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GAMMA RADIATION TREATMENT FOR AFLATOXIN DECONTAMINATION IN GARRI: ENHANCING FOOD SAFETY AND QUALITY

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Abstract: *Aflatoxins, toxic and carcinogenic compounds produced by Aspergillus fungi, contaminated garri, a stable food in West Africa, posing significant health risks to consumers. This study is to investigate the efficacy of gamma radiation treatment for aflatoxin decontamination in garri. The highest total bacterial count (TBC) is 3.4 x 10^4 CFU/g and total fungi count (TFC) is 6.3x 10^4 CFU/g. This indicates that the garri samples had bio-load concentration below the recommended limit of 1.0 x 10^4 except for the mixed sample contaminated because the recommended limit of bio-load in a ready to eat food is less than 1.0 x 10^4 coliform unit (CFU/g) for the food to be satisfactory (Adebayo B et al, 2012). After irradiation, results shows that doses used were able to reasonably disinfect the growth of bacteria and fungi in the garri samples. Highest TBC after irradiation was 1.2 x 10^3 CFU/g and highest TFC was 6.3 x 10^3 CFU/g and highest TFC after irradiation was 3.0 x 10^2 CFU/g. this result clearly shows that both bacteria and fungi has been disinfected.*

Key words: *aflatoxin, aspergillus, fungi, contaminated, garri, decontamination, contaminated, irradiation, bio-load, toxic.*

1.0 INTRODUCTION

Garri is an edible, fermented, acidic, starchy, granular dry product made from fresh cassava or partially gelatinized cassava. It has been marked as the most important single traditional staple food in West Africa. As granules, garri could be soaked in cold water and consumed along various ingredients like sugar, groundnut, milk, biscuits, coconut, roasted peanut, fish, or boiled cowpea (Akpu kpa, or Okpa) as complements e.t.c. All to the consumers specification, or it could be cooked and stirred into a paste or dough-like product called 'Eba' and eaten with soup or stew. (Lawani et al., 2015). Garri is massively consumed in the West African sub region, regardless of ethnicity or socio-economic class (Ogiehor et al., 2007).It is, produced from peeled, washed, grated, fermented and roasted cassava tubers. Most of the time, cassava for garri production is harvested manually in the farm with the aid of a cutlass, hoe and flat iron sheet (digger), which occasionally inflicts various degrees of injuries on the root tubers. After harvesting, the root tubers are hauled to the market where they are heaped in 20s, 40s, 50s, or 100s for sales under humid and warm tropical conditions. These practices predispose the

root tubers to contamination and infestation by various groups of organisms (especially moulds), mites and insects which potentiate bio deterioration.

The processing of cassava tuber to garri and its handling involve different stages. At each stage, there is a level of contamination by solid and microbial pathogen (Adejumo et al., 2015). After frying garri is further spread on the bare floor or on mat to allow it to cool before final sieving and packaging for marketing. The sales and distribution of garri in local markets is associated with practices such as display of product in open sacs, open basins, bowls and mats at points of sale and the use of bare hands during handling and sales. These unhygienic practices which may lead to microbial contamination due to deposition of bio aerosols on exposed products, transfer of microbes from dirty hands and utensils and frequent visits by animals and fomites (which may carry infectious agents), can contribute to the post – process problems of this product. These practices potentiate contamination by various groups of microorganisms and may predispose public health hazard. In as much as this staple food product is a well-known and highly demanded product, much is written in literature about its health hazards such as food poisoning that could have resulted from contamination during its production process.

Numerous methods have been used locally in an attempt to isolate and expel contaminants that threaten consumer's health (Mulade, 2015). The US Food and Drug Administration (FDA) has set limits of 20 µg/kg for total aflatoxins for human and animals, and 0.5 µg/kg for milk and its products. The Nigeria's National Agency for Food and Drugs Administration and Control (NAFDAC) enforces a standard of 4 µg/kg for ready-to-eat foods and 10µg/kg for raw food items, for packaged goods and export-bound products. (Source: NAFDAC food irradiation regulation, 2021 Federal Republic of Nigeria, Official Gazette)

Statement of the Problem

Garri is mainly contaminated during its pre-harvest, harvest, production, drying, packaging, storing and marketing stage. (Kolewole *et al*., 2012). The quality of garri is defined on the basis of its safety and fitness for consumption by the target consumers. Which means in order to satisfy the taste and quality of garri, the processor needs to integrate better and more efficient management qualities into the processing process of garri granules (Adebayo *et al*., 2012)Previous reports have revealed high a vast array of microorganisms in market samples of garri. (Bartram J, 2003).Studies conducted by many researchers, which analyzed garri from different sources and Published in many Journals, have reported that several bacteria general namely (Bacillus, Staphylococcus, Streptococcus, Pseudomonas, Clostridium, Salmonella *Klebsiella* and *coliforms* group) genera and fungi genera (*Aspergillus, Penicillium, Rhizopus*, *Botrytls, Fusarium* and *Cladosporium*) In addition to Aflatoxins B1, B2, G1 and G2 are present in garri samples sold in the market.

These microorganisms can cause deterioration in food quality and spoilage, serious food borne illnesses and may pose a threat to public health. Moreover, the source of these

microbial contaminants may also be a portal for contamination by more potent pathogenic microbes which may cause an epidemic considering the popularity of the food product (Bartram , 2003, WHO, 2006).*Bacillus cereus* causes food poisoning similar to staphylococcal food poisoning (Bartram, 2003). Some strains produce heat-stable toxin in food that is associated with spore germination and gives rise to a syndrome of vomiting within 1-5hours of ingestion. Other strains produce a heat-liable enterotoxin after ingestion that causes diarrhea within 10-15hours. *Bacillus cereus* is also known to cause bacteremia in immune compromised patients as well as symptoms such as vomiting and diarrhea. *Bacillus anthracis* causes anthrax in humans.

In an attempt to obtain a more efficient mean of garri disinfection, research dating back to the early 1950s, focus on the use of machinery in the processing of garri however this only reduces the contaminations. Recent increased scientific knowledge about the most suitable and precise mechanisms for the removal of toxins and bio-loads from food generally, led to the research into the field of radiology in food science (Nweke *et al*., 2004; Kolawole *et al*., 2012).

Objectives of the Study

The aim of this study is to disinfect hydrocynanide and bio-load contaminants in garri using gamma irradiation method. The Specific Objectives of the Study are as follows

1 To collect samples of garri sold in the open market

2 To identify the pathogenic (Microbial loads) Microorganisms that can cause deterioration, spoilage or harm to potential consumers of garri.

3 To investigate the concentration of hydrocynanide and nutritional composition of garri before irradiation.

4 To irradiate samples of garri using gamma-ray of different doses.

5 To investigate whether gamma-ray irradiation can eliminate bioload thus disinfecting microorganisms from garri

6 To investigate whether the disinfection reduce the concentration of hydrocynanide and retains the nutritional contents of the samples irradiated.

7 To make garri product safe and fits for human consumption.

2.0 LITERATURE REVIEW

Post-Harvest losses constitute the major factor contributing to food insecurity in Nigeria and Africa at large, but the problems are often overlooked and not taken too serious. This leads to malnutrition, diseases and death of millions of children in our country. Chemicals which are widely used have often proved hazardous. Hence developing other techniques to preserve fresh vegetables such as okra is important. In this research work, X-ray of different doses are

used to irradiate fresh okra and the effects of the radiation was monitored based on the fibrous nature and texture of the samples and shelf life of the fresh Okra fruit to ensure its continues availability and to reduce the post-harvest loses of the vegetable crops. This research work shows that the shelf life vegetables such as okra can be greatly enhanced by irradiating the fruits at a required dose of 0.051 Gy which is in compliance with the NAFDAC and USFD recommendation. Yissah *et al.,*(2006)

Utile, (2016) investigated the effects of X-ray irradiation on freshly ripped plucked tomato fruits with focus on local varieties. Five samples of cultivar panchy were exposed using X-ray irradiation at factors of 40kvp, 45kvp, 50kvp, and 55kvp, 5mAS, 7mAS, 9mAS, and 12mAS and Dose of 36.5µGy, 38.90µGy, 39.30µGy, and 40.05µGy respectively. The samples were examined for extension desiccators, crucible, moisture sample dishes and the kjeldahl procedure and physiological analysis were carried out using Digital weighing balance. Results showed that freshly ripped plucked tomato fruits using X-ray dose of 40.05µGy will extend the shelf life to keep it fresh for 10days. However, the Bio-chemical analysis of carbohydrate, crude protein, ash content and moisture content showed negligible changes in the nutritional value of irradiated tomatoes. The physiological analysis of weight loss also showed a negligible amount in weight loss of the irradiated tomatoes.

Mulade, (2015), investigated the microbiological contamination of Garri sold in two different markets in Benin City metropolis, using the pour plate technique. The mean total count ranged from 15.0 to 29.4 × 104 cfu/g in Oba market and Santana market respectively. A total of six organisms were identified in Santana Market samples while a total of ten probable organisms were identified from Oba market sample, using their morphological characteristics on Nutrient Agar plate. The use of hygienic packaging by producers and retailers in Benin City, is highly recommended to ensure food safety and consumer protection.

Ana Luiza Freire Cintia et al., (2015), investigated the microbial population and metabolites produced during cassava fermentation. In all assays, the inoculated microorganisms fermented cassava, judged by lowering the pH from 6.0 to 4.0–5.0 within 24 h. *Lactobacillus fermentum* CCMA 0215 isolated from the indigenous fermented cassava beverage *yakupa* was used as single or mixed starter culture with five different yeast strains (*Torulaspora delbrueckii* CCMA 0234 and CCMA 0235, *Pichia caribbica* CCMA 0198, and *Saccharomyces cerevisiae* CCMA 0232 and CCMA 0233) to ferment cassava. Lactic acid bacteria (LAB) and yeast population increased during fermentation. Lactic acid was the main organic acid produced, reaching a maximum value of 4.5 g/L at 24 h in the co-culture .Fermentations using each yeast as single starter culture were also performed. Other organic acids, such as malic, tartaric, and succinic acids, were detected in low concentrations (less than 0.5 g/L). Ethanol and glycerol were produced in all assays inoculated with yeasts (single and co-cultured with LAB), reaching the maximum concentration of approximately 2.3 g/L and 0.6 g/L, respectively. Twenty-two volatile compounds were detected after 48 h of fermentation, varying widely between single and co-cultures. The compounds 2-phenylethyl alcohol, 1-butanol, 3-methyl (isoamyl alcohol),

and acetoin were detected in single and co-cultures. This study demonstrated co-cultures of yeasts and LAB had the ability to improve the aroma profile of the final product and the safety of the product by lowering the pH.

Health benefits and effects of Garri on the body

Apart from of being a rich source of energy owing to its carbohydrate content, Garri is also a good source of fiber which help promote bowel emptying and prevent stomach cancer. The main side effect of Garri consumption is related to the cyanide content of cassava from which Garri is produced. Garri is made from cassava which is known to contain hydrocyanic acid. Although the processing process of Garri significantly reduces its cyanide content, it has been linked to eye defects which are the main disadvantages of Garri consumption. According to Dr/.Ben Ajayi a Opthalmologist," Cyanide is slightly similar in structure to vitamin B12 (Cyanocobalamin) so it competes with vitamin B12 replacing it and adversely affecting rapidly growing tissues or tissues that are regularly being renewed such as the skin, peripheral nerves and the nerve of the eye (optic nerve). It is the involvement of optic nerve which can lead to eye defects and blindness. A study conducted by the Makerere University Medical School and Published in the African Journal of health sciences which analyzed Garri from different sources contains several bacteria genera namely (Bacillus, Staphylococcus, Streptococcus, Pseudomonas, Clostridium, Salmonella *Klebsiella* and *coliforms* group) genera and fungi genera (*Aspergillus, Penicillium, Rhizopus*, *Botrytls, Fusarium* and *Cladosporium*) In addition to Aflatoxins B1, B2, G1 and G2.(Richard, 2008; Pornsri *et al*,.2011).

