the complex biological systems of *Dioscorea Rotundata* rich in essential nutrients and exhibiting enhanced growth potential compared to others, which may be more susceptible to microbial invasion.

Importance of *Dioscorea Rotundata* in Agriculture and Nutrition

Dioscorea rotundata, stands out as one of the most significant tuber crops in West Africa, with Nigeria being its primary hub of cultivation and consumption. This crop is not only a staple food source but also a vital component of the region's agricultural economy. Despite its critical importance, *Dioscorea rotundata* is often classified as an orphan crop, a term that highlights the historical neglect it has faced in terms of research funding and agricultural investment compared to more mainstream crops like maize and rice (Harikumar & Sheela, 2019). Nonetheless, the resilience and adaptability of Dioscorea rotundata have ensured its continued prominence in the diets of millions, providing essential carbohydrates and nutrients that contribute to food security and overall nutritional health (Harikumar & Sheela, 2019). The yam is celebrated for its versatility in culinary applications, ranging from traditional dishes to modern recipes, making it a cherished ingredient in various cultural cuisines across West Africa.

Table 1: Key production percentages for yam in West Africa, illustrating Nigeria’s leading role

Country of production	Percentage (%)	key contribution
Nigeria	67.4	Dominant global Producer High yield Potential

Ghana	11.1	Significant regional contributor
Cote d' Ivoire	10.3	Important for export and domestic consumption

Source: (Awoyale, *et al.*, 2020).

X-Irradiation as a Preservation Technique

In recent years, the pursuit of effective preservation techniques has garnered considerable attention, particularly concerning the shelf life of perishable crops (Sagar & Pareek, 2020). This is especially true for *Dioscorea rotundata*, which plays a vital role in various culinary applications and possesses significant economic value across numerous regions, especially in West Africa where it is a staple food. The perish-ability of such crops poses a substantial challenge, as spoilage can result in significant financial losses for farmers and suppliers alike. Consequently, the development of innovative methods to enhance preservation is not just beneficial but essential for sustaining agricultural productivity and food security (Sagar & Pareek, 2020). One particularly promising solution that has emerged is the use of X-irradiation, a technique that employs X-ray machines to effectively inhibit microbial growth and enzymatic processes that contribute to the decay of perishable goods.

X-irradiation has shown potential in extending the shelf life of agricultural products by reducing the microbial load and slowing down the biochemical reactions that lead to spoilage. This method not only helps maintain the quality and safety of the crops during storage and transport but also provides an effective means of reducing waste in the supply chain (Moosekian, *et al.*, 2012). By harnessing cutting-edge preservation techniques, the agricultural sector can significantly bolster the resilience of food systems, ensuring that essential crops such as *Dioscorea rotundata*, remain available and accessible to consumers for extended durations. This innovative preservation method has garnered considerable interest due to its remarkable potential to prolong the shelf life of yams while simultaneously safeguarding their nutritional value and sensory attributes (Moosekian, *et al.*, 2012).

Figure 5: X-ray system for Food Irradiation (https://kib.ki.se/en/write)

Principles of X-Irradiation

The X-ray tube operates through a sophisticated high-voltage system consisting of two primary components: the cathode and the anode (Eichhorn, *et al.*, 2013). The cathode serves as the negatively charged electrode (-), while the anode represents the positively charged electrode (+). Central to the function of the cathode is a filament, which, when subjected to thermal excitation, initiates the release of electrons. The process of electron emission begins when the X-ray unit is activated. At this point, the filament within the cathode is heated to a high temperature, a process that induces electron emission via thermionic emission (TE) (Eichhorn, *et al.*, 2013). This phenomenon occurs when the thermal energy supplied to the filament is sufficient to overcome the work function of the material, allowing electrons to escape from the surface of the filament. As a result, a cloud of free electrons forms in close proximity to the cathode, ready to be accelerated towards the anode. This initial step is crucial for the subsequent generation of X-rays, as these emitted electrons will eventually collide with the anode, leading to the production of X-ray radiation. This process is illustrated in Figure 6.

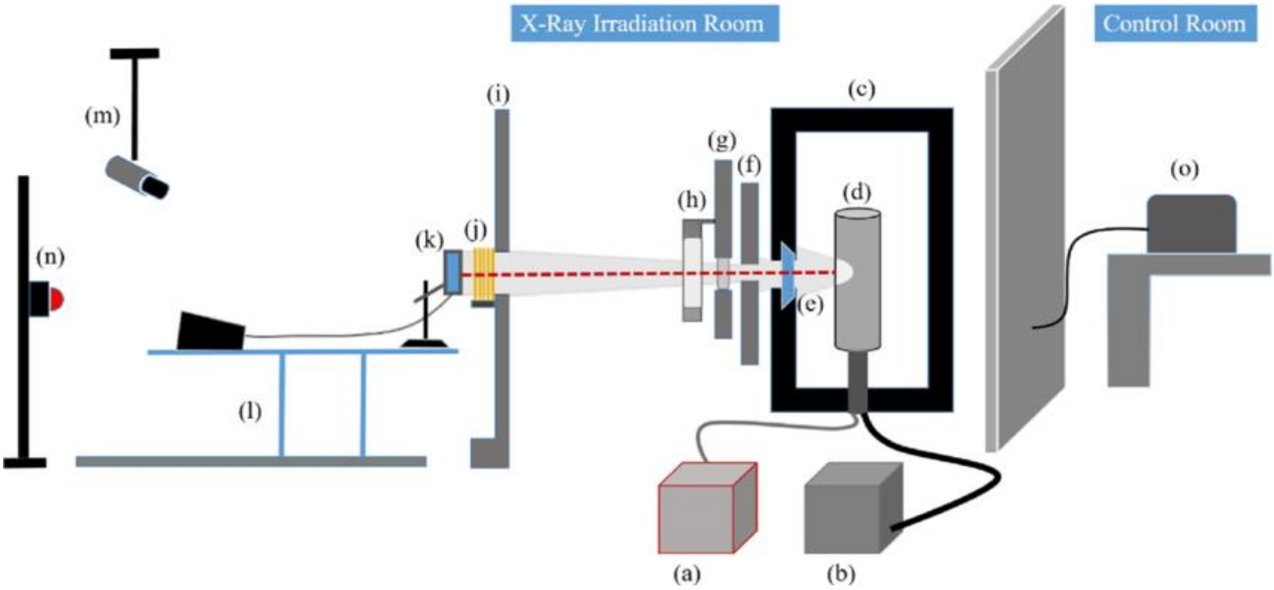

Figure 6: Principle of X- irradiation (Zoryana & Tobias, 2018)

The application of a significant voltage across the cathode and anode typically ranges from 20 to 150 kilovolts (kV). This substantial potential difference (PD) creates a powerful electric field that plays a role in the operation of various electronic devices. As the electric field is established, it exerts a force on the emitted electrons, propelling them with considerable acceleration towards the anode. This acceleration is essential for the effective functioning of devices such as cathode ray tubes and certain types of electron microscopes, where the speed and energy of the electrons directly influence the quality and resolution of the resulting images. The precise control of this voltage is vital, as it determines the kinetic energy (KE) of the electrons, thus impacting the overall performance and efficiency of the system in which they are utilized ("Exploring the Basic Physical Mechanisms of Cathode- and Anode-Initiated High-Voltage Surface Flashover," 2022).

