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Economic Feasibility Study For The Setting Up And Utilization Of A Multipurpose Food Irradiation Facility In Jigawa State, North-West Nigeria

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Abstract

One proven and efficient method for processing and preserving food is food irradiation. Irradiation is a productive and economical technique that has several advantages over other technologies used in food processing. The technique helps prevent food loss and ensure food safety by getting rid of parasites and bacteria that can make people sick or even kill them. Produce from agriculture and animal food products can benefit from radiation treatment to increase shelf life while maintaining microbiological safety and quality. Based on more than 50 years of research and testing data, a number of national and international food and health organizations have acknowledged and supported the safety of food and products treated to ionizing radiation. The purpose of this study was to evaluate the economic feasibility for the establishment and utilization of a multipurpose food irradiation facility in Jigawa state and its environ as a post-harvest treatment for major arable crops cultivated in the state and its environ which include millet, sorghum, groundnut, sesame, rice, maize, tomatoes, pepper, onions, wheat, and dried fish. The study explored ways in which irradiation may be employed for each crops and vegetable with the approved dose rate. The cost of irradiation was also calculated for different sources of colbalt-60. The study results indicate one or more technically economically feasible application points for irradiation in the processing of each commodity considered. The most promising points are the potential for disinfestation of large quantity of crops and vegetables which will ensure food availability all year round and at a cheap rate for citizens as well as the potential for export thereby helping to grow the revenue and GDP of the state.

Keywords: *Food irradiation, Facility, Foodstuffs, Gamma radiation, Jigawa state*

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I. Introduction

Food irradiation is a flexible method that preserves food and helps address a number of problems, including hunger and food waste. The process of "food irradiation" involves subjecting food products to an ionizing radiation source for a predefined amount of time in order to sterilize or disinfect them. Internationally, the World Health Organization (WHO), Food and Agricultural Organization (FAO), and International Atomic Energy Agency (IAEA) have approved three types of radiation-based food processing methods, while National Agency for Food Drug Administration and Control (NAFDAC) has approved them Internationally. There are Gamma rays, X-rays and Electron beams. However, this paper will only address the use of gamma rays, specifically Cobalt 60. This is because, in comparison to an electron beam accelerator, a cobalt-60 treatment unit is more resilient, energy-efficient, less reliant on the quality of the electrical supply, and less dependent on qualified maintenance people. By generating radiation from the elements cobalt 60 or cesium 137, gamma rays irradiate food items or products. This enhances the shelf life of perishable goods by eliminating disease-causing microbes in the food. This technique also reduces the danger of food-borne infections, keeps invasive pests at bay, and delays or even stops sprouting of root crops and ripening of fruits. A radiation facility needs to be constructed in order to use this approach.

Approximately 500,000 Mt of food products are irradiated annually worldwide through 180 large-scale gamma irradiation facilities located in 42 countries. Herbs and spices are among the most commonly irradiated commodities. Apart from a few research facilities owned by the Nigeria Atomic Energy Commission (NAEC), there is only one commercially available Gamma Irradiation Facility operated by NAEC and the facility has not be optimally utilized since commissioning. With this technology, other nations—especially the developed ones—have had significant success. This raises the question of whether Jigawa State in particular and Nigeria as a whole might benefit from a commercial scale facility. First off, food irradiation on a greater scale would address some of the fundamental problems that Nigeria faces, including famine, food waste, and methane emissions. Additionally, it opens up the possibility of profit through facility rentals and more effective exports of food crops.

The necessity for technological advancements to assure the safe delivery of food supplies has arisen due to the world population's rapid development and the resulting rise in food consumption. The challenge of meeting a broad range of international quality standards has more often been a barrier to international free trade, which exacerbates the world's food supply and demand equilibrium. Developed nations have been putting increasing pressure on the market to provide products with extremely complex presentation and appearances, as well as greater diversity and quality. In addition to providing nourishment, food serves cultural and symbolic purposes, and the way it looks can affect whether or not a customer would accept it. By altering its molecular structure, radiation processing of food can stop the growth of bacteria and fungi, which are responsible for food spoiling. However, because such processing modifies the physiological processes of plant tissues, it may also delay down the ripening of fruit and some vegetables. Food irradiation offers a cost-effective way to extend the shelf life of numerous foods while avoiding the use of chemicals and fumigants, many of which leave residue (Dulley, 2002).

The acceptability of foods exposed to radiation has long been hampered by the potential that by-products produced during irradiation could be hazardous to health. Nevertheless, even at large doses, irradiated foods do not constitute a health risk, according to a 1999 report published by WHO (WHO, 1999). Experts from the WHO, FAO convened to form the Joint Expert Committee on Irradiated Foods in 1980. They came to the conclusion that irradiating any food with an average total dose of up to 10 kGy posed no risk and did not necessitate further toxicological testing. Additionally, it said that nutritional or microbiological issues are not produced, even at the highest dosage (GCISIDA, 1991). In addition to food processing and preservation methods, irradiation technology has become more widely employed in an effort to increase production and quality. Food irradiation research extends back to the early twentieth century, but most people are unaware of it. The first American and British patents for using ionizing radiation to destroy microorganisms on food were granted in 1905 (FAO, 1999).