Garri Disinfection

Food disinfection is basically the act of purifying food stuff from toxin microbes which are harmful to human health. It may be imagined that an efficient food disinfecting procedure may consist of a sequence of washing and rinsing may prove unsatisfactory as Garri is mainly contaminated during its production, anytime during the stages of pre-harvest, harvest, drying, packaging, storing and marketing (Kolewole *et al*., 2012). The quality of Garri is defined on the basis of its safety and fitness for consumption by the target consumers. Which means in order to satisfy the taste and quality of Garri, the processor needs to integrate better and more efficient management qualities into the processing process of Garri granules (Adebayo *et al*., 2012).

In an attempt to obtain a more efficient mean of Garri disinfection, research dating back to the early 1950s, focus on the use of machinery in the processing of Garri. Recent increased scientific knowledge about the most suitable and precise mechanisms for the removal of toxins and bio-loads from food generally, led to the research into the field of radiology in food science (Nweke *et al*., 2004; Kolawole *et al*., 2012).

Nutritional Value of Garri

Garri contains lots of nutrients that are useful and beneficial to our health. The nutrients found in garri are;

- Sodium 417mg
- Total fat 2g
- Dietary fiber 12g

- Protein 2g
- Cholesterol 0 mg
- Vitamin A 0%
- Vitamin C 0% iron.
- Calories 340

Fermentation of Cassava and Microbial Quality of Garri

Fermentation is defined as an enzymes induced bio-chemical breakdown of sugars by micro-organisms in foods to produce alcohol, and energy. After fermentation, frying at high temperature dries the fermented pulp to about 10% moisture content and this may result in partial dextrinization of starch (Akindahunsi et al., 1999). Also, high temperature destroys both enzymes and microbes present in the fermented garri, as well as eliminates cyanide gas from the garri product. The fermentation of cassava to produce garri provides an enormous scope of value addition and preserves this starchy food in a wide diversity of flavours, aromas and textures that enrich the human diet and helps to ensure distribution and storage of the product without the need for refrigeration. However, post-process problems of garri still persist and include loss of microbial stability and spoilage during storage, distribution and marketing. The post processing problems associated with garri include loss of microbial stability and spoilage during storage, distribution and marketing (Azam et al., 2003).

The sales of garri in the local markets is associated with practices such as open display in bowls, open buckets, open sacs, bowls and mats at points of sale and the use of bare hands in handling and selling of garri products. These unhygienic practices, may lead to microbial contamination due to deposition of bioaerosols on exposed products, transfer of microbes from dirty hands and utensils (Amadi and Adebola et al., 2008). Frequent visits by animals and fomites (which may carry infectious agents), can contribute to the post-processing problems of this product.(WHO, 2006).

Previous reports have revealed high a vast array of microorganisms in market samples of garri. (Bartram J, 2003). WHO Emerging Issues in Water and Infectious Disease Series. London, IWA Publishing; for *'drinking-water safety 'the significance of HPCs for water quality and human health*' published: These microorganisms can cause deterioration in food quality and spoilage, serious food borne illnesses and may pose a threat to public health. Moreover, the source of these microbial contaminants may also be a portal for contamination by more potent pathogenic microbes which may cause an epidemic considering the popularity of the food product (WHO, 2006).

Effect of Some Microbes found in Garri on the Human Body

***Bacillus* spp., Routes of Exposure and Human health effects**

Bacillus spp. are large (4-10μ), Gram-positive, strictly aerobic or facultative anaerobic encapsulated bacilli. They have the important feature of producing spores that are

exceptionally resistant to unfavourable conditions. *Bacillus* spp. Are classified into the subgroups *B. polymyxa, B. subtillis* (which includes *B. cereus and B. licheniformis), B. brevis* and *anthraicis.*

Infection with *Bacillus* spp. is associated with the consumption of a variety of foods (Garri as one of such). Disease may result from the ingestion of the organisms or toxins produced by the organisms. Although most *Bacillus spp.* are harmless, a few are pathogenic to humans and animals. *Bacillus cereus* causes food poisoning similar to staphylococcal food poisoning (Bartram, 2003). Some strains produce heat-stable toxin in food that is associated with spore germination and gives rise to a syndrome of vomiting within 1-5hours of ingestion. Other strains produce a heat-liable enterotoxin after ingestion that causes diarrhea within 10-15h. *Bacillus cereus* is known to cause bacteremia in immune compromised patients as well as symptoms such as vomiting and diarrhea. *Bacillus anthracis* causes anthrax in humans. Moreover, the source of these microbial contaminants may also be a portal for contamination by more potent pathogenic microbes which may cause an epidemic considering the popularity of the food product. (Bartram, 2003).

Bio-loads

Bio-load are basically the mixture of microbes, dust particles, moulds and other forms of biological wastes that gather or form a colony under, in or on a particular surface. Following processing, garri granules are dried, mostly by spreading them on the bare floor before sieving and package. In the open market on the other hand, garri is displayed in basins, bowels and other open containers. This practice potentially contaminates the produce with various types and strains of microorganism that are major hazards to human health (Ogiehor *et al*., 2004; Ogiehor *et al*., 2007). Various groups of moulds have been found to be associated with garri during its storage and distribution; if present they can grow and if toxigenic, can produce mycotoxins, which can affect the nutritional value and sensory properties of garri (Mulade, 2015).

Electromagnetic Radiation

Electromagnetic radiation, have no mass, are unaffected by either electrical or magnetic fields, and have a constant speed in a given medium, does not require matter for its propagation and Its maximum speed (2.998 X 10^8 m/sec) occurs in vacuum, and travels in straight lines; however, its trajectory can be altered by interaction with matter. This interaction can occur either by absorption (removal of the radiation) or scattering (change in trajectory). In some situations Electromagnetic radiation behaves like waves and in other situations like particles. Categories of electromagnetic radiation (including radiant heat; radiofrequency, TV, and microwaves; infrared, visible, and ultraviolet light; and x- and gamma rays) comprise the electromagnetic spectrum Electromagnetic spectrum is composed of radio, microwave, infrared, visible, ultraviolet, x-rays and gamma rays. (Bush berg et al., 2002. Egbere, 2008)

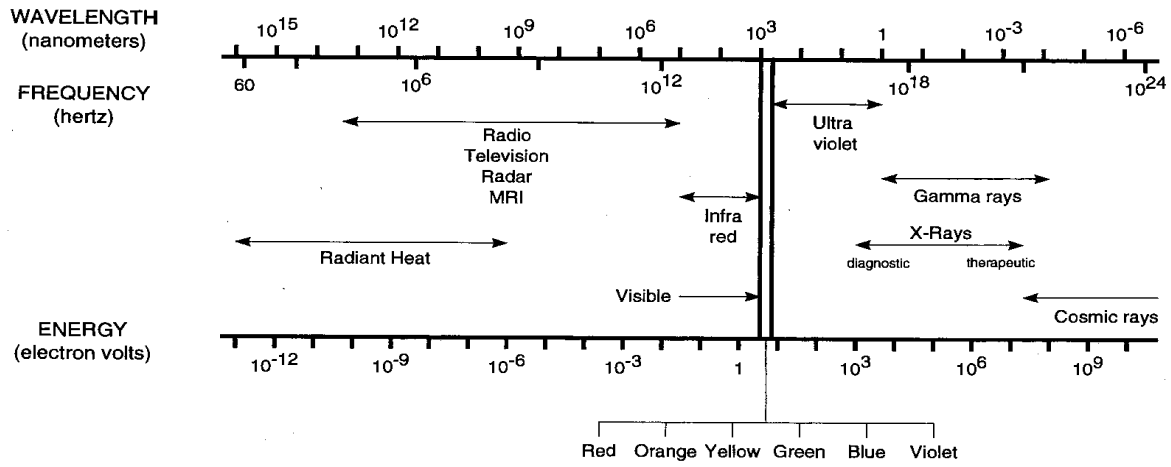

Figure 2.1 The Electromagnetic Spectrum (Bush berg et al., 2002)

Mathematically,

$C=\lambda f$

Where c = speed (3×10^8 ms^{-1} in a vacuum), λ = wavelength and f = frequency

The energy of electromagnetic waves is measured in quanta, given by the formula

$E = hf$

Where h = Planck's constant (6.6×10^{-27} erg sec^{-1}.

Ionizing Radiation

Ionizing radiation is defined as any particles or ray which has sufficient energy to remove electrons from atoms, molecular or ions, (Akpa 2008)

Non-Ionizing Radiation

Non-ionizing radiation refers to any types of electro-magnetic radiation that does not carry any quantum to ionize atom or molecules that is to completely remove an atom or molecule. Instead of producing charged ions when passing through matter, the movement of an electron to higher energy state; nevertheless, different biological effects are observed for different types of non-ionizing radiation (Moulder, 2006)

Source of Radiation

All forms of radiation can generally be traced to either naturally occurring or man-maderadiation (artificial radiation). These sources release radioactive materials to the air as particles or gases as a result of natural forces and from human, industrial, medical and scientific activities (Akpa 2008). The naturally occurring radiations are most widespread and can be of either cosmic (rays from the space) or terrestrial rays from radioactive materials, in air and food.

Natural Sources

Natural sources come from cosmic radiation solar radiation, external terrestrial sources, and radon. Cosmic rays are of two types namely; the primary and secondary cosmic rays. The primary cosmic rays are a result of interaction with the atomic nuclei in the atmosphere (Akpa, 2008).

Artificial sources

Natural and artificial radiation sources are similar in their effects on matter. Above the background level of radiation exposure, the US Nuclear Regulatory commission (NRC) requires that its licenses limit human- made radiation exposure for individual members of the public to 100mrem (1mSv) per year. Some artificial radiation sources affect the body through direct radiation, while others take the form of radioactive contamination and irradiate the body from within (Akpa, 2008).

Interaction of Radiation with Matter

Particles of ionizing radiation includes charged particles such as alpha particles (α), protons (p^+), electrons (e-), beta particles (β-), and positrons and uncharged particles, such as neutrons. The behavior of heavy charged particles e.g alpha particles and protons is different from that of higher charged particles such as electrons and positrons (Durrant, 2001). When a beam of radiation of any kind penetrates matter some of the radiation may be absorbed completely, some may be scattered and some may pass straight through without any interaction at all. Particles in the beam of radiation strike particles in the material and are either stopped or scattered (Ageda, 2018). Charged particles have discrete tracks and they travel in fairly well defined distances before losing all their kinetic energy. The interactions are primarily due to columbic forces. The mechanisms by which a photon loses its energy or is deflected from its original path include mainly the following; photo-electric effect, Compton Effect and pair production. These mechanisms predominate between the photon energies of 0.01-10MeV (Agba, 2017).

There are two broad kinds of process by which a particle travelling through matter can lose energy. In the first kind the energy loss is gradual; the particle loses energy nearly continuously through many interactions with the surrounding material. In the second kind the energy loss is catastrophic; the particle moves without any interaction at all through the material until, in a single collision, it loses all its energy. (www.physics.usydedu.au/superlifescience/AN/ANDpdf). The motion of charged particles through matter is characterised by gradual energy loss whereas photon interactions are of the "all-or-nothing" type. We will start by considering the interaction of photons with matter and then proceed to look at the absorption of material particles.