When high-energy electrons collide with the anode material, which is often tungsten due to its remarkable atomic number and high melting point, two primary interactions occur that are crucial for X-ray production. The first of these interactions is known as Bremsstrahlung Radiation, which translates from German as "braking radiation." This phenomenon occurs when the high-speed electrons, upon striking the nuclei of the tungsten atoms, experience a rapid deceleration due to the strong electromagnetic forces at play ("Analysis of Hypervelocity Impacts: The Tungsten Case," 2022). As these electrons lose kinetic energy during this interaction, the energy is emitted in the form of X-ray photons. The intensity and energy spectrum of the emitted X-rays depend on various factors, including the energy of the incoming electrons and the atomic structure of the anode material. The second interaction is referred to as Characteristic Radiation. This occurs when an incoming electron from the cathode has sufficient energy to eject an inner-shell electron from an atom of the tungsten anode.

The vacancy created in the inner shell leads to a transition of an outer-shell electron into the lower energy state, thereby filling the void. This transition releases energy, which is emitted as X-ray photons that possess specific energies characteristic of the tungsten atom's atomic structure. The energies of these photons correspond to the differences between the energy levels of the electrons in the atom, resulting in a distinct emission spectrum (Li *et al.*, 2022). The X-ray photons produced from these interactions are emitted isotropically, meaning they radiate uniformly in all directions from the source. To harness this radiation effectively for imaging or therapeutic purposes, a lead-lined collimator is typically employed. This device serves to shape and confine the X-ray beam to a predetermined area of interest, minimizing exposure to surrounding tissues and enhancing the precision of the resulting images or treatments (Li *et al.*, 2022). By controlling the direction and intensity of the emitted X-rays, the collimator plays a vital role in optimizing the efficacy and safety of X-ray applications in medical and industrial settings.

Interaction with Matter: An In-Depth Analysis of X-Ray Interactions with Dioscorea Rotundata

As X-rays penetrate yam tubers, they engage in a complex interplay with the atomic structures that compose these tubers, primarily through three distinct mechanisms: The Photoelectric Effect, Compton Scattering, and Rayleigh Scattering. Each of these interactions plays a role in determining how X-rays are absorbed and scattered, ultimately influencing the quality and detail of the resulting images (Aighewi, *et al*., 2021).

Photoelectric Effect: The Photoelectric effect is a fundamental interaction that occurs when X-ray photons are completely absorbed by the atomic constituents of the yam tubers. This absorption leads to the ejection of inner-shell electrons from their respective atomic orbits, resulting in ionization of the atoms (Jho, *et al.*, 2023). The likelihood of this effect occurring is significantly enhanced in tissues with higher atomic numbers and densities, as these materials are more effective at absorbing X-ray photons. Consequently, denser regions within the yam tubers will appear more radiopaque on X-ray images (Fioreze & Morini, 2000).

Compton scattering: Another pivotal interaction is Compton Scattering, which occurs when X-ray photons collide with loosely bound electrons in the yam tubers. This collision results in a transfer of energy, leading to a change in the direction and energy of the incident X-ray photon. Compton Scattering is particularly prevalent in heterogeneous materials like yam tubers, which exhibit a variety of densities and compositions. This scattering effect contributes to the overall contrast of the X-ray images, as it can cause some regions to appear darker or lighter depending on the scattering angles and the energy loss of the X-rays. The resultant variability in image intensity is essential for distinguishing between different tissue types within the tuber (Qiao, *et al*., 2021).

Rayleigh scattering: This involves the small-angle scattering of X-ray photons without any accompanying loss of energy. Although this process is not as significant as the Photoelectric effect or Compton scattering in terms of its contribution to image formation, it still plays a role in enhancing the overall quality of the X-ray images. By causing slight deviations in the paths of X-ray photons as they interact with the yam tuber's atomic structures, Rayleigh Scattering can help to refine the details captured in the imaging process, aiding in the visualization of subtle features that might otherwise go unnoticed (Seidel, *et al*., 2001).

In summary, the interaction of X-rays with yam tubers is governed by a combination of the Photoelectric Effect, Compton scattering, and Rayleigh scattering. Each of these mechanisms contributes uniquely to the absorption and scattering of X-rays, which shapes the quality and clarity of the images produced. Figure 7 shows the interaction that occurs. Understanding these interactions is vital for optimizing imaging techniques and enhancing diagnostic capabilities in the study of yam tubers and similar biological materials.

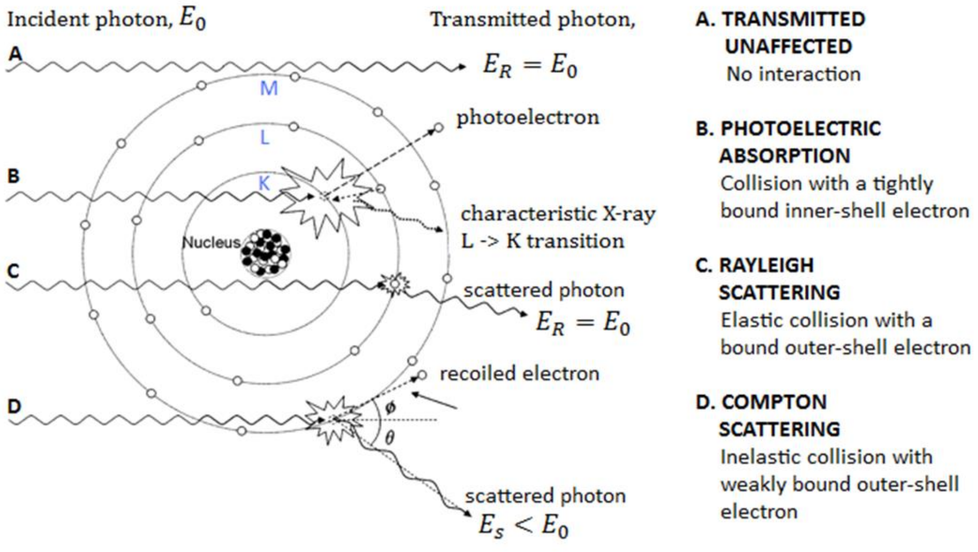

Figure 7: Interactions of X-rays with matter (Seidel, *et al*., 2001).

Advisory Technological Dose Limits

The International Consultative Group on Food Irradiation (ICGFI) is a prominent international organization founded in 1984, operating under the auspices of three esteemed entities: The Food and Agriculture Organization (FAO), the International Atomic Energy Agency (IAEA), and the World Health Organization (WHO). The primary purpose of the ICGFI is to provide expert guidance and recommendations concerning food irradiation practices on a global scale (Singh & Singh, 2019). Its functions encompass the evaluation of advancements in food irradiation technology, offering informed advice to member states and various international organizations, and supplying critical information to the Joint FAO/IAEA/WHO expert committee on the Wholesomeness of Irradiated Food, as well as the Codex Alimentarius Commission, which sets international food safety standards (Singh & Singh, 2019).

In terms of regulatory recommendations, the ICGFI suggests a maximum dose range for food irradiation of up to 10 kilogray (kGy). This guideline is supported by a variety of regulations and standards across different countries. For instance, the Food Irradiation Regulations in Nigeria explicitly establish a maximum average irradiation dose of 10 kGy for food products. The World Health Organization also emphasizes the safety and nutritional adequacy of foods subjected to irradiation, particularly those treated with doses exceeding 10 kGy (Rahman, *et al.*, 2018).

Absorbed Dose

In the irradiation of food products, emphasis is placed on the quantification of radiation termed 'absorbed dose' to procure precise and significant data regarding the pertinent radiation impacts. The governing regulatory authority or any entity tasked with the endorsement of the food products necessitates documentation that evidences that each component of the processing load in question has been subjected to treatment within the prescribed parameters of acceptable absorbed dose thresholds (“Application of Certified Reference Materials of Absorbed Dose for Process Validation of Irradiation of Medical Supplies and Food Products,” 2022).