Radioactive waste is not accumulated in food irradiation facilities. The food irradiators, which are basically electron accelerators, run on electricity and don't create any radioactive materials. The range radiators use either cobalt-60 or cesium-137, which decay to produce nickel and barium, two non-radioactive elements, as their energy source. These sources become less active with time and are usually replenished when activity levels return to 6–12% of their initial level. The sealed capsules used to carry the radioactive materials feeding the radiators are made in compliance with the "Regulations for Safe Transport of Radioactive Materials," an international set of regulations created by the IAEA. A significant quantity of materials is transported in a secure manner to power the 200 or so irradiators that are deployed globally and are used to treat a range of products. In 870 different shipments from Canada during a 20-year period, almost 190 million Curies of cobalt 60 were finished without posing a radioactive material concern to the environment.

Food-related illnesses pose a serious threat to human health, significantly lower economic output, and raise the expense of the medical care needed to treat them. Radiation can aid in the control of these infections, and as consumer awareness of the benefits grows, so too will the acceptability of irradiated food items. According to FAO estimates, rodents, bacteria, and insects cause around 25% of the world's food production to be lost after harvest. As a result, radiation can help lower these post-harvest losses and lessen the need for chemical pesticides (FAO, 1999). It is anticipated that in developing nations, food loss will be far higher than the average of international norms, with up to 50% of food products perishing quickly, particularly in those with hot climates such as Nigeria. Along with inadequacies in epidemic management in agriculture, there are issues with inefficiency related to the systems of transportation and storage, particularly with regard to fresh crops like bananas, tomatoes and some fruits. The method of irradiation is said to be multifunctional and may be applied to the treatment of animal food (Jayathilakan et al., 2017; Kakatkar et al., 2016), including meat, poultry, and seafood, as well as agricultural commodities (Singh et al., 2016; Gryczka et al., 2018). High-dose irradiation specialized food for immunocompromised individuals is one of the more recent applications (Feliciano, 2018). The ongoing loss of food due to infestation, bacterial and fungal deterioration, growing concern over food-borne illnesses, and stringent import quarantine requirements for global food trade have all sparked interest in radiation technology.

From above, food irradiation can greatly help Jigawa as a State, given its immense agricultural strength, to avoid post-harvest losses in the State and throughout Nigeria. This is because the SWOT analysis of agriculture system in Jigawa State enables a reasonable understanding of its strengths, weaknesses, opportunities, and threats (investJigawa, 2023).

This thoughtful analysis identifies the State's agricultural strengths—plenty of fertile land and a temperate climate—as well as its weaknesses, which include issues like preservation and restricted access to modern farming technologies. Additionally, it points out potential growth directions, like investing more in irrigation infrastructure (i.e. its Opportunities), which will yield a bountiful harvest that will necessitate appropriate storage facilities like irradiation facilities. It also recognizes the threats (i.e. external factors), such as changes in the market, climate change, and post-harvest losses, which call for careful planning and adaptation. By means of this analysis, interested parties can devise focused plans to leverage assets, rectify deficiencies, grab chances, and lessen risks, thereby creating a stable and prosperous agriculture industry in Jigawa State and its environ (Jigawa State Ministry of Agriculture and Natural Resources, 2023). As a result of all the above explanation, the establishment of an irradiation plant in the state is one such method. The aim of this study is to evaluate the economic feasibility for the establishment and utilization of a multipurpose food irradiation facility in Jigawa state and its environ.

II. The Study Area

Jigawa State, located in the north-western region of Nigeria, presents a prime location for evaluating the economic feasibility of establishing a multipurpose food irradiation facility. Positioned between latitudes 11°N and 13°N and longitudes 8°E and 10°E, it shares borders with Kano, Bauchi, and Yobe States, as well as the Republic of Niger. The state's economy is heavily reliant on agriculture, with fertile lands, particularly in the Hadejia River Basin, supporting the cultivation of grains, legumes, vegetables, and fruits (Ibrahim et al., 2020). However, Jigawa faces significant post-harvest challenges, such as pests, microbial contamination, and spoilage, which are exacerbated by high temperatures and humidity. Food irradiation offers a promising solution to these issues by extending the shelf life of agricultural products and enhancing food safety, potentially reducing post-harvest losses by 30-50% (Adeyeye, 2021).