On the other hand, X-rays and gamma rays travels long distances between interactions and their energy cannot be completely absorbed only interact with matter: the photoelectric effect, Compton Effect and pair production (Akpa, 2008). Each of these produces ionization in

the absorber and this is called primary ionization. The electrons production in the primary ionization event then goes on to ionize other atom in the absorber. This is known as secondary ionization. The interactions of X-ray and gamma rays with matter are a result of particulate nature of electromagnetic radiation. Therefore, the interaction will be described in terms of photons or packets of electromagnetic energy (Akpa, 2008)

Types of Interaction

There are three types of interactions of radiation with matter, they include the following: scattering, attenuation and absorption.

Scattering

Scattering refers to an interaction resulting in the deflection of a particle or photon from its original trajectory. A scattering event in which the total kinetic energy of the colliding particles is unchanged is called electric scattering. When scattering occurs with a loss of kinetic energy (i.e the total kinetic energy of the scattered particles is less than that of the particles before the interaction), the interaction is said to be inelastic (Farkas, 1998)

Attenuation

This is the removal of photons from a beam of x-ray or gamma rays as it passes through matter. Attenuation is caused by both absorption and scattering of the primary photons (Gianoli, 1995).

Attenuation Coefficients

If the interactions are of the "all-or nothing" type then the attenuation of a beam of particles with identical energies, all travelling in the same direction, is described by an exponential law. If at some distance into the material no particles are moving through a slab of material, then after penetrating an extra distance x it is found that the number of particles in the beam N(x) is reduced to

$$N(x) = N_0 e^{-\mu l x}$$

The quantity μl is known as the linear attenuation coefficient; it is a measure of how rapidly the original photons are removed from the beam (Ageda, 2018). Since photons interact with individual atoms, the probability that a photon will interact somewhere within a slab of matter depends on the total number of atoms ahead of it along its path. So the attenuation of radiation depends on the amount of material in the beam's path and not on how it is distributed (Ageda, 2018).

Three samples of the same material present the same area to the incident radiation. The masses of all the samples are the same but the densities are different. The density-thickness is the same in each case, so the three slabs will attenuate a beam of monoenergetic photons by the same factor. This is shown below in figure.2. 2 The exponential law will always describe the attenuation of the original radiation by matter. If the radiation is changed, degraded in energy (and not totally absorbed) or if secondary particles are produced then the effective attenuation is less so the radiation will penetrate more deeply into matter than is predicted by the exponential law alone. Indeed it is possible to get an increase in the number of particles

with depth in the material. The process is called build-up and has to be taken into account when evaluating the effect of radiation shielding (Ageda, 2018).

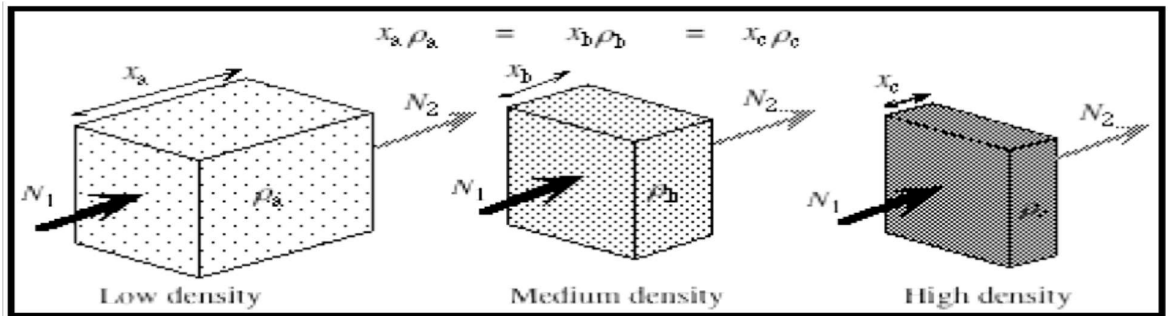

Figure 2.3 Effect of Density on Attenuation

Source: (www.physics.usydedu.au/superlifescience/AN/ANDpdf

Absorption

In absorption interaction, all energy from the incident photons is deposited in the medium. This is very useful in radiotherapy (Agba, 2017).

Energy absorption, transfer and losses during interaction

In general, when interaction of photons takes place in an absorber, part of the photon's energy is then in a form is basically short range in nature (fast electrons for example), and part of the energy reappear as energy of photons of different energy. These scattered photons may or may not leave the system that is under consideration without further energy transfer (scattering events). The process varies widely and is strongly dependent on the initial energy of the photons (Agba, 2006). See table 2.1 below,

Table 2.1 Energy transferred and energy absorbed for incident photons of various energy (Knoll, 1999).

Photon Energy E_{tot} (MeV)	Average energy transferred E_{tr} (MeV)	Average energy absorbed E_{ab} (MeV)
0.01	0.00865	0.00865
0.10	0.0141	0.0141
1.0	0.440	0.440
10.0	7.30	7.04
100.0	95.63	71.90

In a scattering event, it is possible to predict the partition between energy that is transferred to the absorber and energy that is absorbed. It will depend on the definition of the volume of the absorbing medium considering being important, the mean free path of the scattered particles and its range and the number of irradiative event (bremsstrahlung) that takes place.

Photon Interaction

Gamma rays, x rays and light are photons with different energies. Ionizing Photons interact with matter (atoms of a material or absorber) to produce high speed electrons in a variety of ways, depending on their energy and the nature of the material.When x-rays or γ-rays interact with matter, they produce secondary electrons by transferring their photon energy to atomic during the interaction. These secondary electrons then interact and produce ionizations and excitations in the atom of matter.).

X-Ray and Gamma Ray Interactions

When traversing matter, photons will penetrate, scatter, or be absorbed. There are four major types of interactions of x- and gamma-ray photons with matter, the first three of which play a role in diagnostic radiology and nuclear medicine: (a) Rayleigh scattering, (b) Compton scattering, (c) photoelectric absorption, and (d) pair production. (Bush berg et al., 2002, Khan, 1994, Ageda, 2018)

Rayleigh scattering

In Rayleigh scattering, the incident photon interacts with and excites the total atom, as opposed to individual electrons as in Compton scattering or the photoelectric effect. This interaction occurs mainly with very low energy diagnostic x-rays, as used in mammography (15 to 30 keV). During the Rayleigh scattering event, the electric field of the incident photon's electromagnetic wave expends energy, causing all of the electrons in the scattering atom to oscillate in phase. The atom's electron cloud immediately radiates this energy, emitting a photon of the same energy but in a slightly different direction. In this interaction, electrons are not ejected and thus ionization does not occur. In general, the scattering angle increases as the x-ray energy decreases. In medical imaging, detection of the scattered x-ray will have a deleterious effect on image quality. However, this type of interaction has a low prob-Scattered photon. (Bush berg et al., 2002)

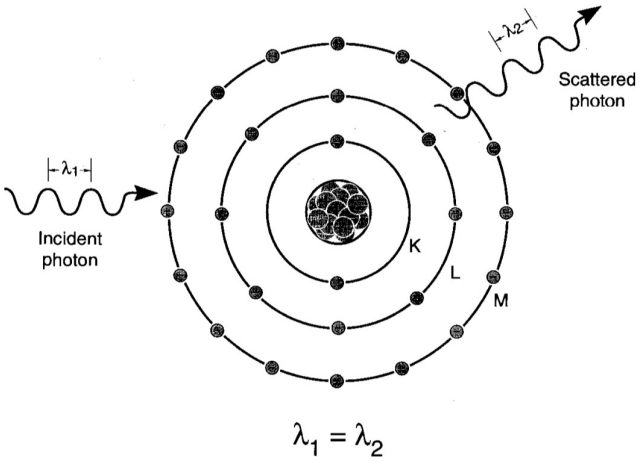

Figure 2. 3 Rayleigh scattering. Diagram show the incident photon λ_1 interacts with an atom and the scattered photon λ_2 is being emitted with approximately the same wavelength and energy. Rayleigh scattered photons are typically emitted in the forward direction faily close to the trajectory of the incident photon K, L, and M are electron shells. (Bush berg et al., 2002).

Linear Attenuation Coefficient

The fraction of photons removed from a monoenergetic beam of x-ray or gamma rays per unit thickness of material is called the linear attenuation coefficient , typically expressed in units of inverse centimeters (cm^{-l}). The number of photons removed from the beam traversing a very small thickness Llx can be expressed as:

$$n = \mu N \Delta x$$

Where n = the number of photons removed from the beam, and N = the number of photons incident on the material. As the thickness increases, however, the relationship is not linear. The attenuation process is continuous from the front surface of the attenuating material to the back exiting surface. To accurately calculate the number of photons removed from the beam using Equation, multiple calculations utilizing very small thicknesses of material (Lh) would be required. Alternatively, calculus can be employed to simplify this otherwise tedious process. For a monoenergetic beam of photons incident upon either thick or thin slabs of material, an exponential relationship exists between the number of incident photons (N_o) and those that are transmitted (N) through a thickness x without interaction.

$$N=Noe^{-\mu x}.$$

Thus, using the example above, the fraction of 100-keV photons transmitted through 6 cm of tissue is $N/N_o = e^{-(0.16cm-1)\ (6cm)} = 0.38$

This result indicates that, on average, 380 of the 1,000 incident photons (i.e., 38%) would be transmitted through the matter without interacting. Thus the actual attenuation (l - 0.38 or 62%) is much lower than would have been predicted from Equation.

Table 2.2 Material Density, Electrons per Mass, Electron Density, and the Linear Attenuation Coefficient (At 50kev) for Several Materials.

Material	Density (g/cm^3)	Electrons per mass (e/g) x 10^{23}	Electron density (e/cm^3)x10^{23}	μ@50 keV(cm^{-1})
Hydrogen	0.000084	5.97	0.0005	0.000028
Water vapor	0.000598	3.34	0.002	0.000128
Air	0.00129	3.006	0.0038	0.000290
Fat	0.91	3.34	3.04	0.193
Ice	0.917	3.34	3.06	0.196
Water	1	3.34	3.34	0.214
Compact bone	1.85	3.192	5.91	0.573

The linear attenuation coefficient is the sum of the individual linear attenuation coefficients for each type of interaction:$\mu = \mu_{\text{Rayleigh}} + \mu_{\text{photoelectric effect}} + \mu_{\text{Compton scatter}} + \mu_{\text{pair production}}$

For a given thickness of material, the probability of interaction depends on the Number of atoms the x- or gamma rays encounter per unit distance. The density (p, in g/cm3) of the material affects this number. For example, if the density is doubled, the photons will encounter twice as many atoms per unit distance through the material. Thus, the linear attenuation coefficient is proportional to the density of the material: $U_{water} > U_{ice} > U_{water\ vapor}$

The relationship between material density, electrons density, electrons per mass, and the linear attenuation coefficient (at 50 KeV).for several materials is shown in table 2.2 above

Photoelectric Effect

In the photoelectric effect, a photon interacts either with an electron which is bound in an individual atom or with an electron in condensed matter, usually a solid, which is not bound to an individual atom but may be shared among many atoms.It is a predominate interaction mechanism for photon energies below 0.1MeV. When the energy of the incident photon (x-rays or γ-rays) is greater than the binding energy of the most tightly bounded electron of an atom or molecule, the electron will be ejected from the innermost shell and the atom is thus ionized. Part of the incident photon energy is utilized in overcoming the binding energy of the electron and the remaining energy is transferred into kinetic energy of the ejected electron. The most tightly bound electrons have the greatest probability of absorbing the incident photon by an atom through photoelectric interaction process. After the electron is ejected with kinetic energy T, another electron jumps (from the outer shell) into the vacancy or hole created in the inner shell and characteristic radiation is emitted. This can sometimes be absorbed by another outer electron, which consequently leaves the atom, resulting in Auger effect .The contribution of photoelectric effect to the attenuation of x-ray or γ-ray is proportional to Z^4. Photoelectric effect occurs during x-ray examinations (Agba, 2017).