The absorbed dose (commonly denoted as ‘dose’), D represents the quantity of energy absorbed per unit mass of irradiated material at a specific location within the area of interest. It is quantitatively expressed as the mean energy, $\mathrm{d}\varepsilon$, imparted by ionizing radiation to the material within a differential volume element, divided by the mass, dm, of that volume element

$$D = \frac{\mathrm{d}\varepsilon}{\mathrm{dm}} \qquad 1$$

The SI derived unit of absorbed dose is the gray (Gy), which has supplanted the previous unit of absorbed dose, the rad, where;

$$1\ \mathrm{Gy} = 1\mathrm{J/kg}\ or\ rad$$

The absorbed dose rate D is characterized as the temporal rate of change of the absorbed dose

$$D = \frac{\mathrm{dD}}{\mathrm{dt}} \qquad 2$$

In practical situations, D and D are measurable only as average values in a larger volume than is specified in the definitions, since it is generally not possible to measure these quantities precisely in a very small volume in the material. In this thesis, the absorbed dose is considered to be an average value, either as measured in the sensitive volume of the dosimeter used if it is of appreciable size or existing in its immediate vicinity if the dosimeter is very small or thin, where cavity theory is applicable (Gustafsson, *et al*., 2023).

For any given irradiation conditions, it is necessary to specify the absorbed dose in the particular material of interest because different materials have different radiation absorption properties. For food irradiation, the material of interest is generally specified as water. With regard to radiation interaction properties, most foods behave essentially as water regardless of their moisture content.

Differential Absorption in Yam Tubers

Within yam tubers, a complex interplay of various constituents including starch, moisture, and fibres exhibits distinct levels of X-ray absorption. This phenomenon can be attributed to the differing densities and atomic numbers of these components. As X-rays traverse the tuber, the varying capacities of these constituents to absorb X-rays lead to a differential absorption effect (Tiamiyu, *et al*., 2019). Consequently, some areas of the tuber absorb a larger quantity of X-rays, while others allow more X-rays to pass through with minimal absorption as seen in Figure 8.

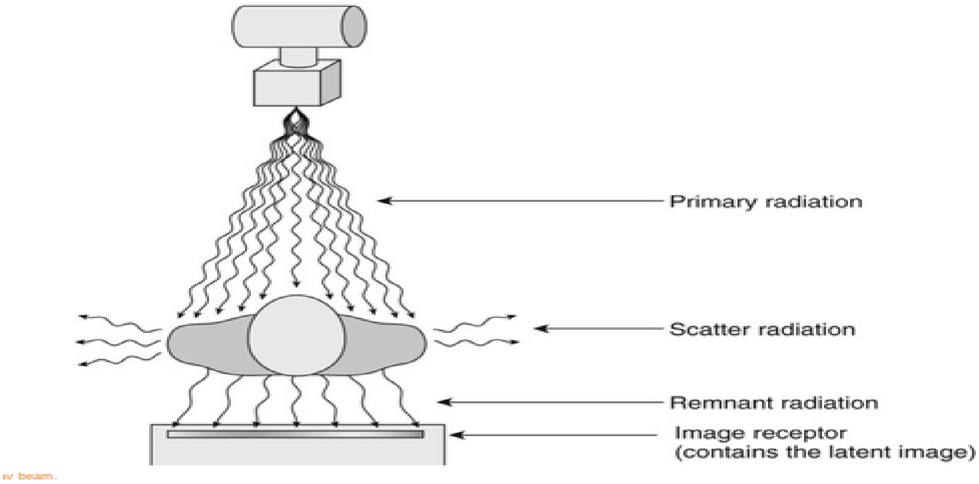

Figure 8: Differential Absorption in X-rays (Tiamiyu, *et al*., 2019).

This differential absorption is crucial, as it creates a gradient of X-ray intensities that can be captured by detection devices. These devices may range from traditional X-ray film to advanced digital detectors, each designed to record the varying levels of X-ray exposure. The result is a representation of the yam tuber's internal structure, where regions that have absorbed a significant number of X-rays appear lighter on the resulting image, while areas that have transmitted more X-rays appear darker (Ckr, 2019).

Attenuation of X- rays during irradiation of *Dioscorea Rotundata*

The attenuation coefficient is a fundamental parameter that significantly influences the intensity of X-rays as they penetrate various materials, including biological specimens such as *Dioscorea Rotundata*. This coefficient serves as a quantitative measure of the extent to which X-ray intensity diminishes due to two primary processes: absorption and scattering. When X-rays pass through a medium, they interact with the atoms and molecules within that medium, leading to a loss of energy and, consequently, a decrease in the intensity of the X-ray beam. Absorption occurs when X-ray photons are absorbed by the material, transferring their energy to the atoms and potentially causing ionization. Scattering, on the other hand, involves the deflection of X-ray photons in various directions, which can also contribute to the reduction in the intensity of the beam that continues along its original path.

Attenuation coefficient is particularly vital in several practical applications, most notably in food irradiation. In this context, X-rays are employed to sterilize and preserve food products by effectively inactivating harmful microorganisms, including bacteria, viruses, and parasites. By precisely controlling the intensity of the X-rays through knowledge of the attenuation coefficient, food safety can be enhanced without compromising the nutritional quality or safety of the food. Thus, the attenuation coefficient not only serves as a critical parameter in the field of radiology and material science but also plays a pivotal role in ensuring public health and safety through innovative food preservation techniques. The attenuation coefficient is a measure of how much the intensity of an X-ray beam is reduced as it passes through a material. It is influenced by the material's thickness, density, and atomic composition. The relationship between the incident and transmitted X-ray intensity is described by the equation:

$$I = I_0 e^{-\mu x} \qquad 3$$

Where;

I_0 = the intensity of the incident beam (W m^{-2})

I = the intensity of the emergent beam (W m^{-2})

μ = the linear absorption coefficient (m^{-1})

x = distance travelled through the material (m)

The attenuation coefficient plays a pivotal role in the interaction between X-rays and materials, particularly in the context of their atomic structure and density. Materials characterized by higher atomic numbers and greater densities exhibit a pronounced attenuation coefficient, which results in a more significant reduction in the intensity of X-rays as they pass through (Ehounou, *et al.*, 2021).

This phenomenon is particularly critical in specialized applications such as food irradiation, where the primary objective is to achieve effective penetration of X-rays to ensure microbial inactivation while maintaining the integrity and quality of the food product. In the context of food irradiation, understanding the attenuation coefficient is essential for optimizing the process. For instance, when considering food items such as *Dioscorea Rotundata*, the attenuation coefficient directly influences how deeply and efficiently X-rays can penetrate the tissue.

A higher attenuation coefficient indicates that the material will absorb or scatter a greater proportion of the X-ray energy, resulting in reduced penetration depth. This necessitates careful calibration of the irradiation parameters; specifically, adjustments may be required in both the energy levels of the X-rays and the duration of exposure to achieve the desired levels of sterilization and microbial control. Moreover, the implications of the attenuation coefficient extend beyond mere penetration depth. They also encompass the balance between effective sterilization and the preservation of sensory qualities, nutritional content, and overall food safety.

Image Formation and Analysis:

The X-rays that successfully penetrate the yam tuber culminate in the creation of a highly detailed radiographic image, as illustrated in Figure 13. This image acts as a comprehensive visual representation of the internal structure of the yam tubers, revealing intricate variations in density and composition across different regions of the tuber (Gatarira, *et al.*, 2020). Such advanced radiographic imaging techniques are indispensable for evaluating the quality and structural integrity of the tubers, enabling researchers and agricultural specialists to identify subtle differences that may remain undetected by the naked eye.