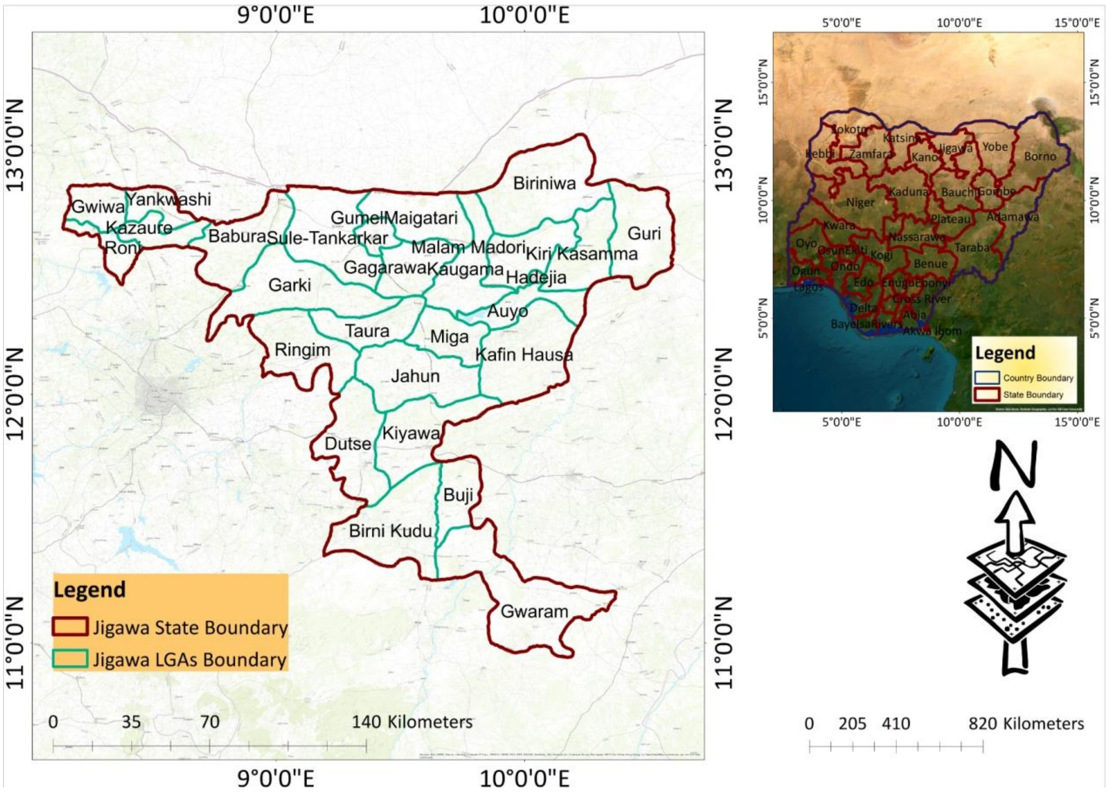

Plate1: Map of Jigawa State showing the local government areas

III. Materials And Methods

This section elaborates on the materials and methods needed for completion of this paper. This study is limited to Jigawa state and its environ. For this study, only secondary data were used. The secondary data sources used are Jigawa state agriculture policy, regulations from international agencies such as WHO, FAO and IAEA and national from NAFDAC, reports and documents published by government and non-governmental organizations, open source information as well as individuals. Data gotten from these documents particularly the state policy on agriculture were utilized for analysis to determine the economic feasibility for establishing commercial multipurpose irradiation facility in Jigawa State.

Options For Irradiation Technique — Irradiation Facility Location And Size

The type of food to be treated and the physical attributes of the technology (dose rate, penetration depth) are the primary determinants of which of the two industrially employed irradiation techniques—accelerated electrons and gamma rays, especially cobalt-60—should be used. Gamma irradiation with cobalt-60 should be chosen over irradiation with accelerated electrons in the current investigation, since a variety of foods of varying shapes and densities will be exposed to radiation (typically at low doses). To minimize the additional transportation costs associated with the ionizing radiation treatment, such a unit should be located close to Dutse, the State capital because of the network of distribution and infrastructure or Gujungu having an international market recognition. It goes without saying that the annual amount of food that is available for radiation treatment influences the choice of radiation source activity. The following equation can be used to define the hourly throughput HT (in t-kGyh^{-1}) in relation to the irradiation source's activity:

$$HT = 0.0533 \times f \times A \quad (1)$$

where f is the cobalt utilization efficiency and A is the source activity (in kCi). According to Kunstadt and Steeves (1993), for a pallet carrier, f, which is dependent upon the apparent density of the foodstuffs irradiated, varies between 0.25 and 0.40. Given the foods indicated in Table I and a monthly treatment hourly rate of 625 (about 20 hours per day), the monthly throughput MT (represented in t-kGy month^{-1}) may be calculated using the following formula:

$$MT = 1000 \times n \quad (2)$$

Here, n stands for the irradiation source's kCi, expressed in hundreds. The annual throughput AT (expressed in t-kGyannum^{-1}) will be as follows if the yearly treatment duration is assumed to be 11 months, with the 12th month required for irradiation unit maintenance.

$$AT = 11{,}000 \times n \quad (3)$$

The selection of the irradiation source's activity (and, consequently, n) must also take into account the diversity of the food items treated's production periods. This is especially true for an irradiation unit meant to treat primarily a variety of plant-based foods whose production is seasonal and whose treatment must be completed shortly after harvest (a storage period of less than one month has been used in this study).

