EFFECTS OF LOW DOSE GAMMA RADIATION ON QUALITY AND STORABILITY OF GROUNDNUT SEED (*Arachis hypogaea L.*)

BY

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DECLARATION

I hereby declare that this thesis has not been submitted for any degree elsewhere and that it is entirely my own work, except for references to other research studies for which due acknowledgement has been given.

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DEDICATION

This work is dedicated to the wonderful and beautiful women in my life, my late mum (Mrs Muyibat Adeyemi), my wife (Qudrah Okunola), my daughter (Sumayyah omodasola), my sisters (Bushrah and Ghaniyah) and my nieces (Sami'ah and A'isha).

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ABSTRACT

The effect of selected low gamma radiation doses on the quality and storability of groundnut seeds cv. *Chinese* was studied for five months under ambient storage conditions. Six radiation doses (0,1,2,3,4 and 5 Gy), two groundnut seed forms (shelled and unshelled) and eight tri-weekly intervals were combined using Completely Randomised Design with three replications. Physiological parameters (germination percentage, speed and peak value of germination; seedling, root and shoot lengths; seedling vigour index, moisture content), sanitary seed quality parameters (pathogen infectivity and insect infestation percentages) and genetic quality parameters (emergence percentage, days to emergence, days to 50% flowering, leaf and petiole colour) were observed during the storage period. Results showed significant differences between irradiated and non-irradiated seeds, and also among radiation doses for physiological parameters except moisture content. There was significant difference between the seed forms in their response to effect of radiation doses (for root and shoot lengths, and speed of germination) and storage periods (germination percentage, speed and peak of germination, and moisture content), with unshelled outperforming shelled seeds. Storage period had a negative effect on all physiological and sanitary parameters with pathogen infectivity increasing from 22 to 79.9% as storage period advanced for both seed forms and in all doses. Interaction effects between dose, form and storage period were significant ($p<0.05$) for all parameters except pathogen infectivity. A dose range of 2-4 Gy was found to impact stimulatory effects on germination and seedling parameters irrespective of the seed forms. However, these low doses had no influence of any sort on the sanitary and genetic quality of the seeds irrespective of the seed forms. Therefore, the irradiation of 2-4 Gy on unshelled groundnut cv. Chinese could significantly enhance quality and storability of the seeds.

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LIST OF ABBREVIATION

%.....Per cent

ANOVA…….…. Analysis of variance

cm…… Centimetre

CV…… Coefficient of variation

et al……... And others

Fig……. Figure

Ha……. Hectare

i.e.……. That is

M ha……. Million hectares

ibid…… In the same source

CRD……. Completely randomised design

S.e.d……... Standard error difference

Gy…… Gray

°C……. Celsius

RH……. Relative Humidity

MC……. Moisture content

FAOSTAT……Food and Agriculture Organisation Statistics

LSD……. Least Significant Difference

ICRISAT…….. International Crop Research Institute for the Semi-Arid Tropics

ATP……Adenosine triphosphate

CHAPTER ONE

1.0 INTRODUCTION

1.1 *Background*

Groundnut (*Arachis hypogaea* L.) is an annual plant of the family *Fabaceae.* It is a very important crop in the West African sub-region as it is planted as a food crop, fodder, and as raw materials for industries. Groundnut is grown in every ecological zone of West Africa but it performs best in the Sahel to savannah regions of West Africa (Subrahmanyam *et al.* 1991). The crop is very rich in oil (40-50%), protein (20-50%) and carbohydrate (10-20%) depending on the variety (Okello *et al.* 2010). The seeds are also a source of vitamin E, niacin, folic acid, calcium, phosphorus, magnesium, zinc, iron, riboflavin, thiamine and potassium (Savage & Keenan, 1994). Due to the increasing surge in costs of animal protein, groundnut is becoming an even more important source of protein. Groundnut is nutritious and act as a protein substitute for households with fewer resources to acquire meat products (Asibuo *et al.* 2008). It is also useful from an agroecological and economic standpoint, as it improves soil fertility through fixation of atmospheric nitrogen into the soil (Mokgehle *et al.* 2014), hence lessening the quantity and effects of synthetic nitrogen fertilizers required.

Groundnut production in West Africa is plagued by many problems which include both biotic and abiotic constraints. These constraints include erratic rainfall, lack of seeds of high-yielding cultivars, pests and diseases, low inputs for cultivation, post-harvest challenges (e.g. Time and method of harvesting) and proper storage among several other constraints (Catherine & Andrew, 2010; Gillier, 1982). Constraints such as pests and diseases and proper storage environment are

very important, as they are major determinants of quality of groundnuts seed needed for cultivation and consumption (Gillier, 1982).