By analysing the resulting radiographic image, one can glean valuable insights into the physiological condition of the yam tubers. This non-invasive imaging method allows for the identification of potential defects, such as internal blemishes, cavities, or irregular growth patterns, which could compromise the tuber's health and viability (Ehounou, *et al.*, 2021). Furthermore, the ability to assess these characteristics without damaging the tuber is crucial for ensuring that only the highest quality specimens are selected for consumption or further cultivation. In addition to quality assessment, the radiographic analysis can also serve as a tool for research into the developmental processes of yam tubers, contributing to a deeper understanding of their growth dynamics and the factors that influence their structural formation (Ehounou, *et al.*, 2021).

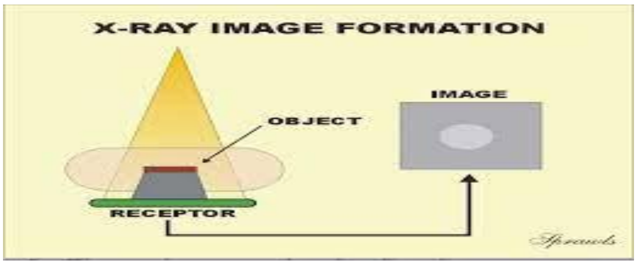

Figure 9: X-ray image formation during Irradiation

The striking contrast within the image plays a crucial role in enabling the discernment of unique characteristics found within the tubers. This visual differentiation is essential for accurate analysis and assessment. In the realm of image processing, the initial raw data captured by the detector is subject to a variety of sophisticated processing techniques. These techniques are meticulously designed to enhance particular features of interest, improve contrast, and elevate overall clarity. The choice of processing methods is heavily influenced by the specific imaging system utilized, which may range from advanced digital imaging technologies to traditional methods.

Each system offers its own set of tools and capabilities, allowing for tailored enhancements that cater to the unique requirements of the analysis. The final images, once processed, are subjected to thorough examination by trained professionals, such as radiologists or agricultural specialists. These experts meticulously analyse the images to assess the quality, health, and overall condition of the yam tubers. Their evaluation encompasses a comprehensive inspection for any internal irregularities, diseases, or other anomalies that may compromise the tubers' integrity (Ehounou, *et al.*, 2021). This detailed interpretation not only aids in ensuring the tubers meet quality standards but also provides vital insights into their overall viability and potential yield in agricultural practices.

Microbial Load impact on Shelf Life of *Dioscorea Rotundata*

This section delves into the comprehensive body of research surrounding the "Microbial Load Impact on the Shelf Life of *Dioscorea rotundata*," with a particular emphasis on the dynamics of spoilage, alterations in texture, and the degradation of essential nutrients. The objective is to synthesize and consolidate the current understanding of how various microbial communities affect the post-harvest quality and longevity of white yam tubers, a significant crop in many tropical regions. The importance of this review cannot be overstated, as microbial spoilage is a critical factor that substantially diminishes both the marketability and nutritional value of *Dioscorea rotundata*.

This staple food crop holds considerable economic significance and plays a vital role in ensuring food security for millions in tropical climates. By examining the intricate relationships between microbial colonization, the enzymatic activities that ensue, and the resultant biochemical changes that occur during storage, this section seeks to elucidate the key factors that influence the shelf life of white yam tubers (Gao, *et al*., 2023). Moreover, this analysis aims to identify and highlight existing gaps in current preservation strategies, thereby providing insight into potential interventions that could mitigate post-harvest losses. By addressing these gaps, the findings of this review could pave the way for the development of more effective methods to enhance the longevity and quality of *Dioscorea rotundata*, ultimately contributing to improved food security and economic stability in regions that rely heavily on this vital crop.

Effects of X-Irradiation on Microbial Load

X-irradiation, also known as X-ray irradiation, is a sophisticated non-thermal food preservation technique that has gained prominence for its ability to significantly diminish microbial populations in food products (Zhang & Zhou, 2022). This method operates by emitting high-energy X-rays, which penetrate the food and induce damage to the DNA of various microorganisms, including bacteria, viruses, and fungi. This genetic disruption results in either the death of these pathogens or the inhibition of their growth, thereby enhancing the safety and shelf life of food items ("The Effect of X-Ray on Food," 2022). The efficacy of X-irradiation is influenced by several critical factors. Firstly, the dose of radiation applied plays a pivotal role; higher doses typically correlate with greater reductions in microbial load, but must be carefully calibrated to avoid compromising the quality and nutritional value of the food. Additionally, the specific types of microorganisms present in the food can affect the outcome, as some pathogens may exhibit varying levels of resistance to radiation.

Furthermore, the physical and chemical characteristics of the food product itself, such as its moisture content, density, and composition—also impact the effectiveness of the irradiation process. For instance, foods with high moisture content may absorb radiation differently compared to drier products, potentially altering the efficacy of microbial inactivation. X-irradiation therefore represents a powerful tool in the arsenal of food preservation methods and its application in the preservation of Dioscorea rotundata could offer significant benefits in extending shelf life while maintaining quality. Microbial Load Reduction Mechanisms

X-irradiation and Microbial Inactivation

X-irradiation is a powerful method employed for the inactivation of microorganisms through the deliberate damage inflicted on their DNA. This process disrupts the genetic material, rendering the micro-organism's incapable of replication and ultimately leading to their death (Zhang & Zhou, 2022). The efficacy of microbial inactivation is closely linked to the dosage of X-rays administered, which is quantified in Grays (Gy), a unit that measures the absorbed radiation dose. Moreover, the dose rate plays a critical role in this process; it defines the amount of energy absorbed by a specific mass of material over a designated period, typically expressed in Gy per second (Gy/s). Higher dose rates can lead to more rapid inactivation of microorganisms, while lower rates may require extended exposure times to achieve similar effects (McEvoy, *et al.*, 2023). Understanding these parameters is essential for optimizing X-irradiation protocols in various applications, from sterilization in medical settings to food preservation, ensuring that the desired level of microbial control is consistently achieved.

The impact of X-irradiation on microorganisms can be quantitatively expressed through the equation:

$$\frac{N}{N_0} = e^{-kD} \qquad 4$$

In this equation, the variables are defined as follows:

N represents the number of surviving microorganisms after exposure to X-irradiation.

N_0 denotes the initial population of microorganisms prior to irradiation, serving as a baseline for comparison.

k is the inactivation rate constant, measured in Gy^{-1}, which indicates the susceptibility of the microorganisms to radiation? This constant varies depending on the type of microorganism and the specific conditions of the irradiation process.

D refers to the absorbed dose of X-radiation, expressed in (Gy) which quantifies the amount of radiation energy absorbed per unit mass of the microorganisms.

The mathematical relationship illustrates the exponential decrease in the number of viable microorganisms as the absorbed dose of X-irradiation increases. As the dose escalates, the probability of survival diminishes significantly, underscoring the effectiveness of X-irradiation as a sterilization method in various applications, including food preservation and medical sterilization. The inactivation rate constant (k) is a measure of the sensitivity of microorganisms to X-irradiation. A higher value of k indicates greater sensitivity to radiation (Soibam, *et al.*, 2017).

The microbial load present on *Dioscorea rotundata*, can be quantitatively expressed through the equation:

$$M = \beta * (\mathrm{T} + \mathrm{RH}) \qquad 5$$

In this equation:

M denotes the microbial load, measured in colony-forming units per gram$(CFU/g\,)$, which provides a standard metric for assessing the level of microbial presence on the yam.