IV. Results And Discussions

This sections deals with results presentation and discussions. We begin the presentation by looking at the various foodstuffs that are produced at commercial quantities in the State. After which we calculated the cost so as to determine the economic feasibility for the establishment of an irradiation facility in the state.

Selected Food Stuffs For An Ionizing Radiation Trestment

Jigawa state is known for the cultivation of many crops. The major arable crops cultivated mainly in the wet season in the state include millet, sorghum, cowpea, groundnuts, sesame, rice, maize, sweet potatoes, Bambara nuts, watermelon, cassava, cotton, okra, etc. Crops produced in the dry season under irrigation include rice, tomatoes, pepper, onions, wheat, sugarcane, carrots, cabbage, lettuce, maize, and a host of other leafy vegetables. Important livestock raised in the state include cattle, sheep, goats, camels, and poultry (JARDA, 2024). However, for the study, few major crops which are produced in high tonnage in the state are selected as presented in Table 1. The table provide the following indications for each food item: production tonnage, the goal of the ionizing treatment, and the dosages that are suggested to achieve these goals as regulated internationally by WHO, FAO and IAEA and nationally by NAFDAC.

The crop Groundnut was not added to this list because of the fact that the ionizing treatment of this leguminous plant does not stop aflatoxins from being created, nor does it remove mycotoxins, which are mostly produced by the mold Aspergillus flavus. Bridges et al. (1956) stated that a dose of 3kGy is required to destroy this mold. However, the ionizing treatment needs to be done right away after the harvest, which is not feasible in reality, in order to stop the generation of aflatoxins. Once formed, aflatoxins are resistant to extremely high doses of radiation (Aibara and Miyaki, 1990), far higher than the maximum value of 10 kGy that is authorized for treating food intended for human consumption. Additionally, once formed, aflatoxins are incompatible with maintaining the organoleptic characteristics of food.

Table 1: Production Volume (Mt) of Priority Commodities in the State

Foodstuffs	Production$^{(a)}$ (Mt)	Purpose	Dose (kGy)
Millet	545, 364	Disinfection	0.25
Sorghum	676, 272	Disinfection	0.25
Rice	334, 415	Disinfection	0.25
Maize	113, 785	Disinfection	0.25
Wheat	33, 710	Disinfection	0.25
Sesame	85, 559	Disinfection	0.25
Dried Fish	109,455	Disinfection	0.50
Mangoes	55, 450	Inhibition of ripening	0.75
Tomatoes	287, 510	Sprout inhibition	0.10
Pepper	98, 652	Sprout inhibition	0.10
Onions	47, 890	Sprout inhibition	0.10
Herbs	54, 655	Improving microbiological safety	5.00
Spices		Improving microbiological safety	5.00

(a) Average value over 3-year period (2021 - 2023).
Source: Jigawa State Agricultural and Rural Development Authority (JARDA), 2024
FAO/IAEA, 1993.

As seen from Table 1, different foodstuffs require different radiation dosage rate. Based on the radiation dosages, there are three kinds of practical uses for food irradiation: low dose applications (up to 1 kGy), medium dose applications (1 kGy to 10 kGy), and high dose applications (above 10 kGy) though not recommended by WHO, FAO, IAEA and NAFDAC. Low doses (0.02-0.2 kGy) are used to prevent sprouts in tubers and bulbs; 0.25 -1.0 kGy are used to postpone fruit ripening; and 0.1-1.0 kGy are used to eradicate food-borne parasites and disinfest insects. To extend the shelf life of meat, poultry, and seafood at refrigeration temperature, medium doses of 1.0–3.0 kGy are used to reduce spoilage microbes; 3.0–7.0 kGy are used to reduce pathogenic microbes in fresh and frozen meat, poultry, and seafood; and 10.0 kGy are used to reduce the microbial load of spices and herbs to improve hygienic quality. These dosage ranges were chosen in order to irradiate the selected foods.