Groundnut being an oil seed has been reported to be a poor "storer" with a rapid deterioration rate when compared to other crops (Sujatha *et al*.2018). Deterioration of seeds is an irreversible and inevitable process which is as a result of a phenomenon known as ageing. Ageing has been reported to lead to loss of vigour and viability (Tian *et al.* 2008). Factors such as temperature and relative humidity of the storage environment (Harrington, 1972); genetic factors (Kueneman, 1983), presence of microflora and insects (Christensen & Meronuck, 1986), mechanical damage (McDonald, 1985; Moore, 1972) and seed maturity (Ries, 1971) have been reported to influence seed deterioration. The loss of seed viability in groundnut has been reported by Nautiyal & Ravindra (1996) to be rapid such that there could be above 50% loss in viability at the end of five months. This loss or decrease in viability in groundnut has been attributed to invasion of storage pests in combination with poor initial seed quality and unfavourable storage conditions (Begum *et al.* 2013; Ranga Rao *et al.* 2010). Species of fungal genera like *Aspergillus, Fusarium, Alternaria, Curvalaria*, *Macrophorma* are reported to cause discolouration, progressing death of cells and tissues, loss of viability and synthesis of mycotoxins especially in seeds with high oil content (Chavan & Kakde, 2008). While insect pests such as groundnut bruchid have been reported to cause various degrees of damage such as shrivelling, discolouration, holes, contamination with webbings and frass which render the seeds unfit for use (Ranga Rao *et al.* 2010).

Seed quality is a concept which comprises physical, physiological, genetic and health components. These components are mostly manifested in terms of seed viability and vigour of the resulting plants. Knowledge of storage potentials of seed is highly important in preventing losses due to lack

of market for the seeds and also to prevent using old seed stocks for planting. Maintaining seed quality during storage is of importance for seed and grain production. To extend the shelf life, groundnuts seeds are normally stored unshelled, as shelled seeds are known to lose viability quicker (Sharanappa *et al.* 2018).

Irradiation is a procedure which involves exposure of matter to ionizing and non-ionizing radiation such as X-rays, gamma rays and electron beams (Mokobia & Anomohanran, 2005). It has been widely utilized in various fields such as food processing, medicine, industrial chemistry and in agriculture. Irradiation has been reported to inhibit activities of organisms that causes food spoilage and it is also effective in prolonging the mean life of agricultural crops by creating changes in biological processes that are related to post harvest processes such as ripening of fruits, and sprouting of root and tubers, and ageing (FAO & WHO, 1988). Gamma rays is the most utilised form of irradiation due to its high energy and penetrating power (Kovács & Keresztes, 2002).

Gamma radiation has been used in mutation breeding of agricultural crops and also as a seed enhancer depending on the dose applied (Yamaguchi *et al.* 2003; Okamura *et al.* 2003; Ahuja *et al.* 2014; Araujo *et al.* 2016). Gamma radiation have been reported to affect growth and development by bringing about alterations in biological processes in cells and tissues (Kiong *et al.* 2008). The effect of gamma radiation on biological entities has been reported to be as a result of interactions between gamma rays and cellular molecules such as water, to form free radicals (Kovacs & Keresztes, 2002). Ashraf *et al.* (2003) reported that these radicals possess the ability to alter constituents of plant cells and consequently influence biological processes of plants.

However, the effect of gamma radiation on plants has been reported to vary depending on the species, varieties, range of doses, dose rate and matrix of irradiated matter (Boyer *et al.* 2009; Kim *et al.* 2009; Ahuja *et al.* 2014).

Low doses of gamma radiation have been reported to have a stimulatory effect on plant growth and development by increasing enzyme activation and inciting embryo development, which consequently improve germination and plant growth (Singh & Datta, 2010). This is in contrast to high doses of irradiation which have been reported to induce damages in seeds (Mehetre, *et al.*1994). Low doses (0.0832-100 Gy) have been reported by various authors working with different species and varieties of crops to have a positive effect on germination, growth and development and do not results in significant mutations (Habtamu, 2016; Ahuja *et al.* 2014; Jan *et al.* 2012; Wi *et al.* 2007; Abo-hegazi *et al.* 1988).