β represents the microbial growth rate constant, expressed in (h^{-1}) This constant is pivotal as it reflects the inherent capacity of microbial populations to proliferate under specific environmental conditions

T indicates the temperature in degrees Celsius) (°C), a factor influencing the metabolic activities of microorganisms. Higher temperatures generally accelerate microbial growth, while lower temperatures can inhibit it.

RH stands for relative humidity, expressed as a percentage, (%) which plays a significant role in moisture availability.

Elevated humidity levels can create favourable conditions for microbial growth, whereas lower humidity may lead to desiccation and reduced microbial activity (Ew, 2022). The microbial growth rate constant β is not a static value; it is subject to variation based on a multitude of factors, including but not limited to temperature fluctuations, relative humidity levels, and the specific storage conditions under which Dioscorea rotundata is kept.

Impact of X-Irradiation on Various Yam Varieties

While X-irradiation can have adverse effects on specific nutrients found in Dioscorea rotundata, or yams, it is crucial to examine this process within the larger framework of food safety and preservation. X-irradiation serves as an effective method for significantly reducing microbial contamination, which is a common cause of food spoilage. By minimizing the presence of harmful bacteria, fungi, and other pathogens, this technique not only prolongs the shelf life of yams but also enhances their safety for consumer consumption. Moreover, research indicates that the impact of irradiation on the overall nutrient composition of foods is generally minimal. Studies have shown that the nutritional losses incurred through this process are often outweighed by the advantages it offers in terms of food safety. In fact, irradiated foods have been rigorously tested and are recognized as safe for human consumption by various food safety authorities worldwide.

Thus, while it is essential to acknowledge the potential nutritional trade-offs associated with X-irradiation, the significant benefits of improved food safety and extended preservation may indeed surpass the drawbacks of nutrient depletion in certain situations. This consideration becomes particularly relevant in contexts where food borne illnesses pose a substantial risk, and where the availability of safe, preserved food is paramount. The decision to utilize X-irradiation should take into account both its implications for nutrient retention and its vital role in ensuring food safety and longevity.

A study conducted by Wall, 2004, investigated the sensory analysis of sweet potatoes subjected to X-ray irradiation, shedding light on the intricate effects of this treatment on various quality parameters. The investigation revealed that the X-ray irradiation process did not significantly alter the moisture content of sweet potatoes across both tested varieties: the red-skin, yellow-flesh (RY) clones and the white-skin, purple-flesh (WP) clones. The average moisture levels remained consistent, measuring at 66.4% for the WP variety and 59.7% for the RY variety, indicating that the irradiation process is effective in preserving the inherent moisture characteristics of these sweet potatoes.

In contrast, the study uncovered a notable decline in the concentrations of alcohol insoluble solids (AIS) and starch as the dosage of irradiation increased for both sweet potato clones. This linear decrease suggests a significant reduction in the crude starch content, which could have implications for the nutritional and culinary qualities of the sweet potatoes. The sensory analysis component of the study provided intriguing insights, particularly noting that sweet potatoes treated with a 600 Gy irradiation dose were perceived to possess a sweeter flavour profile compared to the control group.

Despite this enhanced sweetness perception, the overall acceptability ratings remained statistically similar between the control roots and those subjected to the 600 Gy treatment for both clones, indicating that while flavour perception may change, consumer preference may not necessarily follow suit. Furthermore, the study highlighted variations in texture, with firmness levels of the RY roots decreasing at higher irradiation doses, while the WP roots maintained their firmness despite increased irradiation exposure.

This discrepancy suggests that the two clones may respond differently to irradiation in terms of textural integrity. Additionally, maltose levels were specifically affected in the cooked RY roots, showing a decline only at the higher irradiation doses, which could further influence the sweet potato's flavour and texture characteristics post-cooking. Overall, this research not only enhances our understanding of how X-ray irradiation affects the sensory qualities of sweet potatoes but also raises important considerations for their processing and consumption, particularly in the context of maintaining quality while exploring innovative preservation techniques.

Investigation by Zehi, *et al*., 2020, aimed at evaluating the effects of X-ray irradiation on both the safety and nutritional quality of food, substantial evidence has emerged highlighting the remarkable efficacy of this technology in mitigating pathogenic and spoilage microorganisms across a diverse range of food products. This includes critical categories such as dairy, seafood, and fresh produce. The application of X-ray irradiation has been shown to result in a significant reduction of microbial populations, thereby enhancing food safety and extending shelf life, which is crucial in the prevention of food borne illnesses. The findings of this review underscore that X-ray technology stands out as a promising alternative to traditional methods such as electron beam and gamma ray treatments within the food industry.

Notably, X-ray irradiation has not been associated with any detrimental side effects on human health, making it a safer option for food preservation. Furthermore, the review examines the implications of X-ray treatment on the nutritional value of food, suggesting that, unlike some preservation methods that may compromise nutrient content, X-ray irradiation maintains the essential nutritional components, ensuring that the food remains not only safe but also nutritious for consumers.

A recent article Anikieva, *et al*., 2021, delves into the numerous benefits associated with irradiated agricultural products, emphasizing their remarkable ability to extend shelf life, mitigate disease transmission, and safeguard against insect infestations. The paper provides an in-depth examination of how varying radiation doses affect the biochemical constituents of these agricultural items, including proteins, fats, carbohydrates, and vitamins. Furthermore, it explores the potential ramifications of structural and compositional alterations in irradiated food products on human health. By scrutinizing these changes, the article seeks to illuminate the intricate relationship between food irradiation and nutritional quality, as well as its implications for consumer safety and dietary practices. This comprehensive analysis not only underscores the technological advancements in food preservation but also raises important questions regarding the long-term effects of consuming irradiated foods on human physiology and overall well-being (Anikieva, *et al*., 2021).

Approaches in Evaluating X-Irradiation Effects

X-irradiation on *Dioscorea rotundata* tubers, are variety of specific methodological approaches can be employed. These methodologies can be categorized into several key areas:

i. Experimental Design and Controlled Irradiation Trials: Implementing well-structured experimental designs is crucial for assessing the impact of X-irradiation. Controlled irradiation trials can be established to systematically expose yam tubers to varying doses of X-rays. This allows for a thorough comparison of different irradiation levels and their corresponding effects on the tubers, ensuring that the results are reliable and reproducible.

ii. Sensory Evaluation Panels: To understand the consumer perspective, sensory evaluation panels can be utilized. Trained panels can assess the organoleptic properties of the irradiated yam tubers, including taste, texture, aroma, and overall acceptability. This qualitative analysis is essential for determining whether X-irradiation affects.

iii. Biochemical Analyses: A critical component of this evaluation involves biochemical analyses aimed at assessing nutrient retention and microbial load reduction. Techniques such as High-Performance Liquid Chromatography (HPLC) or Gas Chromatography-Mass Spectrometry (GC-MS) can be employed to quantify the retention of essential nutrients post-irradiation, while microbial assays can help determine the efficacy of X-irradiation in reducing pathogenic and spoilage microorganisms.

iv. Gamma-ray and X-ray Irradiation Facilities: Utilizing specialized irradiation facilities equipped for gamma-ray and X-ray exposure is vital. These facilities ensure precise control over the irradiation environment, allowing for the administration of controlled doses of X-rays to yam tubers under standardized conditions.

v. Irradiation Protocols: The development and optimization of irradiation protocols are essential for achieving the desired outcomes. This includes determining appropriate dose rates, exposure times, and temperature controls during irradiation. Fine-tuning these parameters can enhance the effectiveness of the treatment while minimizing potential adverse effects on the tubers.

vi. DNA Damage Assays: Investigating the effects of X-irradiation on the genetic material of yam tubers is crucial. Techniques such as comet assays, which can detect DNA strand breaks, DNA fragmentation assays, and gene expression analysis can provide insights into the integrity of DNA and how irradiation influences gene expression patterns in response to stress.

vii. Cellular and Tissue Analysis: To gain a deeper understanding of the physiological effects of X-irradiation, cellular and tissue analysis can be conducted using microscopy and histological techniques. These analyses enable the examination of cellular structures and tissue integrity, revealing any alterations that may occur as a result of irradiation.

viii. Germination and Growth Assays: Evaluating the impact of X-irradiation on the germination rates and subsequent growth and development of yam tubers is essential. Controlled experiments can measure the effects on seedling vigour, root and shoot development, and overall plant health.

ix. Biochemical and Nutritional Analysis: Finally, a thorough assessment of the biochemical and nutritional composition of yam tubers post-irradiation is necessary. This can involve analysing macronutrients, micronutrients, and phytochemical profiles to understand how X-irradiation affects the nutritional quality of the tuber.