Interaction of photons with atoms

The atomic photoelectric effect involves the absorption of a photon by an atomic electron which is then ejected from the atom. This can occur only when the incoming photon has energy greater than the ionisation energy (EB) of the electron to be removed. Since an atom is much more massive than an electron the ejected electron takes practically all the energy and momentum of the photon. The kinetic energy (K) of the ejected electron is then K = hf-EB. The ejected electrons are known as photoelectrons and, since the atom is ionised, the process is one form of photo ionisation (Ageda, 2018).

Photoelectric absorption;

A photon loses all its energy to an atomic electron which is raised to a higher energy level. The mass attenuation coefficient for photoelectric absorption decreases with increasing photon energy; i.e. high energy photons are more penetrating than low energy radiation. For a fixed value of the energy the attenuation coefficient increases with the atomic number Z of the substance.

Interaction of photons with condensed matter

In many solids the valence electrons are not attached to individual atoms but are shared by all the atoms. As in the case of isolated atoms, photons can either remove electrons from the material or excite them to higher energy levels. In a metal the energy required to remove the conduction electrons from the material (typically 1 to 3 eV) is less than that required to ionise an isolated atom, so an electron can be removed from a piece of metal by ultraviolet light. This phenomenon is also known as the photoelectric effect. It is the mechanism used to produce an electric current when light enters a photomultiplier.

On the other hand most of the electrons in insulators and semiconductors are more tightly bound than the conduction electrons in metals. If the energy of an incident photon in insufficient to release an electron from the surface of the material it may nevertheless be enough to raise the electron to a higher energy level in the material (Ageda, 2018). This process will allow the electron to move and so it increases the conductivity of the material. This effect, known as photoconductivity, is exploited in light detecting devices such as light-dependent resistors and photodiodes.(www.physics.usydedu.au/superlifescience/AN/ANDpdf)

In a semiconductor the valence band is full and the conduction band is empty. Very few electrons can get enough thermal energy to reach the conduction band. A photon can give an electron enough energy to cross the gap, leaving a hole in the valence band.

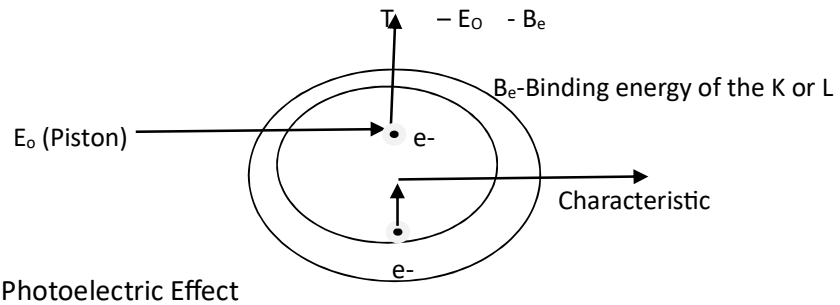

Figure 2.4 Photoelectric Effect

Compton Effect

In the Compton Effect, a photon hits a loosely bound electron and it is scattered with a lower energy, (with a longer wavelength). The photon-electron interaction can be regarded as collision between two particles. (Agba, 2017) .In the Compton Effect, the photon interacts with an atomic electron as though it were a free electron. The term free here means that the binding energy of the electron is much less than the energy of the bombarding photon (Khan, 1994). The photon scatters from a free electron or a loosely bound atomic electron. The scattered photon has less energy than the incident photon and the excess energy is transferred to the electron. For large photon energies (more than about 5 MeV) all but about 0.25 MeV goes to the scattered electron, an important feature in detecting gamma rays. The scattered photon as illustrated in Figure.2.5 has less energy than the incident photon. The energy distribution of the scattered electrons is shown below in figure. 2.5 Most of the electrons have energies close to K_{max}. The sharp decrease in K_{max} is known as the Compton edge. Values marked beside the curves are energy of the incident photon. The mass attenuation coefficient for Compton scattering, $\mu_m[C]$, varies as shown in Figure.2.5 Both the maximum value of $\mu_m[C]$ and the energy, at which it occurs, increase slowly with increasing atomic number (Ageda, 2018).

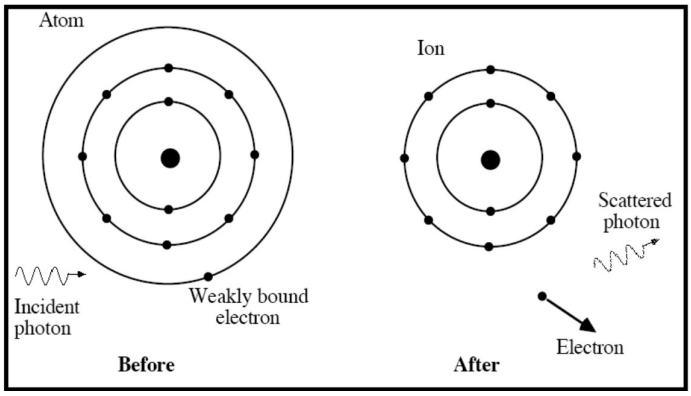

Figure.2.5 Compton Scattering by a Weakly Bound Electron;

Source: (www.physics.usydedu.au/superlifescience/AN/ANDpdf)

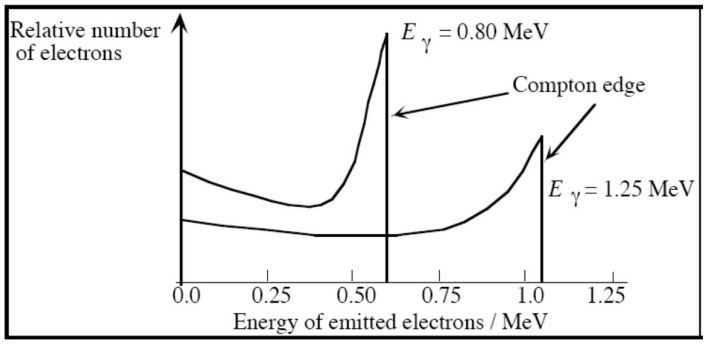

Figure.2.6 Energy Distributions of Compton-scattered Photons

Source: (www.physics.usydedu.au/superlifescience/AN/ANDpdf)

Pair Production

This is the production of electron-positron pair from a photon with energy in excess of the rest mass energies of the two particles. A photon with energy above 1.02MeV (rest mass energy of electron and positron) can produce a particle anti-particle pair, an electron and a positron in the vicinity of a nucleus in order to ensure the conservation of momentum by the recoil of the nucleus(Agba, 2017).
In pair production a high energy photon is transformed into an electron-positron pair:

$\Upsilon \rightarrow e^+ + e^-$

Pair production can occur when a photon with sufficient energy encounters the strong electric field in the neighbourhood of a nucleus. This process cannot happen in free space it needs the presence of a third body, usually a nucleus, to simultaneously conserve energy and momentum. Since the rest energy of an electron is 0.51 MeV, pair production is energetically impossible for photon energies less than 1.02 MeV (Ageda, 2018). However, when pair production becomes possible it soon becomes the dominant interaction process for beams of very high energy photons. The attenuation coefficient for pair production varies with photon energy and the atomic number of the absorbing material.Figure.2.8 shows the variation of photon energies at which different photon interactions become important. Both the photoelectric effect and Compton scattering can leave ionised atoms behind in the material. The effects of these ions may have important consequences, especially in biological materials (Ageda, 2018).

Figure 2.7 Pair Production

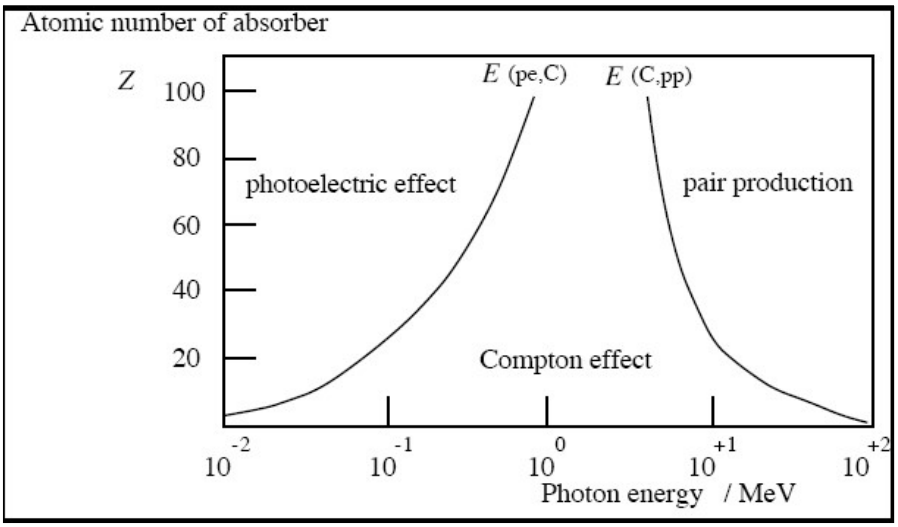

Figure.2.8 Variation of Photon Energies at which Different Effects Become Important

Source: (www.physics.usydedu.au/superlifescience/AN/ANDpdf)

Stopping power

Here E is the particle's energy and x is the distance travelled. This rate of energy loss with distance travelled depends on the material and is called the linear stopping power, S_l, of the material: $\mathbf{S_l = - dE/dx}$

A common unit for linear stopping power is $MeV.m^{-1}$. It depends on the charged particle's energy, the density of electrons within the material (and hence on the atomic numbers of the atoms). A more fundamental way of describing the rate of energy loss is to specify the rate in terms of the density thickness, rather than the geometrical length of the path. So energy loss rates are often given as the quantity called the mass stopping power:

$\mathbf{S_m = -dE/d(\rho x) = -(1/\rho)(dE/dx)}$

Where ρ, is the density of the material and ρx is the density-thickness (Ageda, 2018).

Radiation Field

Fluence, Φ

$\Phi = dN/da$

Where dN is the number of particles incident on a sphere of cross-sectional area da, (NPL, 2010). The use of a sphere expresses the fact one considers the area perpendicular to the direction of each particle. Φ is expressed in m^{-2}

Energy Fluence, Ψ

$\Psi = dR/da$

Where dR is the radiant energy incident on a sphere of cross-sectional area da. Ψ is expressed in J m^{-2}

Note: Energy is often expressed in unit of electron volts (symbol eV). It is equal to the energy gained by an electron in passing through a potential difference of 1 volt (eV is not an SI unit, but is accepted for use with the SI. 1 eV equals 1.6×10^{-19} joule approximately) (National Physics Laboratory, NPL, 2010).

Dosimetry

Radiation Dosimetry is the calculation of the absorbed dose in matter and tissue resulting from the exposure to radiation. It is focused on the calculation of internal and external doses from ionizing radiation (Greening, 1985, NPL, 2010, Ageda, 2018).

Dose is reported in gray (Gy) for the matter or sievert (Sv) for biological tissue, where 1 Gy or 1 Sv is equal to 1 joule per kilogram. Note; sievert is a unit and not a quantity. Non-SI units are still prevalent as well, where dose is often reported in rads and dose equivalent in rems. By definition, 1 Gy = 100 rad and 1 Sv = 100 rem (Ageda, 2018).