Moreover, sprouting causes large post harvest losses of tuber crops and vegetable such as yam, ginger, potatoes, onions,and garlic. However, in order to guarantee a consistent supply for the customers, storage for up to several months is required. Certain pesticides applied both before and after harvest as well as refrigeration might prevent sprouting. In tropical and sub-tropical regions of the world including Nigeria, inhibiting sprouting by refrigeration is highly. It is rather cheap and effective to chemically treat with sprout inhibitors such as maleic hydrazide, isopropyl carbamate, and chloroisopropyl carbamate; but these substances leave harmful behind, and several nations have outlawed their usage (Mostafavi et al., 2010). For potatoes, onion bulbs, yams, and other foods made from sprouting plants, radiation is a secure and practical substitute (Singh et al., 1998; Singh, 2000; Barkai-Golan and Follett, 2017). As 0.2 kGy or less of extremely low radiation suppresses sprouting, leaves no trace, and permits greater temperature storage (Singh and Singh, 2020).

The elimination of insects in grains (i.e. cereals), flours and their derivatives, dried fish, and spices13 is a particularly promising use of radiation. Significant losses in agricultural production are caused by pest and insect infestations. Pathogenic bacteria and parasites can also be spread by insects, mites, and other pests (Mostafavi et al., 2010). A range of fumigants, including methyl bromide, ethylene dibromide, and phosphine, have been employed to manage insects in agricultural goods. However, the use of these pesticides is either completely prohibited or heavily limited in the majority of countries, Nigeria inclusive. When it comes to drying fish, dried fruits, and cereals, radiation is a highly effective way to reduce pest infestation and loss (Azelmat et al., 2004; Boshra and Mikhaiel, 2006). Radiation doses between 0.1 and 1 kGy are needed to suppress pests at various phases of growth. It would be ideal to prolong the extremely short shelf life of fresh fruits and vegetables such as tomatoes. Tomatoes were successfully exposed to radiation at doses of 0.75 to 1.0 kGy, which increased shelf life without affecting quality or sensory characteristics (Singh et al., 2016).

The most popular food products that are commercially irradiated for microbial decontamination are spices and vegetable seasonings. Microorganisms can contaminate spices during harvest, processing, and storage. Contaminated spices may contain pathogenic bacteria such as Salmonella, Escherichia coli, Clostridium perfringens, Bacillus cereus, and toxic molds (Thanushree et al., 2019). Food processors are extremely concerned about contaminated spices and dry ingredients because they might cause food to deteriorate and reduce microbiological safety (Farkas, 1998). A dependable technique to increase microbiological safety for spices, herbs, and other dry items is to expose them to radiation at doses ranging from 3 to 10 kGy (Farkas, 1988; Gryczka et al., 2018). Numerous investigations have demonstrated that spices can be irradiated at a dose of 10 kGy to remove the microbial load without experiencing appreciable organoleptic or chemical changes (Singh and Tak, 1997; Singh et al., 2002; Esmaeili et al., 2018). In comparison to thermal treatment, ionizing radiation treatment of spices, herbs, and dried vegetable seasonings removes microbiological contamination more effectively and leaves no chemical residue, unlike fumigants (Loaharanu, 1994; Olson, 1998). Spices that have been irradiated minimize post-harvest losses, guarantee hygienic quality, and promote commerce. More than 20 countries engage in the commercial radiation of spices.

High tonnage foods (cereals, vegetables, spices, and dried fish) will be treated between September and December, according to Table 2, which also provides information on production times and ionizing treatments.

Table 2: Major Irradiation and production times for the Foodstuffs items under study

Foodstuffs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Millet								■	■	■	■	■
Sorghum								■	■	■	■	■
Rice								■	■	■	■	■
Maize								■	■	■	■	■
Wheat								■	■	■	■	■
Sesame								■	■	■	■	■
Dried Fish	■	■	■	■	■	■	■	■	■	■	■	■
Mangoes								■	■	■	■	■
Tomatoes								■	■	■	■	■
Pepper								■	■	■	■	■
Onions								■	■	■	■	■
Herbs								■	■	■	■	■
Spices								■	■	■	■	■

As seen in Table 1, the production tonnage and irradiation doses utilized for each foodstuffs are stated. Given that these foods are produced at an average rate of about 33,000 Mt per month during the production months, and that the selected irradiation doses for the cereals, vegetables, spices/herbs and dried fish are 0.25 kGy, 0.1kGy, 5.0kGy, and 0.50 kGy, respectively, the maximum percentage of production that can be treated on a monthly basis is determined by the ratio n/80 (this is assuming that the monthly production of a foodstuff stays constant throughout all the months of its production). As a result, it is 1.25% for 100 kCi of activity, 3.75%for 300 kCi, and 6.25% for 500 kCi of activity. Figures 1-3 display the monthly utilization rates of this unit for 100kCi, 300kCi and 500kCi obtained under the assumption that 10% of the total production of each food item (or, in the event that this is not possible, the maximum percentage) is irradiated [which takes into account the monthly throughput of the irradiation plant. Then, based on an 11-month calculation, the annual use rates are 72% (100 kCi), 49% (300 kCi), and 41% (500 kCi). Given these findings, it would appear implausible to select an activity which is higher than 500 kCi. This is because a high profit can be generated when compare to starting cost.