Comparative Effectiveness of X-Irradiation on Different Varieties

The comparative effectiveness of X-irradiation on the shelf life of various yam varieties can be comprehensively analysed through the framework established by gamma irradiation research, given the inherent similarities in the mechanisms employed by both irradiation techniques for food preservation. Extensive studies on gamma irradiation have demonstrated its efficacy in significantly prolonging the shelf life of yams by effectively inhibiting the sprouting process and minimizing spoilage caused by microbial activity and enzymatic deterioration.

This preservation method not only extends the longevity of yams but also safeguards their nutritional value, ensuring that essential vitamins, minerals, and other beneficial compounds remain intact. Additionally, gamma irradiation has been shown to preserve the sensory attributes of yams, including texture, flavour, and colour, which are critical for consumer acceptance. Consequently, X-irradiation emerges as a promising alternative for extending the shelf life of various yam varieties, offering a practical solution to enhance food security and reduce post-harvest losses in yam production. By leveraging the insights gained from gamma irradiation studies, researchers and food technologists can optimize X-irradiation protocols to maximize the benefits of this preservation technique across different yam cultivars.

CONCLUSION

The review of the study emphasizes the efficacy of X-irradiation as a method for extending the shelf life of *Dioscorea rotundata*. This observation is particularly encouraging, as it indicates that *Dioscorea rotundata* retains its nutritional value and moisture content for an extended duration, thereby demonstrating superior shelf life. The review raises important questions about the role of post-harvest preservation. Furthermore, the study reveals a complex interplay between the effects of irradiation on both microbial activity and the nutritional profile of *Dioscorea rotundata*. The study suggests that X-irradiation plays a vital role in extending the shelf life of yams, with all irradiated varieties outperforming their unirradiated counterparts in terms of longevity.

This study not only highlights the efficacy of X-irradiation but also prompts a re-evaluation of irradiation practices in the context of post-harvest yam storage, paving the way for more effective preservation strategies in the future.

REFERENCES

1. Abd El-Ghany, H., Moussa, Z., Salem E.A. and Abd El-Rahman A.F. (2017). Management of Potato Soft Rot by Gamma Irradiation. Arab Journal of Nuclear Sciences and Applications, 50 (3), 159-173. ISSN 1110 0451 (ESNSA) Web site: esnsa-eg.com
2. Adetunji, M.O., Afolabi, F. O., & Adepoju, O. T. (2018). Effect of gamma radiation on the sprouting of yam (Dioscorea spp.) tubers during storage. Journal of Food Science and Technology, 55(5), 1871-1880. https://doi.org/10.1007/s11483-018-2093-3
3. Adomėnienė, A., and Venskutonis, P. (2022). Dioscorea spp.: Comprehensive Review of Antioxidant Properties and Their Relation to Phytochemicals and Health Benefits. Molecules. https://doi.org/10.3390/molecules27082530
4. Agbaka, J.I., and Ibrahim, A. N. (2020). Irradiation: Utilization, Advances, Safety, Acceptance, Future Trends, and a Means to Enhance Food Security, Article Review. Advances in Applied Science Research, Vol.11 3:1. doi: 10.36648/0976-8610.11.3.1
5. Aighewi, B. A., Maroya, N., Kumar, P. L., Balogun, M. O., Aihebhoria, D., Mignouna, D., & Asiedu, R. (2021). Seed Yam Production Using High-Quality Minitubers Derived from Plants Established with Vine Cuttings.Agronomy. https://doi.org/10.3390/AGRONOMY11050978
6. Akinyele, B. J., Adeleke, O. B., & Oloyede, F. M .(2016). Induction of genetic variation in taro using gamma irradiation. Egyptian Journal of Applied Sciences, 31(7), 173-184.
7. Alfarobbi, R., and Anggraini, N. (2018). Preservation of Foodstuffs with Gamma Ray Irradiation Technology for Decreasing Pathogen Bacteria on Food and Maintain Sustainable Food Security:A Review.Social Science Research Network. https://doi.org/10.2139/SSRN.3201078
8. Alumuku , L., Daniel, T., Iortile, J. T., and Ikyumbur, J.T. (2026). X-Irradiation for Extended Shelf Life: Analysis of Rot and Sprout Control in Unfertilized and Fertilized Dioscorea Rotundata Varieties. Dutse Journal of Pure and Applied Sciences (DUJOPAS), 12 (1a): 173-185, 2026. https://dx.doi.org/10.4314/dujopas.v12i1a.17
9. Analysis of hypervelocity impacts: the tungsten case. (2022). Nuclear Fusion. https://doi.org/10.1088/1741-4326/ac42f6
10. Anikieva, E.N., Astapov, A., Yu., Anikiev, A.A., and Anikieva, E.A.(2021). Irradiation influence on the chemical composition and morphological properties of the agricultural products.IOP Conference Series: Earth and Environmental Science, 845.012036. https://doi.org/10.1088/1755-1315/845/1/012036
11. Application of certified reference materials of absorbed dose for process validation of irradiation of medical supplies and food products. (2022). Эталоны. Стандартные Образцы. https://doi.org/10.20915/2687-0886-2021-17-4-23-32
12. Application of irradiation in the food industry. (2023). https://doi.org/10.1016/b978-0-12-818717-3.00014-7
13. Arapcheska, M., Spasevska, H., & Ginovska, M. (2020). Effect of irradiation on food safety and quality. https://doi.org/10.47068/CTNS.2020.V9I18.014
14. Awoyale, W., Awoyale, W., Oyedele, H., & Maziya-Dixon, B. (2020). Correlation of the sensory attributes of thick yam paste (amala) and the functional and pasting properties of the flour as affected by storage periods and packaging materials. Journal of Food Processing and Preservation. https://doi.org/10.1111/JFPP.14732
15. Basirat, M., Tavakkol Afshari, R., Naserian, A. A., & Mesbah, M. (2020). Sprout inhibition of potato tubers using gamma irradiation: Effects on quality attributes during storage. Journal of Food Science and Technology, 57(12), 4530-4540. https://doi.org/10.1007/s13197-020-04624-5
16. Behera, T., Sahu, S., & Sahoo, K. (2019). Impact of gamma radiation on sweet potato [Ipomoea batatas (L.) Lam.] CV. Gouri. The Pharma Innovation Journal, 8(10), 1923-1927.
17. Bisht, B., Bhatnagar, P., Gururani, P., Kumar, V., Kumar, V., Tomar, M. S., Sinhmar, R., Rathi, N., & Kumar, S. (2021). Food irradiation: Effect of ionizing and non-ionizing radiations on preservation of

fruits and vegetables– a review. Trends in Food Science and Technology. https://doi.org/10.1016/J.TIFS.2021.06.002