1.2 *Justification*

The long-term maintenance of groundnut seed quality in storage is highly desirable in promoting and sustaining groundnut cultivation. However, this has been hampered by attack from storage pests on seeds in storage, poor initial seed quality and unfavourable conditions (Tripathi & Kumar, 2007; Ranga-Rao *et al.* 2010; Begum *et al.* 2013). The above-mentioned factors have been reported to cause reduction in germination capacity, shrivelling, discolouration, shrinking, seed necrosis, rotting and toxification (aflatoxin production) of the seeds thereby rendering the seeds unfit for cultivation or consumption (Chavan & Kakde, 2008; Ranga-Rao *et al.* 2010).

Losses between 50-94% viability in groundnut seeds stored for up to six months have been reported by Nayartal and Ravindra (1996) and Santos *et al.* (2016). Reduction in germination rate,

loss in amount of essential biochemicals, increase in moisture content and enhancement of other deteriorating biochemical changes have been reported to be caused by storage pests and unfavourable storage conditions on groundnut (Begum *et al.* 2013). The use of low doses of gamma radiation has the potential to enhance the quality of groundnut seeds prior to storage with minimum effect on quality, thereby helping to maintain and prolong groundnut seeds in storage.

Maintaining qualities of seed during storage is needed for sustaining productivity levels in food or seed production. Groundnut has been reported to store poorly and it is influenced by factors such as those involving living and non-living entities. (Gillier, 1982; Begum *et al.* 2013; Sujathal *et al.* 2018).

Groundnut is stored and marketed in pods with chemicals and packaged in containers that prevent quality deterioration with time (Vasudevan *et al.* 2014). This however, makes the product bulky, impractical to store large quantities due to limited storage facilities/space, difficulty in transportation and distribution and quite disadvantageous due to toxic residue accumulation (Juliana & Amos, 2016; Vasudevan *et al.* 2014; Ramakrishana *et al.* 1991).

Shelled groundnut seeds are reported to be more sensitive to quality deteriorating factors especially storage pests and unfavourable environment (Vasudevan *et al.* 2014). Shelling before storing can take care of the problems associated with bulk storage and marketing of groundnut seeds, if appropriate methods or technology could be utilized in protecting or enhancing the shelled seeds for extended periods.

Gamma radiation is one of the techniques employed in preserving food items and also in invigorating seed quality. The technique may have a potential to protect some commodities from

storage pests and at the same time enhance seed quality (FAO & WHO, 1988; Araujo *et al.* 2016). Low radiation doses between 0.0082- 5 Gy have been reported to increase germination and plant vigour in groundnut to between 10-25% and 22 – 84% respectively (Ahuja *et al.* 2014). This technique can therefore be used as an effective technology to enhance and preserve the quality of groundnut seeds before storage with minimum deterioration in seed quality.

With this background information, there was a need to ascertain the effectiveness of selected low doses on the quality of groundnut seeds during an extended period of ambient storage. The current study proposed to assess alterations in seed quality parameters of groundnut seeds subjected to selected low doses of radiation under ambient conditions for five months.

1.2 *Objectives of study*

The main objective of the study was to assess the effects of selected low radiation doses on the quality and storability of groundnut seeds.

The specific objectives for the study were to:

- identify the radiation dose rate(s) that provides optimum protection while maintaining viability to acceptable standards;
- measure the effect of gamma radiation on physiological and sanitary quality of shelled and unshelled groundnut seeds during ambient storage;
- assess the impact of the doses on the investigated genetic qualities (emergence percentage, days to emergence, days to 50% flowering, leaf and petiole colour) of evaluated groundnut variety.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 *Groundnut Origin, Distribution, Types and Uses*

2.1.1 *Origin and Distribution*

Groundnut (*Arachis hypogaea* L.) is a member of the genus *Arachis* in family *Fabaceae*. The crop is an annual and self-pollinating legume with minimal cross pollination occurring in locations where bee activity is high (Nigam *et al.*1983). Groundnut is one of the most important oilseed crops in the world. The seed contains 40-50% oil and 20-50% protein, and is a rich source of dietary fibre, minerals and vitamins. (Ntare *et al.* 2008; Okello *et al.* 2010). Groundnut has been reported to have originated and was domesticated in South America, and introduced into Africa around 16th century by Portuguese merchants (Waele & Swanevelder, 2001; Tweneboah, 2000). Groundnut cultivation is carried out on 26.4 Mha with a global production of 44 million tonnes and an average productivity of 1.6 metric tonnes/ha (FAOSTAT, 2017). Developing countries make up 97% of the global area and 94% of world's production (FAO, 2003).

According to Tweneboah (2000), major production in Africa is from savannah zones of West African countries such as Nigeria, Niger and Senegal. China is the current largest world producer by far with India coming second (FAOSTAT, 2017). Other significant producers include USA, The Gambia, Mali, Ghana and Malaysia.