Kerma, K **(**K**inetic** E**nergy** R**eleased per unit** Ma**ss)**

Defined as: $K = dE_{tr}/dm$

Where, $dE_{tr,}$ is the sum of initial kinetic energies of all the charged particles liberated by uncharged particles in a mass. The medium should always be specified. There are various primary standards to realise K for various particle types and energies,(Greening,1985,Khan,1994,NPL,2010) The special name for the unit of Kerma is gray (Gy). Unit: J kg^{-1}

Relation to Fluence

The kerma is usually expressed in terms of the distribution Φ(E) of the uncharged particle fluence with respect to energy. The kerma K is then given by

$$K = \int \Phi(E)\, E\, (\mu_{tr}/\rho)\, dE$$

Where (μ_{tr}/ρ) is the tabulated mass energy transfer coefficient of the material for uncharged particles of energy E (Ageda, 2018).

Absorbed Dose, D

The absorbed dose D is the quotient of the average energy transferred to the matter in a volume element by ionizing radiation and the mass of the matter in this volume element:

$$D = d\varepsilon/dm$$

Where dε is the mean energy imparted to matter of mass dm. Energy imparted is the energy incident minus the energy leaving the mass and minus the energy released in nuclear transformations (to stop the dose becoming negative when the mass contains a radioactive source). The medium should always be specified, there are various primary standards to realise the Gy for various particle types and energies. And its special unit name is gray (Gy).

The former unit name was rad (symbol: rd or rad). 1 Gy = 100 rd; 1 rd = 1/100 Gy. Unit: J kg^{-1} (Greening, 1985, Cember, 2000, European Nuclear Society, 2010, Ageda, 2018).

Radiation damage depends on the absorption of energy from the radiation and is approximately proportional to the mean concentration of absorbed energy in irradiated tissue. One gray is an absorbed radiation dose of one joule per kilogram.

$1Gy=1\frac{J}{kg}$ The gray is universally applicable to all types of ionizing radiation dosimetry irradiation due to external fields of gamma rays, neutrons, or charged particles as well as that due to internally deposited radionuclides (Cember, 2000).

Note; Radiation is measured in roentgen which is a measure of radiation rads or the gray (Gy) or 100erg/g (1Gy = 100 rad).

Stochastic and Non-Stochastic Quantities

As the mass of a sample decreases in general the energy per unit mass will become more random (stochastic). The energy imparted per unit mass can still be defined in a region, but the definition of absorbed dose implies an averaging to give D (a non-stochastic quantity) (Ageda, 2018).

Relation to Fluence

For a differential Fluence Φ (E) of identical charged particles, the absorbed dose D is given by:

$D = \int \Phi(E) (S/\rho) dE$

Where (S/ρ) is the tabulated mass stopping power of the material (Ageda, 2018).

Under charged particle equilibrium

$D = K_{air} (\mu_{tr}/\rho)_m / (\mu_{tr}/\rho)_{air}$

Dose versus Activity

Radiation dose refers to the amount of energy deposited in matter and/or biological effects of radiation, and should not be confused with the unit of radioactive activity (Becquerel, Bq). Exposure to a radioactive source will give a dose which is dependent on the activity, time of exposure, energy of the radiation emitted, distance from the source and shielding. The equivalent dose is then dependent upon the weighting factors. Dose is a measure of deposited dose, and therefore can never go down; removal of a radioactive source can only reduce the rate of increase of absorbed dose, never the total absorbed dose (Ageda, 2018)

Irradiation

While radiation is defined as the purposeful generation and propagation of energy through a vacuum or a material medium, irradiation is the beneficial application of such energy for the preservation of foods. There are electromagnetic radiations with spectra of varying wavelengths but more penetrating and effective when shorter wavelengths of the radiations are used. Electromagnetic spectrum is composed of radio, microwave, infrared, visible,

ultraviolet, x-rays and gamma rays. (Bush berg et al., 2002, Egbere, 2008). Not all of the spectra of the electromagnetic energy find application in food preservation. The ones of practical application include microwave radiation, ultraviolet radiation and ionizing radiations particularly, the gamma rays and X rays. Radiation is measured in roentgen while the absorbed dose of ionizing radiation is measured in rad or 100erg/g (1gy = 100 rad).

The microwave region of the electromagnetic spectrum lies between the radio waves and infra red ray occupying frequencies between 10^9 – 12^{10}hz (915 to 2450 mega cycles). Microwaves electromagnetic field in which the dipolar water molecules try to align themselves with the rapidly changing alternating current field. In microwave irradiation of foods, the constant oscillation of these molecules at 2 or 5 x 10^9 times per second results in intra molecular friction, thereby generating heat that kills microbial cells. (Egbere, 2008)

Uses of Ionizing Radiation for Food Preservation

Ionizing radiation has a frequency of up to 1018 Hz carrying enough energy to produce excited electrons from any molecule it comes in constant with. The types of ionizing radiation used in food include X-rays and gamma rays. The ionizing radiations have great penetrating ability to induce the shortness of the wavelength. The damaging effect of therapy on the microbial cells is the disruption of intra-cellular molecular structures leading to alternation in the normal metabolic biochemistry of cell and subsequently loss of reproductive ability and death.

The ability of a microbial cell to reorganize or repair its cellular structure and composure after being damaged by lower levels of irradiation is the measure of its resistance or sensibility to radiations. The radio resistance of microorganisms is log-linear similar to that of the thermal death curve, except for some radio resistant organisms which produce sigmoidal curve behavior. Generally microorganisms resist ionizing radiations than man and other higher animals by 10 folds. The pattern of resistance of organisms is as follows;

Man < Gram negative < gram positives < moulds < spores < yeast < viruses

Micrococcus radiodurans is one of the most radio resistant bacteria.

Food Irradiation

Food Irradiation is the process of exposing food to ionizing radiation such as gamma rays and X-rays, with the primary objective of disinfecting from microbes and diseases (Deelay *et al*., 2006). This treatment is used to improve food safety by significantly reducing the risk of food borne illnesses, toxins that are present from pre-harvest and bio loads that may have contaminated food produce at any stage (Diehi, 2002). Food irradiation (the application of ionizing radiation to food) is a technology that improves the safety and extends the shelf life of foods by reducing or eliminating microorganisms and insects. Like pasteurizing milk and canning fruits and vegetables, irradiation can make food safer for the consumer. The Food and Drug Administration (FDA) is responsible for regulating the sources of radiation that are used to irradiate food. The FDA approves a source of radiation for use on foods only after it has determined that irradiating the food is safe.

Irradiation can serve many purposes.

- Prevention of Food borne Illness – to effectively eliminate organisms that cause food borne illness, such as *Salmonella* and *Escherichia coli* (*E. coli*).
- Preservation – to destroy or inactivate organisms that cause spoilage and decomposition and extend the shelf life of foods.
- Control of Insects – to destroy insects in or on tropical fruits imported into the United States. Irradiation also decreases the need for other pest-control practices that may harm the fruit.
- Delay of Sprouting and Ripening – to inhibit sprouting (e.g., potatoes) and delay ripening of fruit to increase longevity.
- Sterilization – irradiation can be used to sterilize foods, which can then be stored for years without refrigeration. Sterilized foods are useful in hospitals for patients with severely impaired immune systems, such as patients with AIDS or undergoing chemotherapy. Foods that are sterilized by irradiation are exposed to substantially higher levels of treatment than those approved for general use. (WHO, 2006).

The idea of using ionized radiation in the processing of food dates back to the 1900s, when there were reports of scientists using X-rays to kill insects, eggs and larvae in tobacco leaves and to eliminate various parasites (Nordion, 2011). Modern area of food irradiation application research began when the united states Atomic Energy Commission (USAEC) initiated a coordinated research program into the use of ionizing radiation for food preservation in 1950 (Lelieveld,2012). Irradiation does not make food radioactive or toxic, science and research shows that irradiation creates significantly minor changes on food, that it is not easy to physically ascertain if food has been irradiated (Guedes *et al*.,2010).

There are three sources of radiation approved for use on foods.

- Gamma rays are emitted from radioactive forms of the element cobalt (Cobalt 60) or of the element cesium (Cesium 137). Gamma radiation is used routinely to sterilize medical, dental, and household products and is also used for the radiation treatment of cancer.
- X-rays are produced by reflecting a high-energy stream of electrons off a target substance (usually one of the heavy metals) into food. X-rays are also widely used in medicine and industry to produce images of internal structures.
- Electron beam (or e-beam) is similar to X-rays and is a stream of high-energy electrons propelled from an electron accelerator into food.

Gamma Rays

A nucleus which is in an excited state may emit one or more photons (packets of electromagnetic radiation) of discrete energies. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from a higher to a lower energy state (unstable to stable). Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes. Gamma radiation is one of the three types of natural radioactivity. Gamma rays are electromagnetic radiation, like X-rays. The other two types of natural radioactivity are alpha and beta radiation, which are in the form of particles. Gamma rays are the most energetic form of electromagnetic radiation, with a very short wavelength of less than one-tenth of a

nanometer. Gamma radiation is the product of radioactive atoms. Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. When the binding energy is not strong enough to hold the nucleus of an atom together, the atom is said to be unstable. Atoms with unstable nuclei are constantly changing as a result of the imbalance of energy within the nucleus. Over time, the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as radioactive decay. Various types of penetrating radiation may be emitted from the nucleus and/or its surrounding electrons. Nuclides which undergo radioactive decay are called radionuclides. Any material which contains measurable amounts of one or more radionuclides is a radioactive material. Newman et al., (2014).

Gamma rays production

There are several physical processes that generate cosmic gamma rays:

1. A high-energy particle can collide with another particle
2. A particle can collide and annihilate with its anti-particle
3. An element can undergo radioactive decay
4. A charged particle can be accelerated. Newman et al., (2014)

Particle-Particle Collisions

In gamma-ray astronomy, "particle-particle collision" usually means a high-energy proton, or cosmic ray, strikes another proton or atomic nucleus. This collision produces, among other things, one or more neutral pi mesons (or pions). These are unstable particles that decay into a pair of gamma rays. Since the pion is usually moving at a high velocity as a result of its violent birth, the gamma rays are projected forward in a slight "V" formation. This process gives rise to gamma rays with a broad spectrum of energies (all greater than 72 mega-electron-volts, which is a measurement of the kinetic energy in the incident particles). Newman et al., (2014)

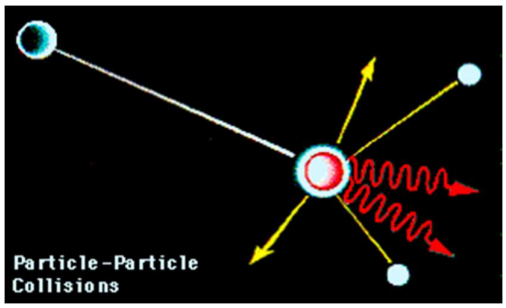

Figure.2.9: Particle-Particle Collisions
Source: (www.physics.usydedu.au/superlifescience/AN/ANDpdf)

Matter-antimatter annihilation

A particle and its anti-particle, such as an electron and a positron, will undergo something called an annihilation process. In physics, this process produces neutral pions that quickly decay into gamma rays. Newman et al., (2014).

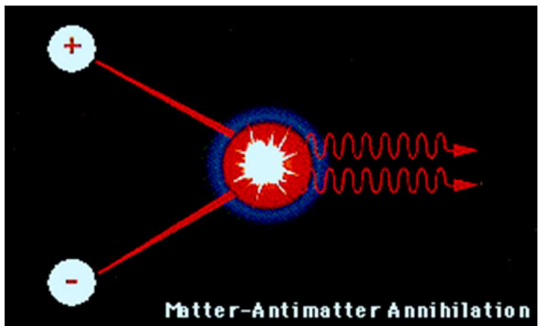

Figure 2.10: Matter-antimatter annihilation
Source:

(www.physics.usydedu.au/superlifescience/AN/ANDpdf)

Radioactive Decay

Radioactive decay results when an element changes to another element by virtue of changes within the atom's nucleus. These changes leave the nucleus in an excited state. The atom emits a gamma ray as it decays into the ground state. We not only observe these gamma rays, but their fluxes and spectra identify the specific nuclei and the rate of their excitation. Extreme physical conditions are required to produce excited nuclei, thus allowing us to probe unique physical environments with these observations. Radioactive gamma-ray sources in space are associated with events of nucleonsynthesis, such as supernovae. Newman et al., (2014).