18. Cha, M.-Y., & Ha, J. (2022). Low-energy X-ray irradiation effectively inactivates major foodborne pathogen biofilms on various food contact surfaces. Food Microbiology. https://doi.org/10.1016/j.fm.2022.104054
19. Chang, H. (2023). Advancements in Food Processing Technologies: Enhancing Safety, Quality, and Sustainability.Indian Scientific Journal of Research In Engineering And Management. https://doi.org/10.55041/ijsrem23682
20. Chun, H. H., Yu, D. J., & Song, K. B. (2013). Effects of combined nonthermal treatment on microbial growth and the quality of minimally processed yam (Dioscorea japonica Thunb) during storage. International Journal of Food Science and Technology. https://doi.org/10.1111/J.1365-2621.2012.03191.X
21. Ckr, M. G. (2019). Yam: Is It a Functional Food?https://doi.org/10.31031/NTNF.2019.04.000585
22. Dahoud, M. S. A., & Mustafa, I. S. (2014). Radiation Dosimetry By Tlds Inside Human Body Phantom While Using 192Ir HDR In Breast Brachytherapy.International Journal of Scientific & Technology Research.
23. Dâmaris, C. L., Alberto, C.M., Pedro E. D., Valter A. (2018). Effect of gamma irradiation on nutritional quality of carioca beans (Phaseolus vulgaris, L). DOI: https://doi.org/10.3329/sja.v17i1.42768
24. Denadi, N., Yolou, M., Dadonougbo, A. E., Zoundjihékpon, J., Dansi, A., Gandonou, C. B., & Quinet, M. (2022). Yam (Dioscorea rotundata Poir.) Displays Prezygotic and Postzygotic Barriers to Prevent Autogamy in Monoecious Cultivars.Agronomy. https://doi.org/10.3390/agronomy12040872
25. DeWerd, L. A., & Smith, B. R. (2021).Ionization Chamber Instrumentation. https://doi.org/10.1201/9781351005388-2
26. Dhali, K., Basak, N., And Bhattacharya, S. (2018). Effect of gamma irradiation on potato (Solanum tuberosum L.) tubers influencing post-harvest quality parameters. Journal of Crop and Weed, 13(2): 129- 135. DOI: 10.13140/RG.2.2.21432.80646
27. Dowlath, M. J. H., Karuppannan, S. K., Sinha, P., Dowlath, N. S., Arunachalam, K. D., Ravindran, B., Chang, S. W., Nguyen-Tri, P., & Nguyen, D. D. (2021). Effects of radiation and role of plants in radioprotection: A critical review. Science of The Total Environment. https://doi.org/10.1016/J.SCITOTENV.2021.146431
28. Ehounou, A. E., Cornet, D., Desfontaines, L., Marie-Magdeleine, C., Maledon, E., Nudol, E., Beurier, G., Rouan, L., Brat, P., Lechaudel, M., Nous, C., N’guetta, A. S.-P., Kouakou, A. M., & Arnau, G. (2021). Predicting quality, texture and chemical content of yam (Dioscorea alata L.) tubers using near infrared spectroscopy. Journal of Near Infrared Spectroscopy. https://doi.org/10.1177/09670335211007575
29. Eichhorn, R., Hoffmann, C., Matschulla, J., & Pham, G. K. (2013).X-ray tube.
30. Ew, E. (2022). Effect of Temperature on Dehydration Kinetics of Pre-Treated and Untreated Yam (Dioscorea spp) Slices.Saudi Journal of Engineering and Technology. https://doi.org/10.36348/sjet.2022.v07i01.001
31. El-Kameesy, S. U., Salama, E., Ghannam, M .M., and Roshdy, S. (2019). The influence of gamma irradiation doses on the morphological and physical properties of wheat. IOP Conf. Series: Journal of Physics: Conf. Series 1253, 012031. doi:10.1088/1742- 6596/1253/1/012031
32. Exploring the Basic Physical Mechanisms of Cathode- and Anode-Initiated High-Voltage Surface Flashover. (2022). IEEE Transactions on Plasma Science. https://doi.org/10.1109/tps.2022.3171129
33. Eze, C. D., Adesoye A. I., &. Adeosun C. A. (2021). Effect of Gamma Radiation on Morphological and Molecular Character of Sphenostylis stenocarpa (Hoechst. ex. A. Rich.) Harms. Ghana J. Sci. 62 (2), 79 – 90. https://dx.doi.org/10.4314/gjs.v62i2.8
34. Eze, S. C., & Ogu, J. L. (2016). Effect of gamma irradiation on the shelf life and quality of potato (Solanum tuberosum L.) tubers stored under ambient conditions. Global Scientific Journal (referred to in systematic reviews).
35. Figueroa, J. (2022). Irradiación en Alimentos. https://doi.org/10.35429/h.2022.1.1.16
36. Fioreze, R., & Morini, B. (2000). Yam (Discorea sp) drying with different cuts and temperatures: experimental and simulated results. Food Science and Technology International. https://doi.org/10.1590/S0101-20612000000200023