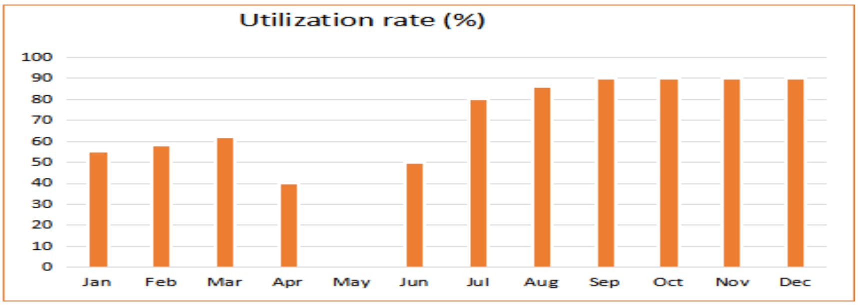

Figure 1: Monthly utilization rates of the irradiation plant with activity of the irradiation source of 100 kCi

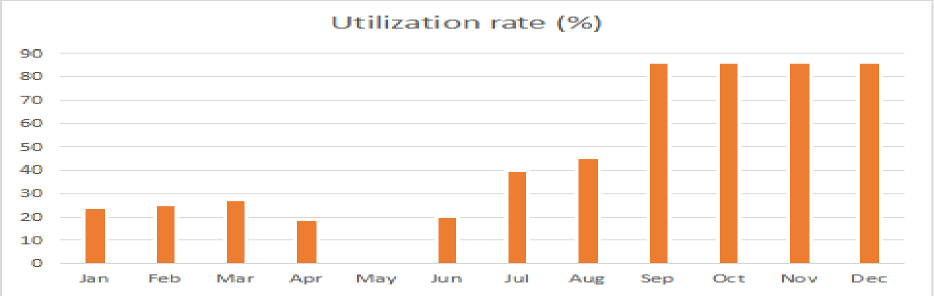

Figure 2: Monthly utilization rates of the irradiation plant with activity of the irradiation source of 300 kCi

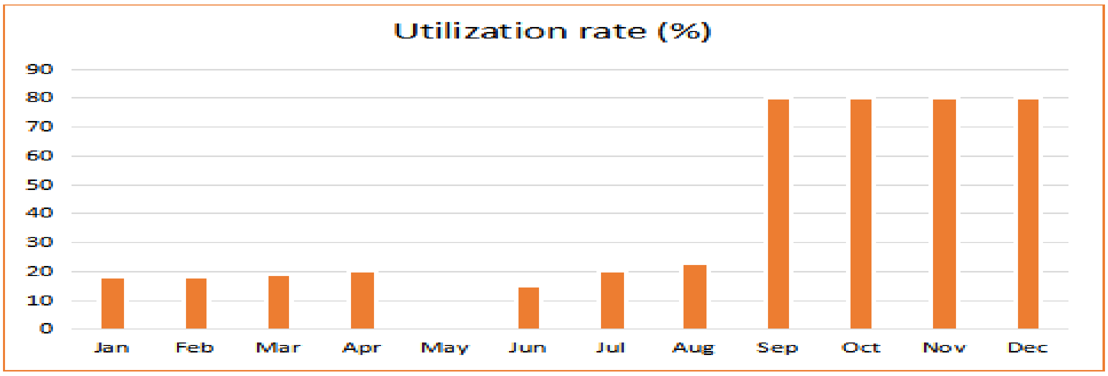

Figure 3: Monthly utilization rates of the irradiation plant with activity of the irradiation source of 500 kCi.

As seen from Figure 1to 3, no irradiation is carried out in the month of May. This is because the month of May is reserved for maintenance of the irradiation plant. Thus, mangoes and dried fishes produced in May will be treated in June.

V. Calculation Of The Mean Cost Of The Ionizing Radiation Treatment For A Cost-Effective Radiation Facility/Unit

The assessment of the mean cost of the ionizing radiation treatment required for a cost-effective irradiation facility is made feasible by knowledge of the initial total investment (capital costs), operational costs, loan costs, and the fixing of a return on investment. The capital and operating cost items that were considered in this analysis was based on Urbain (1993) explanation. The initial total outlay required to establish a cobalt-60 irradiation plant with activity sources of 100, 300, or 500 kCi is displayed in Table 3. The figures in the table pertaining to the expenses of the plant, machinery civil works, transportation cost, cobalt-60 etc were obtained from the projection of the cost put forward by Kunstadt and Steeves (1993) to 2024 using world inflation rate. The irradiation chamber's concrete thickness is calculated so that, should the source's activity grow from 100 to 500 kCi, no modifications would be necessary. The pallet system conveyor was selected because it is the most suitable for the variety of goods that need to be irradiated and human loading is favoured over automation in a nation where labour is cheap and automation is expensive.