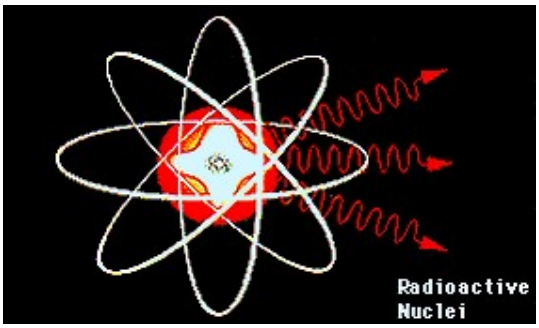

Figure 2.11: Radioactive Decay
Source: (www.physics.usydedu.au/superlifescience/AN/ANDpdf)

Acceleration of Charged Particles

A magnetic field exerts a force on a charged particle that is moving in it. This causes the particle to radiate, with the emitted power being proportional to the square of the force divided by the square of the mass of the particle. For electrons, this radiation is often in the gamma-ray region of the electromagnetic spectrum. Newman et al., (2014).

Gamma irradiation

Gamma irradiation is produced from the radioisotopes cobalt-60 and caesium-137, which are derived by neutron bombardment of cobalt-59 and as a nuclear source by-product, respectively. Cobalt-60 is the most common source of gamma rays for food irradiation in commercial scale facilities as it is water insoluble and hence has little risk of environmental

contamination by leakage into the water systems. As for transportation of the radiation source, cobalt-60 is transported in special trucks that prevent release of radiation and meet standards mentioned in the Regulations for Safe Transport of Radioactive Materials of the International Atomic Energy Act. The special trucks must meet high safety standards and pass extensive tests to be approved to ship radiation sources. Conversely, caesium-137, is water soluble and poses a risk of environmental contamination. Insufficient quantities are available for large scale commercial use. An incident where water-soluble caesium-137 leaked into the source storage pool requiring NRC intervention has led to near elimination of this radioisotope.

Figure 2.12:Cobalt 60 stored in Gamma Irradiation machine

Gamma irradiation is widely used due to its high penetration depth and dose uniformity, allowing for large-scale applications with high through puts. Additionally, gamma irradiation is significantly less expensive than using an X-ray source In most designs, the radioisotope, contained in stainless steel pencils, is stored in a water-filled storage pool which absorbs the radiation energy when not in use. For treatment, the source is lifted out of the storage tank, and product contained in totes is passed around the pencils to achieve required processing. The radioisotope cobalt 60 is the energy source for use in gamma irradiation with the irradiation process taking place in a specially designed cell. A key characteristic of gamma irradiation is the high penetration capability. This enables moderately dense or sealed products to be processed with relative ease and facilitates treatment of palletized product. The unit of absorbed dose is kiloGray, expressed as kGy. The absorbed dose is determined by product density, pack size, dose rate, exposure time and to some degree by plant design. Newman et al., (2014)

The gamma process can effectively sterilize a wide variety of products composed of different materials, with varying densities, configurations and orientations. Some examples of products processed include:

- Medical devices
- Pharmaceuticals
- Combination drug/device products
- Animal husbandry
- Archives
- Cosmetics and toiletries
- Horticultural supplies
- Packaging

The treatment of medical devices by gamma processing has been one of the principal methods of sterilization in the healthcare industry since the introduction of the concept of single use, sterile, disposable medical devices in the 1960s. This simple, proven process is safe, reliable, and highly effective at treating single-use medical devices. With the ability to penetrate products while sealed in their final packaging, gamma irradiation supports the manufacturing and distribution process by facilitating final packaged product as well as raw materials, whilst still ensuring full sterility of the product. Newman et al., (2014)

Uses

Irradiation is used to reduce or eliminate the risk of food-borne illnesses, prevent or slow down spoilage, arrest maturation or sprouting and as a treatment against pests. Depending on the dose, some or all of the pathogenic organisms, microorganisms, bacteria, and viruses present are destroyed, slowed down, or rendered incapable of reproduction. Irradiation cannot revert spoiled or over ripened food to a fresh state. If this food was processed by irradiation, further spoilage would cease and ripening would slow down, yet the irradiation would not destroy the toxins or repair the texture, color, or taste of the food. When targeting bacteria, most foods are irradiated to significantly reduce the number of active microbes, not to sterilize all microbes in the product. In this respect it is similar to pasteurization.

Gamma Irradiation is also used to create safe foods for people at high risk of infection, or for conditions where food must be stored for long periods of time and proper storage conditions are not available. Foods that can tolerate irradiation at sufficient doses are treated to ensure that the product is completely sterilized. This is most commonly done with rations for astronauts, and special diets for hospital patients. It is used to create shelf-stable products. Since irradiation reduces the populations of spoilage microorganisms, and because pre-packed food can be irradiated, the packaging prevents recontamination of the final product. Irradiation is used to reduce post-harvest losses. It reduces populations of spoilage micro-organisms in the food and can slow down the speed at which enzymes change the food, and therefore slows spoilage and ripening, and inhibits sprouting (e.g., of potato, onion, and garlic).

Food is also irradiated to prevent the spread of invasive pest species through trade in fresh vegetables and fruits, either within countries, or trade across international boundaries. Pests such as insects could be transported to new habitats through trade in fresh produce which could significantly affect agricultural production and the environment were they to establish themselves. This "phytosanitary irradiation" aims to render any hitch-hiking pest incapable of breeding. The pests are sterilized when the food is treated by low doses of irradiation. In general, the higher doses required to destroy pests such as insects, mealy bugs, mites, moths, and butterflies either affect the look or taste, or cannot be tolerated by fresh produce. Low dosage treatments (less than 1000 gray) enables trade across quarantine boundaries and may also help reduce spoilage.

Impact

Irradiation reduces the risk of infection and spoilage, does not make food radioactive, and the food is shown to be safe, but it does cause chemical reactions that alter the food and therefore alters the chemical makeup, nutritional content, and the sensory qualities of the food.[21] Some of the potential secondary impacts of irradiation are hypothetical, while others are demonstrated. These effects include cumulative impacts to pathogens, people, and the

environment due to the reduction of food quality, the transportation and storage of radioactive goods, and destruction of pathogens, changes in the way we relate to food and how irradiation changes the food production and shipping industries. Newman *et al*., (2014).

3.0 METHODOLOGY

The study is Jos a city found in Plateau, Nigeria. It is located 9.93 latitude and 8.89 longitude and it is situated at elevation 1186 meters above sea level. Jos has a population of 816,824 making it the biggest city in Plateau. It operates on the WAT time zone. The research was carried out in the following areas; Chobe market, Main market, Mangu market, Bukuru and Abattoir of Plateau State. Ten samples of Garri to be collected from Plateau State. These samples to be collected in sterile containers and taken to the laboratory for Microbial Analysis in the Department of Biological sciences, and Food Science and Technology, University of Mkar, Gboko, Benue State, Nigeria before and after irradiation to determine if the irradiation could effectively disinfect bio load and hydro cyanide.

Material and Equipment

The equipment for this research work are: SPECTECH ST360 counter Nuclear Lab Station (Power 9VDC, 500 mA) Gamma Sources were 2 Co-60, Ba-133, Co-57, Mn-54, Cd-109 all with activity of 1μ $curie$ each, Radiation alert meter (inspector EXP), Mac Conkey Agar, Nutrients agar, Potato Dextrose Agar (PDA), Distilled water, Buffered peptone water, Gram's staining reagents: Crystal violet, Lugol's iodine, Alcohol, Safranin, Immersion Oil. Hand gloves, Refrigerator, Weighing balance, Conical flakes, Masking tape Foil paper Cooler containing ice, sterile pipette, Dilutions bottles, Petri dishes, clean sterile glass slide and cover slip, Water bath, Incubator, Colony counter, Microscope with oil immersion, Bunsen flame, Autoclave, Hot air oven, Wire loop, Retort stand, medical wool Digital weighing balance, filter paper, beakers, conical flask, Digital weighing balance, spatula, test tubes, incubator, measuring cylinder, flask shaker, autoclave, water bath, slides, syringes, stirring rod, refrigerator, hot air oven, desiccators, kjedahl flask, selenium tablets, concentrated H_2SO_4, fume cupboard, NaOH, boric acid, methyl orange, Hcl, diethyl, crucible, alkaline picrate solution

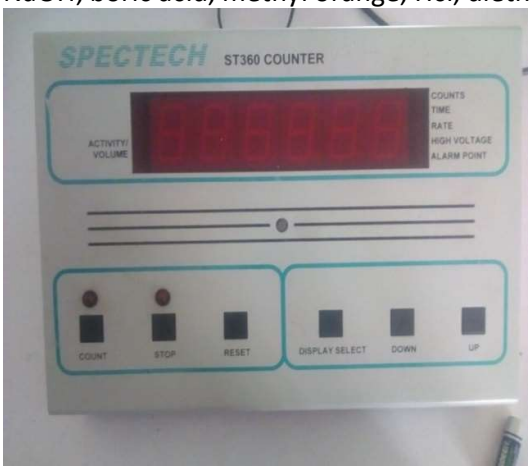

Fig. 3.1: SPECTECH ST360 counter Nuclear Lab Station (Power 9VDC, 500 mA)

Fig. 3.2: Radiation alert meter (inspector EXP)

Fig. 3.3: Gamma radiation Sources

Microbiological Method of Analysis

The bacteriological analysis of samples to be carried out for Total Bacterial Count and Total Coliform Count using the method described by Koneman et al., (2008) and Total Fungi count according to Alexopoulus et al., (2009).

Sterilization of media / glass wares

All media were prepared according to the standard and sterilized in an autoclave at 121^{o}c for 15 minutes also the glassware to be sterilized at 160^{o}c for 1 hour using hot air oven.

Preparation sample homogenate

The sample homogenate to be prepared by the addition of 5g of Garri aseptically into 45ml of sterile Buffered peptone water contained in 50ml conical flask to make 1:10 (10^{-1}) dilution.

Decimal serial dilution

Decimal serial dilution to be carried out by transferring 1ml from 10-1 dilution a tube containing 9ml of sterile Buffered peptone water (to form 10^{-2} dilution) the same procedure was carried out to obtain dilution of 10^{-3} and 10^{-4}

Aerobic plate count

With a separate sterile pipette, 0.2ml each to be transferred from the dilutions (10^{-1} and 10^{3}) into duplicate Petri plates and 20ml of nutrient agar maintained at 44 - 45^{0}c was added, mixed properly by swirling and to solidify. The plates to be inverted and inoculated at 35 ± 2^{0} for 24

hours and 48 hours. The colonies with numbers between 25-250 to be counted and average numbers of colonies in the duplicate plates to be recorded.

CFU/ml = Average number of colonies/ ml of dilution plated X reciprocal of dilution.

Culture method

The culture method to be use is Pour Plate Method. After doing the serial dilution, 1ml to be drawn from each of the tubes in to the petri dishes and the prepared medium to be then poured in to it and allowed to cool. After which will be incubated for 24 hours and after that the result to be read. Total Bacterial Count (TBC), Total Coliform Count and total fungal count (TFC) to be carried out respectively before and after irradiation.

Total Bacteria Count (TBC)

With a separate sterile pipette, 1ml each to be transferred from the dilutions (10^1,$10^2$and 10^3) into duplicate petri plates and about 15ml of nutrient agar maintained at 44-45^0 c to be added, mixed properly by swirling and to solidified. The plates to be inverted and inoculated at 35$\pm 2^0$ for 48 hrs. The colonies with numbers between 25-250 to be counted and average numbers of colonies in the duplicate plates to be recorded.