37. Gao, J., Hu, X., Xiao, R., Luo, F., Tang, Y., Luo, J., & Guo, M. (2023).The microbiome and typical pathogen multiplication, qualities changes of baoxing yam at different storage temperatures. https://doi.org/10.1016/j.lwt.2023.115402
38. Gatarira, C., Gatarira, C., Agre, P., Matsumoto, R., Edemodu, A., Adetimirin, V. O., Bhattacharjee, R., Asiedu, R., & Asfaw, A. (2020). Genome-Wide Association Analysis for Tuber Dry Matter and Oxidative Browning in Water Yam (Dioscorea alata L.).https://doi.org/10.3390/PLANTS9080969
39. Gómez-Contreras, P., Figueroa-Lopez, K. J., Hernández-Fernández, J., Cortés Rodríguez, M., & Ortega-Toro, R. (2021). Effect of Different Essential Oils on the Properties of Edible Coatings Based on Yam (Dioscorea rotundata L.) Starch and Its Application in Strawberry (Fragaria vesca L.) Preservation.Applied Sciences. https://doi.org/10.3390/APP112211057
40. Gustafsson, J., Ljungberg, M., Alm Carlsson, G., Larsson, E. G., Warfvinge, C. F., Asp, P., & Sjögreen Gleisner, K. (2023). Averaging of absorbed doses: How matter matters. Medical Physics. https://doi.org/10.1002/mp.16528
41. Harikumar, P., & Sheela, M. N. (2019). Identification of a Novel Single Sequence Repeat (SSR) Marker Linked to Dwarf Plant Stature in White Yam (Dioscorea rotundata Poir.). International Journal of Current Microbiology and Applied Sciences. https://doi.org/10.20546/IJCMAS.2019.811.019
42. Hedreen, R. (2022). Natural Radioactivity, Transfer Factor and Associated Radiological Risk in Commercially Cultivated Yam (Dioscorea Rotundata) in Northcentral Nigeria. https://doi.org/10.1007/978-981-16-8903-1_13
43. Jho, H., Lee, B., Ji, Y. R., & Ha, S. (2023). Discussion for the enhanced understanding of the photoelectric effect. European Journal of Physics. https://doi.org/10.1088/1361-6404/acb39d
44. Ju, S., Ih, Y., Huh, S., Choi, B., Park, Y. H., Ahn, Y. C., Kim, D. Y., & Kong, Y. K. (2002). Film Dosimetry for Intensity Modulated Radiation Therapy: Dosimetric Evaluation.The Journal of The Korean Society for Therapeutic Radiology and Oncology.
45. Li, L., Ren, X., Chen, J., Cao, W., Ren, G. Y., Bhandari, B., Ren, A., & Duan, X. (2022). Changes and relationships of viscoelastic and physical properties of Chinese yam during a novel multiphase microwave drying process. https://doi.org/10.1016/j.lwt.2022.113969
46. McEvoy, B., Žgomba Maksimović, A., Howell, D., Reppert, P., Ryan, D. H., Rowan, N. J., & Michel, H. (2023). Studies on the comparative effectiveness of X-rays, gamma rays and electron beams to inactivate microorganisms at different dose rates in industrial sterilization of medical devices.Radiation Physics and Chemistry. https://doi.org/10.1016/j.radphyschem.2023.110915
47. McMillin, K. W. (2020). Modified Atmosphere Packaging. https://doi.org/10.1007/978-3-030-42660-6_26
48. Mohamed, S. A., et al. (2021). Food irradiation: an effective but under-utilized technique for food preservation. Journal of Food Science and Technology, 60(10), 2517-2525.
49. Montanha, G. S., Marques, J. P. R., Jones, M. W. M., & Carvalho, H. W. P. de. (2023). Physiological responses of plants to in vivo X-ray damage from X-ray fluorescence measurements: insights from anatomical, elemental, histochemical, and ultrastructural analyses. Metallomics. https://doi.org/10.1093/mtomcs/mfad034
50. Moosekian, S. R., Jeong, S., Marks, B. P., & Ryser, E. T. (2012). X-ray irradiation as a microbial intervention strategy for food. Annual Review of Food Science and Technology - (New in 2010). https://doi.org/10.1146/ANNUREV-FOOD-022811-101306
51. Mounir, S., et al. (2022). Impact of irradiation on physico-chemical and nutritional properties of fruits and vegetables: A review. Heliyon, 8(10), e11181
52. Murthy, K. V. R. (2013). Applications of TLDs in Radiation Dosimetry.Defect and Diffusion Forum. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/DDF.341.211
53. Nurul K., SinthoWahyuning A., Mita D., and Muhamad S. (2015). Cassava (Manihot esculenta Crantz.) Improvement through Gamma Irradiation. International Symposium on Food and Agro-biodiversity, Procedia Food Science. 3 (2015) 27 – 34. doi: 10.1016/j.profoo.2015.01.003
54. Obidiegwu, J., Lyons, J. B., & Chilaka, C. A. (2020). The Dioscorea Genus (Yam)—An Appraisal of Nutritional and Therapeutic Potentials.Foods. https://doi.org/10.3390/FOODS9091304
55. Oluwatosin, G. A., Adejumo, B. A., & Olowolafe, T. A (2017). Effect of gamma irradiation on sprouting and growth of cassava (Manihot esculenta Crantz) plantlets. International Journal of Science and Nature, 8(3), 456-461.

56. Öztürk, N. Z., & Ceylan, H. (2023). Frequently Used Additives in the Food Industry and Their Toxicological Effects on Human Health. https://doi.org/10.59287/icras.700
57. Pranay S., and Sidhant K.M. (2020). Effect of Gamma Irradiation on Sprout Inhibition and Physical Properties of Kufri Jyoti Variety of Potato. Curr.Microbio l.App.Sci 9(7):1066 - 1079, https://doi.org/10.20546/ijcmas.2020.907.125.
58. Qiao, C.-K., Wei, J.-W., & Chen, L. (2021). An Overview of the Compton Scattering Calculation.arXiv: Other Condensed Matter. https://doi.org/10.3390/CRYST11050525
59. Rahman, M. H., Islam, Md. S., Begum, S., Ali, Md. L., Sutradhar, B. C., O'neil, V., Hossain, Md. A., & Nandwa, C. (2018). Scientific Opinion on the Standards and Regulations of Irradiated Food.Journal of Nutrition and Food Sciences. https://doi.org/10.4172/2155-9600.1000718
60. Reduction of the microbial load of food by processing and modified atmosphere packaging. (2023). https://doi.org/10.1016/b978-0-12-819470-6.00064-0
61. Role of Gamma Irradiation in the Preservation of Fruits and Vegetables. (2023). https://doi.org/10.1201/9781003304999-4
62. Sagar, N. A., & Pareek, S. (2020). Safe Storage and Preservation Techniques in Commercialized Agriculture. https://doi.org/10.1016/B978-0-12-819304-4.00019-1
63. Seidel, G. M., Lanou, R. E., & Yao, W. (2001). Rayleigh Scattering in Rare Gas Liquids.arXiv: High Energy Physics - Experiment. https://doi.org/10.1016/S0168-9002(02)00890-2
64. Singh, R., & Singh, A. (2019). Food Irradiation an Established Food Processing Technology for Food Safety and Security.Life Science Journal. https://doi.org/10.14429/DLSJ.4.14397
65. Soibam, H., Singh, A. V., & Mitra, S. (2017). Effect of temperature treatment on the chemical composition, microbiology and sensory evaluation of Yam chips during storage. Journal of Pharmacognosy and Phytochemistry.
66. Sonar, C. R., Wang, X., & Ao, J. (2023). Thermal Pasteurization. https://doi.org/10.1016/b978-0-12-822521-9.00072-1
67. Syombua, E. D., Syombua, E. D., Zhang, Z., Tripathi, J. N., Ntui, V. O., Kang, M., George, O. O., Edward, N. K., Wang, K., Yang, B., Yang, B., & Tripathi, L. (2021). A CRISPR/Cas9-based genome-editing system for yam (Dioscorea spp.).Plant Biotechnology Journal. https://doi.org/10.1111/PBI.13515
68. Tan, Y., Duan, Y., Chi, Q., Wang, R., Yin, Y. X., Cui, D., Li, S., Wang, A., Ma, R., Li, B., Jiao, Z., & Sun, H. (2023). The Role of Reactive Oxygen Species in Plant Response to Radiation.International Journal of Molecular Sciences. https://doi.org/10.3390/ijms24043346
69. The Effect of X-ray on Food. (2022). NeuroQuantology. https://doi.org/10.14704/nq.2022.20.2.nq22079
70. Tiamiyu, H. K., Babajide, J. M., Yamamoto, K., Hirose, M., & Manami, F. (2019). Some quality attributes of heat-moisture treated water yam (Dioscorea alata) starch. Nigerian Food Journal. https://doi.org/10.4314/NIFOJ.V37I1
71. Wall, M.M. (2004). Compositional and Sensory analyses of sweet potatoes after X-ray irradiation quarantine treatment. HortScience, 39(3): 574-577.
72. Yu, Q., Kai, F., Li, L., Xueling, C., Lan, W., Wenjin, W., Anzi, D., Defang, S., Xiuzhi, F., Jun, W., & Xin, M. (2016). Preservation method for fresh-cut common yam rhizomes.
73. Zare, L., Tahmouzi, S., Nematollahi, A., Mollakhalili-Meybodi, N., Abedi, A.-S., & Delshadian, Z. (2023). Effect of irradiation treatment on microbial, nutritional and technological characteristics of cereals: A comprehensive review. Radiation Physics and Chemistry. https://doi.org/10.1016/j.radphyschem.2023.111124
74. Zehi, Z. B., Afshari, A., Noori, S. M. A., Jannat, B., & Hashemi, M. (2020). The Effects of X-Ray Irradiation on Safety and Nutritional Value of Food: A Systematic Review Article. Current Pharmaceutical Biotechnology. https://doi.org/10.2174/1389201021666200219093834
75. Zhang, H., & Zhou, W. (2022). Low-energy X-ray irradiation: A novel non-thermal microbial inactivation technology.https://doi.org/10.1016/bs.afnr.2022.02.001