Table 3. Total initial outlay (in thousands of US dollars) required to establish a facility for cobalt-60 irradiation, taking into account the radiation source's activity in Jigawa State.

Items	Activity		
	100kCi	300kCi	500kCi
Plant, machinery and installation charges	2, 700	2, 700	2, 700
Civil works of about 1500m^2 building including irradiation cell with labyrinth, control room, offices and labs, excluding land cost and cold storages	1350	1350	1,350
Cost of laboratory equipment for dosimetry and microbiology and other Auxiliary plant and machinery required for the facility including DG set, CCTV camera system, X-ray package scanner etc	1, 400	1, 400	1, 400
Transport cost	65	65	65
Estimated cost of Cobalt-60	665	1, 495	2, 325
Total initial investment	6, 180	7, 010	7, 840

For food items that are being irradiated and stored, no freezing nor refrigeration is offered. The construction project's cost estimate accounts for current Nigerian pricing. Table 4 lists the financing and operating costs for an irradiation facility according to the activity of the irradiation source. Salaries for a manager, an officer in charge of quality control and radiation safety, a secretary, four operators, and thirteen handlers are included in the operating costs. Additional expenses include research and development, travel and training courses, the cost of replenishing cobalt-60 (12.5% of the source's initial cost), maintenance, and other costs like electricity, water, fuel, taxes, and other miscellaneous expenses, which are estimated to be 2% and 4% of the total initial investment, respectively. Depreciation costs are based on formulas for amortizing conveyor and auxiliary equipment, 15 amortizing cobalt-60, and 25 amortizing buildings (Kunstadt and Steeves, 1993; Morrison, 1985). The loan costs are based on the assumption that the entire investment was borrowed with a 20-year repayment period and an interest rate of 7%. The following equation therefore represents the annuities An:

$$An = K \times \frac{i \times (1+i)^n}{(1+i)^n - 1} \qquad (4)$$

where K represents the original total investment, i the loan's interest rate, and n the loan's repayment duration (given in years).

Table 4: shows the irradiation facility's annual operating and loan costs as well as the necessary annual profit (in thousands of US dollars) to achieve a 20% return on investment relative to the irradiation source's activity.

Costs	Activity (kCi)		
	100	300	500
Salaries and supplementary costs	500	500	500
60Co replenishment	68	100	150
Maintenance	40	55	70
Miscellaneous (water, electricity, taxes, insurance, etc.)	150	160	175
Depreciation	230	245	268
Operating costs	988	1060	1163
Invested cost	610	655	740
Required profit	862	912	992

Based on the assumptions that the investment is a government based and that the investment would be recoup in 5 years (a 20% return on investment), the necessary annual profit (Table 4) has been computed. In addition to operating costs, invested costs, and required profit, the investor must also consider the utilization rate of the irradiation plant and, consequently, the total amount of foodstuffs treated annually when determining the mean cost of the ionizing radiation treatment (Cm) that must be charged a farmer or producer for their irradiated food. The equation expresses it as follows (in US $-f ^kGy"1):

$$C_m = \frac{OC + LC + RP}{X_t} \qquad (5)$$

where X_t is the total amount of food treated annually (in t-kGy), RP is the annual needed profit (in US dollars), LC is the annual loan charges, and OC is the annual operational costs.

The calculation of the average cost of ionizing radiation treatment in relation to the total amount of food treated each year and the radiation source's activity is shown in Fig. 2. It should be noted that even when the maximum throughput of the irradiation facility (say 19,000 t-kGy) is achieved, the mean cost value is always greater than 110 US S-t'^kGy"1 with an irradiation source of 100 kCi, which eliminates the choice of such a source.When the mean cost value is less than 100 US S-f^kGy"1, more than 32,000 t-kGy of food must be treated, which means that an irradiation source with at least 300 kCi activity must be used. This amount of contaminated food is by no means insignificant. With an irradiation source of 300 kCi, this amount can only be reached by irradiating 7.5% of the entire output of cereals and spices (the maximum percentage that can be achieved) and roughly 25% of the total production of the other foodstuffs. It is necessary to irradiate 9.25% of the entire production of cereal and spices (the greatest percentable possible) and 12% of the total production of the other foods with an irradiation source of 500 kCi. Thus, it appears improbable to further reduce the average cost of the ionizing radiation treatment by raising the proportion of foods treated. It also appears unlikely that the foods selected for this project will allow for the achievement of the highest throughput possible from the various sources (32,000 t-kGya"1 (300 kCi) or 36,000 t-kGy-a"1 (500 kCi)).