CFU/ml=Average number of colonies ×reciprocal of dilution.

Total Coliform Count (TCC)

With a separate sterile pipette, 1ml each was transferred from the dilutions (10^1,$10^2$and 10^3) into duplicate petri plates and about 15ml of MacConkey agar maintained at 44-45^0 c was added, mixed properly by swirling and to solidified. The plates to be inverted and inoculated at 35$\pm 2^0$ for 48 hrs. The colonies with numbers between 25-250 to be counted and average numbers of colonies in the duplicate plates expected to be recorded.

CFU/ml=Average number of colonies ×reciprocal of dilution.

Total Fungi Count (TFC)

With a separate sterile pipette, 1ml each to be transferred from the dilutions (10^1,$10^2$and 10^3) into duplicate petri plates and about 15ml of Potato Dextrose Agar maintained at 44-45^0 c to be added, mixed properly by swirling and to solidified. The plates were inverted and inoculated at 35$\pm 2^0$ for 48 hrs. The colonies with numbers between 25-250 to be counted and average numbers of colonies in the duplicate plates to be recorded.

CFU/ml=Average number of colonies ×reciprocal of dilution.

Gram Staining

Gram staining procedure was adopted as described by Cheesbrough, (2006). A primary stain (crystal violet) to be applied to a heat-fixed smear of a bacterial culture on a clean, grease-free slide allow to stay for 30-60 seconds. Heat fixation kills some bacteria but is mostly used to affix the bacteria to the slide so that they don't rinse out during the staining procedure, the stain to be washed off with clean tap water, the water will be tipped off and the smear to be covered with Lugo's Iodine for 30-60Seconds. The Iodine to be washed off with clean tap water after which, it will be decolorized rapidly with acetone-alcohol and washed with clean tap water. The smear to be covered with neutral red stain for 1 minute and to be washed off with clean tap water. The back of the slide was cleaned and placed in a draining rack for the smear to air-dry. The smear was examined microscopically with the oil immersion Objective (X100 objective) lense.

Identification of Bacteria

Pure cultures of bacterial isolates obtained from the primary culture will be subculture using Nutrient Agar plates. The colonial morphology on growth medium and cellular morphology under a light microscope will be examined. The following biochemical tests; motility test, indole test, urease test, catalase test, coagulase test, citrate utilization test, Methyl Red Voges Proskauer test **a**nd triple sugar iron (TSI) test will be using the method described in Chees brough (2006).

Identification of the Fungal Isolates

The procedure of Alexopoulus et al., (2009) to be used for the identification of the fungal isolates using morphological and colonial characteristics and also lacto phenol cotton wool to be used. Colonial or morphological appearance of the isolates from the respective cultures were made and recorded taking note of the size, color and edge of each colony, and the nature of surface using Atlas for identification of fungi before and after irradiation.

Irradiation Procedure

The mixture of all the contaminated Garri samples to be subjected to gamma-ray radiation at different time intervals at the Physics Laboratory Benue State University, Makurdi or SHETSCO. The gamma–ray radiation of the Garri sample to be carried out using the SPECTECH ST360 counter Nuclear Lab Station (Power 9VDC, 500 mA) and Gamma Sources (2 Co-60, Ba-133, Co-57, Mn-54, Cd-109 all with activity of 1μ $curie$), The samples labeled 1 to 10 to be irradiated with the gamma sources and varying the time interval from 10 minutes to 100 minutes as shown below in table 3.1. The initial total absorbed dose from the combined sources to be obtained as 7.71 x 10^{-5}. But this increased as irradiation time expected to increase.

Table 3.1: Gamma radiation sources

S/No	Gamma Source	Activity on source in Beckuerel (Bq)	Dosage in gray
1	Co-60	37000	2.85 x 10^{-5}
2	Co-60	37000	2.85 x 10^{-5}
3	Ba-133	37000	4.39 x 10^{-6}
4	Co-57	37000	1.22 x 10^{-6}
5	Mn-54	37000	1.02 x 10^{-5}
6	Cd-109	37000	4.33 x 10^{-6}
		Total Dosage	7.708 x 10^{-5}

HV=820v, d=2cm

Rate = $\frac{Activity}{Time}$3.1 (Oeflke et al., ND)

$\dot{D} = \Psi\frac{\mu_{en}}{\rho} = \frac{CE}{4\pi r^2}\frac{\mu_{en}}{\rho}$ 3.2 (Oeflke et al., ND)

Where $\dot{D} = Dose\ rate$

$\Psi = energy\ fluence\ rate$

C= activity

E = energy per decay

μ_{en}/ρ = mass energy – absorption coefficient of air 3.3 (Oeflke et al., ND)

Dose = $\frac{energy\ absorbed}{mass}$ 3.4 (Oeflke et al., ND)

Conversion software for activity to dose

Table 3.2: Samples to be irradiated with respective dosage, count rate and time

S/No	Sample	Time (minutes)	Activity/s (Bq)	Count rate/m	Absorbed Dose (gray/second)
1	1	10	8010	801.00	1.71×10^{-9}
2	2	20	16520	826.00	3.53×10^{-9}
3	3	30	32540	1084.67	6.95×10^{-9}
4	4	40	64680	1617.00	1.38×10^{-8}
5	5	50	129160	2583.20	2.76×10^{-8}
6	6	60	257320	4288.67	5.49×10^{-8}
7	7	70	516640	7380.57	1.10×10^{-7}
8	8	80	1055280	13191.00	2.25×10^{-7}
9	9	90	2080560	23117.33	4.44×10^{-7}
10	10	100	4161120	41611.20	8.88×10^{-7}

The initial total dose to be determined by use of radiation alert meter to be placed by the sides and top center at fixed positions and the average calculated to get the average initial dose dosage. The samples to be placed at 2cm from the source in the radiation counter. The samples to be placed in the chamber for the various time intervals as shown in the table above. This is be done for all the samples irradiated.

Evaluation of Proximate Composition Analysis

Determination of moisture content

Moisture content was determined as described by Association of Analytical Chemist (AOAC) (2012) Using Hot Air Oven Method. 2g of samples to be weighed into petri dishes of known

weight, shaking until evenly distributed and covered immediately. These to be transferred into oven, uncovered at 105±5°c for3 hours and allowed to cool in a desiccator for 15minute before weighing. The process will be repeated until constant weigh was recorded and the loss in weight from the original weight is expected as the moisture content,

$$\% \text{ moisture content} = \frac{\text{weight loss of sample} \quad \times 100}{\text{weight of sample}}$$

Determination of crude protein

The crude protein content to be determined using AOAC (2012) Official Methods. 1g of samples to be digested in 500cm^3 kjedahl flask using selenium tablets as catalyst and 12ml concentration H_2SO_4 followed by the addition of two selenium tablets. The contents of the flask to be heated gently at 420°c in fume cupboard in an inclined position and swirl occasionally until the liquid is clear. The digested samples after cooling to be mixed with 50mls of 40% NaOH solution and then distilled into 30cm^3 of 2% boric acid solution containing screened methyl orange indicator. The distillate to be titrated against 0.1M HCL solution. A blank titration to be carried out and the percentage protein content estimated as nitrogen x 6.25 assuming that 1ml of 0.1M HCL is equivalent to 0.014g.

$$\% \text{ kjedahl} = \frac{(\text{Vs} - \text{Vb}) \times \text{M} \times 14.01}{\text{W} \times 10} \qquad 3.6$$

Crude protein % = % kjedahl x F

Where Vs=Volume (cm) of standardized acid used to titrate a test

Vb= Volume (cm) of standardized acid used to titrate reagent blank

M= Molarity of standard HCL

14.01 =Atomic weight of Nitrogen

10 = factor to convert mg to g

Determination of crude fibre

The crude fibre to be determined by the procedure described by AOAC (2010) five grams of sample to be weighed into a 500cm^3 beaker and the content to be filtered and the residue will be washed vigorously with boiling water until it will be free from the acid. The residue to be boiled again in a 200cm^3 of 0.313M NaOH for 30 minutes. The flask content expected to boil for 30 minutes and allowed to stand for 1minute and filtered immediately through a filter paper. The insoluble material to be transferred into 100cm^3 beaker by means of boiling water to free it from acid. The insoluble material to be finally washed with alcohol twice and three times with diethyl ether. The resulting residue was transferred to petri dish (previously ignited, cooled and weighed) with boiling water. The dish containing the residue to be dried at 100°c for 2 hours cooled in desiccators and weighed (W1) the dried cooled and weighed residue to be then transferred into a muffle furnace and ignited at 600°c for 30 minutes cooled and weighed (W2). The percent crude fibre to be calculated as follows:

$$\% \text{ crude fibre} = \frac{\text{W1}-\text{W2} \times 100}{\text{Weight of sample}} \qquad 3.7$$

Determination of ash content

Ash content determined according to the method of AOAC (2012). 2g of sample to be weighed and placed in an already weighted crucible dish. The dish and content to be placed on furnace rack at a furnace temperature of 500^{o}c for 16 hours until the sample expected to completely burn to ashes. The crucible dish to be removed and kept in a desiccators to cool and the percentage ash to be determined as;

$$\%\text{Ash} = \frac{\text{Weight of the extracted} \quad \times 100}{\text{Weight of sample}}$$

Carbohydrates determination

The percentage carbohydrate content of the samples was determined by summing up the percentages of the moisture, ash, crude protein, crude fat determinations, and subtracting the value from 100 (Onwuka, 2005). The difference in value to be taken as the percentage total carbohydrate content of the sample.

% carbohydrate content =100- (% protein+% moisture+% fat+% ash)

Statistical Analysis

Data to be collected will be analyzed by Analysis of Variance (ANOVA) with the statistical package for social sciences (SPSS) for Windows version 16. The Duncan post hoc test to be used to identify the means that differ significantly at $p < 0.05$. Results to be expressed as Mean ± SEM

4.0 RESULTS

4.1 Microbial Counts

Table 4.1: Result of Microbial Load of Garri (showing Total Bacterial Count, Total Coliform Count and Total Fungal Count) beforeirradiation

S/No	Sample	Total Bacterial Count (cfu/g)	Total Coliform Count (cfu/g)	Total Fungal Count (cfu/g)
1	Chobe Market (1)	8.0×10^1	0.0×10^0	1.0×10^1
2	Main Market (1)	2.0×10^1	0.0×10^0	0.0×10^0
3	Mangu (1)	2.0×10^1	0.0×10^0	0.0×10^0
4	Main Market (2)	6.0×10^1	0.0×10^0	0.0×10^0
5	Mangu (2)	3.0×10^2	0.0×10^0	4.3×10^2
6	Bukuru (1)	4.0×10^1	0.0×10^0	0.0×10^0
7	Chobe Market (2)	5.0×10^1	0.0×10^0	0.0×10^0
8	Abattoir (1)	1.8×10^2	0.0×10^0	0.0×10^0
9	Bukuru (2)	1.1×10^2	0.0×10^0	1.0×10^1
10	Abattoir (2)	1.2×10^2	0.0×10^0	0.0×10^0
11	Mixed sample	3.4×10^4	0.0×10^0	6.3×10^3

4.1.1 The microbiological counts (Bioloads) results of Garri before irradiation for TBC is within the range of 1.1×10^2 to 3.4×10^4 , TCC is recorded 0.0×10^0 and TFC is within the range of 0.0×10^0 to 6.3×10^3 as shown inTable 4.1

Table 4.2: Result of Microbial Isolates from Garri before irradiation

Key: NG = No Growth.