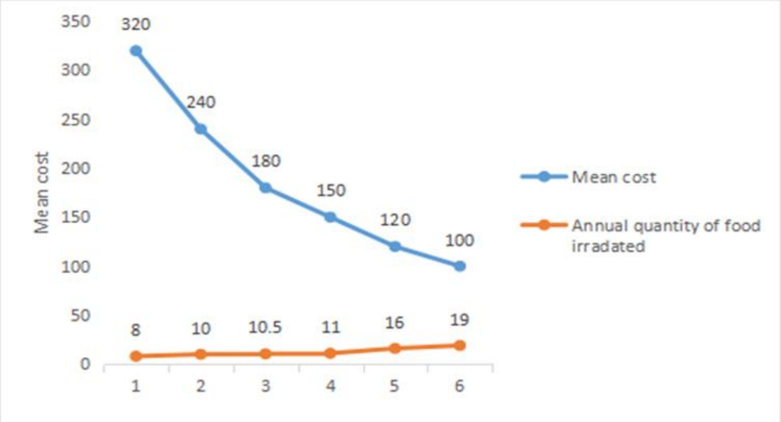

Figure 4. Variation of the mean cost of the ionizing radiation treatment (in US S-f'-kGy'1) in relation to the annual quantity of foodstuffs treated for 100kCi

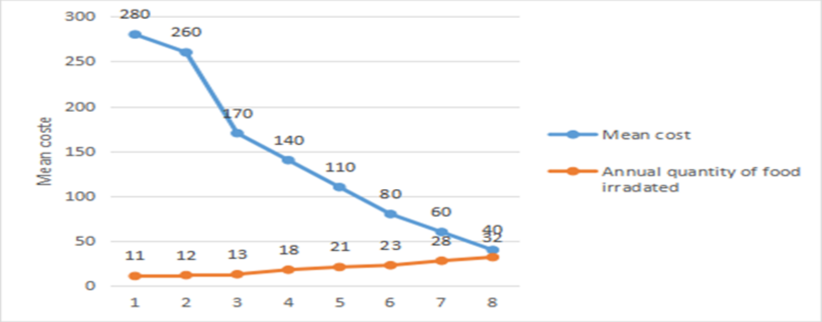

Figure 5. Variation of the mean cost of the ionizing radiation treatment (in US S-f'-kGy'1) in relation to the annual quantity of foodstuffs treated for 300kCi

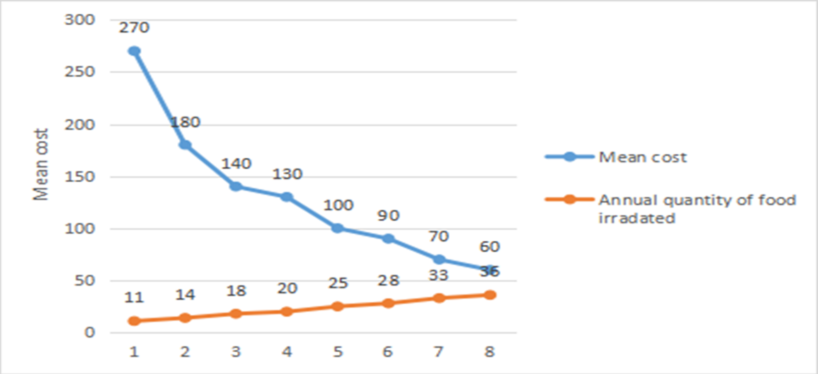

Figure 6. Variation of the mean cost of the ionizing radiation treatment (in US S-f'-kGy'1) in relation to the annual quantity of foodstuffs treated for 500kCi

VI. Conclusion

A significant advancement in food preservation that has been shown to be healthful and toxicologically safe is food irradiation. Though, eating food that has been radiation-treated raises concerns, this technology has remained underutilized. The technological superiority and safety of food irradiation processing have been proven via extensive study and testing by the highest organisation of the world in the form of WHO, FAO and IAEA. Food irradiation is a healthy substitute for chemicals that harm people's health and the environment. The technique is currently being used globally for a variety of commodities, and both the food business and consumers are beginning to accept it. Technology for radiation processing can be a useful tool in addressing post-harvest losses and concerns about food safety. The study's findings indicate that establishing a cobalt-60 with various activity of 100kCi, 300kCi and 500 kCi irradiation facility in Jigawa state, to treat a variety of foods intended for local consumption and export can be deemed financially advantageous for a state government, provided that the amount of foods treated is sufficient.

Increasing further the percentage of each food treated could increase the irradiation unit's profitability, but the profit might only be marginal. In fact, it should be noted that, with a 500 kCi source, no more than 9.25% of the production of cereal and spices can be irradiated; under these conditions, more than 12% of the total production of other foods must be treated in order to treat the adequate volume of foodstuffs. Therefore, in order to boost the irradiation plant's utilization rates, it is more likely that adding additional food items to the list of those research on in this study and other services like sterilization of medical equipment would result in a profit enhancement.

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