4.1.2 Result of irradiation

Sample 11 (mixed sample) was divided into 10 samples of 15g each andwere irradiated at different time intervals ranging from 10 minutes to 100 minutesat a distance of 2cm.

Table 4.3 Result of irradiation

S/No	Sample	Bacteria Isolate Suspected	Fungi Isolate suspected
1	Chobe Market (1)	*pp.*	*Aspergillus fumigatus*
2	Main Market (1)	*Bacillus spp*	*NG*
3	Mangu (1)	*Bacillus spp.*	*NG*
4	Main Market (2)	*Streptobacillus spp*	*NG*
5	Mangu (2)	*Bacillus spp.*	*Aspergillus niger, Penicillin spp., Aspergillus flavus, Trichophton spp.*
6	Bukuru (1)	*Bacillus spp.*	*NG*
7	Chobe Market (2)	*Bacillus spp.*	*NG*
8	Abattoir (1)	*Streptobacillus spp*	*NG*
9	Bukuru (2)	*Bacillus spp.*	*Aspergillus niger, Penicillin spp.,*
10	Abattoir (2)	*Bacillus spp.*	*NG*
11	Mixed sample	*Bacillus spp,. Staphylococcus spp., Streptobacillus spp., Streptobacillus spp*	*Aspergillus fumigatus, Aspergillus flavus, Penicillin spp., Trichophton spp., Aspergillus niger,*

S/No	Sample	Time (minutes)	Activity/s (Bq)	Count rate/m	Absorbed Dose (gray/second)
1	1	10	8010	801.00	1.71×10^{-9}
2	2	20	16520	826.00	3.53×10^{-9}
3	3	30	32540	1084.67	6.95×10^{-9}
4	4	40	64680	1617.00	1.38×10^{-8}
5	5	50	129160	2583.20	2.76×10^{-8}
6	6	60	257320	4288.67	5.49×10^{-8}
7	7	70	516640	7380.57	1.10×10^{-7}
8	8	80	1055280	13191.00	2.25×10^{-7}

9	9	90	2080560	23117.33	4.44×10^{-7}
10	10	100	4161120	41611.20	8.88×10^{-7}

Table 4.4: Result of Microbial Load of Garri (showing Total Bacterial Count, Total Coliform Count and Total Fungal Count) after irradiation

Sample	Total Bacterial Count (cfu/g)	Total Coliform Count (cfu/g)	Total Fungal Count (cfu/g)
1	2.0×10^{2}	0.0×10^{0}	0.0×10^{0}
2	3.0×10^{1}	0.0×10^{0}	3.0×10^{2}
3	2.0×10^{1}	0.0×10^{0}	1.0×10^{1}
4	3.0×10^{1}	0.0×10^{0}	4.0×10^{1}
5	1.2×10^{3}	0.0×10^{0}	0.0×10^{0}
6	1.3×10^{2}	0.0×10^{0}	1.0×10^{1}
7	3.0×10^{1}	0.0×10^{0}	0.0×10^{0}
8	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
9	1.0×10^{1}	0.0×10^{0}	0.0×10^{0}
10	4.0×10^{1}	0.0×10^{0}	0.0×10^{0}

Sample	Bacteria Isolate Suspected	Fungi Isolate suspected
1	*Streptobacillus spp*	*NG*
2	*Bacillus spp,. Streptobacillus spp*	*Aspergillus fumigatus, Aspergillus flavus,*
3	*Bacillus spp. Streptobacillus spp*	*Aspergillus flavus*
4	*Bacillus spp, Staphylococcus spp.*	*Aspergillus fumigatus*
5	*Streptobacillus spp*	*NG.*
6	*Bacillus spp.*	*Aspergillus flavus*
7	*Bacillus spp.*	*NG*
8	*NG*	*NG*
9	*Bacillus spp.*	*NG*
10	*Streptobacillus spp*	*NG*

Table 4.5 : Result of Microbial Isolates from Garri After irradiation

Key: NG = No Growth.

The microbiological counts (Bioloads) examined were Total bacteria counts (TBC) and Total Fungi Counts (TFC) determined on a single sample 1-10 and varied at time range from 10 to 100 minutes.

4.1.3 Result of Proximate Analysis forUn-Irradiated Samples

Table 4.6 Result of proximate composition

Samples	MC%	ASH%	CP%	FAT%	CF%	CHO%	HCN(mg/kg)
Chobe Market (1)	10.40	1.58	2.66	1.66	0.82	84.64	6.27
Main Market (1)	10.10	1.82	1.45	0.55	0.84	86.01	5.68
Mangu (1)	10.20	1.44	2.34	0.85	1.00	85.53	7.96
Main Market (2)	10.57	1.55	2.22	0.62	0.66	85.67	5.9
Mangu (2)	10.72	1.44	1.93	0.75	0.67	86.45	6.19
Bukuru (1)	10.54	1.46	1.77	0.47	0.80	86.27	6.52

Chobe Market (2)	10.37	1.66	1.88	0.37	1.11	86.43	7.8
Abattoir (1)	10.32	1.45	1.55	0.34	0.90	87.06	8.5
Bukuru (2)	9.81	1.41	1.87	0.29	0.85	83.14	7.04
Abattoir (2)	9.58	1.41	1.80	0.27	0.84	84.24	7.14
Mixed sample	10.72	2.66	1.58	1.66	1.11	87.06	7.97

Key: MC% = Moisture content

ASH % = Ash content

CP% = Crude protein

CF% = Crude fiber

HCN% = Hydrogen cyanide

4.1.4 Result of Proximate Analysis for Irradiatedsamples

Sample 11 (mixed sample) was divided into 10 samples of 15g each and irradiated at different time interval ranges from 10 to 100 minutes.Proximate analysis was carried on theseirradiated samples as shown in table4.7.

Table 4.7 Result of proximate composition for irradiated sample

Samples	MC%	ASH%	CP%	FAT%	CF%	CHO%	HCN(mg/kg)
1	9.40	1.21	2.63	1.22	0.82	83.62	5.21
2	9.33	1.11	1.35	0.46	0.79	85.00	4.56
3	9.30	1.01	2.32	0.85	0.89	84.52	6.76
4	9.47	1.22	2.10	0.55	0.74	84.40	4.88
5	10.01	1.33	1.90	0.76	0.67	85.33	5.07
6	09.99	1.32	1.75	0.45	0.78	84.27	5.51
7	8.39	1.23	1.67	0.22	1.02	84.43	6.76
8	8.52	1.80	1.45	0.32	0.70	84.16	7.42
9	7.8	1.30	1.88	0.21	0.84	85.24	5.12
10	7.9	1.30	1.77	0.26	0.84	85.24	5.88

Key: MC% = Moisture content
ASH % = Ash content

CP% = Crude protein

CF% = Crude fiber

HCN% = Hydrogen cyanide

4.2 Discussion

From the result in table 4.1, the highest Total Bacterial Count (TBC) is 3.4 x 10^4cfu/g and Total Fungi Count (TFC) 6.3 x 10^4cfu/g.This indicates that the Garri samples had bioload concentration below the recommended limit of 1.0 x 10^4 except for the mixed sample contaminated because; the recommended limit of bioload in a ready to eat food is less than 1.0x10^4coliform unit (cfu/g) for the food to be satisfactory (Adebayo B *et al*, 2012).

After irradiation, the results from table 4.4 shows that doses used were able to reasonably disinfect the growth of bacteria and fungi in the Garri samples.From tables 4.1 and 4.4 the initial highest TBC before irradiation was3.4 x 10^4cfu/g and Highest TBC after irradiation was1.2 x 10^3cfu/gand Highest TFC was6.3 x 10^3cfu/gand Highest TFC after irradiation was3.0 x 10^2cfu/g. This result clearly shows that both bacterial and fungi has been disinfected. Although Fungi vary in their radiation resistance, the theory of the "multiple hit" has been proposed to explain this difference in radiation resistance. This theory assumes that the target within the organism, usually DNA, must be hit a number of times before the organism is destroyed. The multiple hit theories suggest that even if only one cell escapes damage, the spore may still have the ability to germinate. Thus, these spores are more radiation resistant as higher doses will be needed to destroy all the cells; this is in contrast to the unicellular spores of Aspergillus spp. and Penicillium spp (Patterson, 2005).

The result of moisture content (MC) of the un-irradiated samples from table 4.6 shows that it ranges from 9.81% to 10.72%it means that the moisture content for all Garri samples analysed were below acceptable limit and for irradiated sample table 4.7ranges from 7.8% to 10.01%. This shows that the moisture content for the un-irradiated samples were high compared to the irradiated samples. That is to say the moisture from the Garri samples was reduced by the irradiation. The accepted limit for moisture is 12% (Adebayo et al, 2012). Excess moisture content attracts the growth of bio load because of the water activity. (Adebola *et al*, 2014). It therefore means that bio load contamination were not from high moisture contents but from other processing and storage and marketing conditions.

The ash content (ASH) from table 4.6for un-irradiated sample ranges from 1.41% to 1.82% and for irradiated sample in table 4.7 ranges from 1.30% to 1.80%. Following the permissible limit for ash content in Garri by Codex Aliment commission, there ash content obtained was not within the permissible limit which is 0.1 % Adebayo *et al*, 2012). Though ash content was reduced by irradiation.

The crude protein (CP)forun-irradiated samples from the result in table 4.6ranges from 1.45% to 2.66% and for irradiated samples in table 4.7 ranges from 1.35% to 2.63%. This is also the permissible limit by Codex which should not be more than 6%. The crude protein was reduced with the irradiated dosage.

The fat and crude fiber which was between the ranges of 0.27 to 1.66 for un-irradiated sample and 0.22% to 1.22%for irradiated sample in tables 4.6 and 4.7 respectively is also within the permissible limit which is 2% (Adebayo *et al*, 2012).

The hydrogen cyanide ranges from 5.68mg/kg to 8.5mg/kg for un-irradiated sample in table 4.6and 4.88mg/kg to 7.42mg/kg for irradiated sample in table 4.7. The accepted limit for hydrogen cyanide is 10mg/kg (Adebayo *et al*, 2012). The fat and crude fibre were also reduced with increase in dosage. There is no hydro cyanide threat in all samples analysed as the concentrations were all below 10 mg/kg.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Food irradiation (the application of ionizing radiation to food) is a technology that improves the safety and extends the shelf life of foods by reducing or eliminating microorganisms and insects pest. The FDA (Food and Drug Administration) has evaluated the safety of irradiated food for more than 30 years and has found the process to be safe. The World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC) and the U.S. Department of Agriculture (USDA) have also endorsed the safety of irradiated food. From the result of this research work which is the disinfection of bio-load contaminants and hydro cyanide in Garri using gamma-ray irradiation, it shows clearly that when irradiation is used as approved on foods;

- Disease-causing microorganisms are reduced or eliminated
- The nutritional value is essentially unchanged
- The food does not become radioactive.

5.2 Recommendations

Disinfection of bio-loads (bacteria and fungi) and hydro-cyanide in Garri can be achieved with the required dosage of gamma irradiation, thus the following recommendations;

Work be done to ascertain the actual gamma irradiation threshold dosage for total disinfection of bacteria, fungi and hydro-cyanide in Garri. Study should be carried out on the roots through which pathogenic micro-organisms gets into the Garri product so as to maintain the micro-biological quality and status of the product. Proper storage media should be put in place for proper storage after disinfection. The use of gamma-rays irradiation for the treatment of food is not prominent within our locality and as such very expensive. This is because there is little or no knowledge about this technique of disinfection. There is therefore serious need for the government to put in place food irradiation centers. And proper sensitization be carried out. A comprehensive research should also be carried out on more of our local farm products so that the information disinfection, storage and safety can be available to farmers and traders.

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