2.1.2 *Types of Groundnuts*

According to Gregory & Gregory, (1986), branching and floral axis patterns are the two discriminating characters employed in distinguishing types of groundnut. Based on these criteria,

there are three distinct botanical types of cultivated groundnuts (Ntare *et al.* 2008). The three types of groundnuts are Virginia, Valencia and Spanish types.

(i) ***Virginia/ runner:*** This type of groundnut has no reproductive axes on the central stem. Reproductive axes are present on the branches, and are interspersed with vegetative axes. The vegetative branches can be moderate to excessive with primary branches being lengthy than central stem. The growing habit could be spreading, intermediate, or erect. The inflorescence is simple and usually bears double seeds per pod. Pod beak is unnoticeable and seed size ranges from medium to large. The hue of the testa is mostly tan though there are red, white, purple and variegated types. The seed is moderately dormant and days to maturity can be medium or late (Ntare *et al.* 2008).

(ii) ***Valencia:*** For this type of groundnut, reproductive axes are obvious on the central stem. There are uneven patterns of vegetative and floral branches with floral branches dominating. The vegetative branches are scanty with elementary branches shorter than central stem. The growth habit is erect and the inflorescence is usually simple and pod seed number ranges from double to quartet. Pod beak could be discernible, unnoticeable or modest. Seed size ranges from small to medium and seed coat shade could be red, yellow-brown or variegated. The seed undergoes little dormancy (Ntare *et al.* 2008).

(iii) ***Spanish:*** There are reproductive axes on central stem with uneven arrangement of floral and vegetal branches. floral branches predominate and elementary branches are shorter than the central stem. The growth habit is erect and pods usually bears two seeds. Pod beak is either absent or

present, and seed size ranges from small to medium. Seed coat color could be red, yellowish-brown or purple and limited dormancy occurs in the seed (Ntare *et al.* 2008).

2.1.3 *Uses*

Groundnut has a number of uses, especially as a food crop and as income security for households and poor resource farmers.

Groundnut haulms are used as fodder for livestock; the seed are used as food or snack when boiled, roasted or as a paste and consumed alone or in combination with other food items including sandwiches or other confectionaries (Kochhar, 1986; World Book of Encyclopaedia, 1990). In parts of Africa, groundnut may be consumed either raw, boiled or roasted as a snack and in soups and stews (Waele and Swanevelder, 2001). Oils of groundnuts may be used as ingredients in cooking and several industrial processes including cosmetics, paints, soaps, lubricants and illuminants. The residue after oil extraction is also very high in protein and may be used to supplement livestock feed. Groundnuts can also be processed into flour and peanut milk for human consumption.

2.2 *Seed deterioration*

Seed deterioration has been defined and explained by various authors. Delouche (1973) defined it as an aggregation of all changes in biological processes occurring in a seed, which consequently result in total loss of viability. The author further characterised seed deterioration as an inevitable and irreversible process which is minimal at physiological maturity but subsequently becomes progressive and varies among species, cultivars, seed lots and in individual seeds. Kapoor *et al.* (2010) defined it as gradual reduction of seed quality due to effect of unfavourable environmental

conditions. The phenomenon was further defined aptly by Malik & Jyoti (2013) as degenerative changes that occurs with time which increases exposure to biotic and abiotic factors thereby decreasing the life span of the seed during storage.

Deteriorative changes are enhanced when there is an increase in seed exposure to external challenges (high temperature and humidity) which will lead to decrease in the ability of the seed to survive. Losses as a result seed deterioration could be ≥25% of the total harvested especially during post-harvest processes (Malik and Jyoti, 2013). Deterioration has been pinpointed as one of the fundamental factors responsible for mediocre yield in agriculture and deterioration of seed quality has been reported to take place during harvesting, storage and also due to weathering prior to harvesting (Shelar *et al.* 2008). Several biotic and abiotic elements contribute to susceptibility of seed to deterioration, from which among are temperature and relative humidity of the storage environment, amount of water in the seeds and storage pests. Stunted growth, reduction in germination percentage and vigour, and subsequently death of seeds are from the "symptoms" of seed deterioration (Tilebeni & Golpayegani, 2011; Maity *et al.* 2000).

Seed deterioration involves a combination of physiological and biochemical processes which result in loss of viability. Alterations in the aforementioned processes such as abnormalities in chromosomal structure, deoxyribonucleic acid impairment, alterations in formation of RNA and protein and enzymes activity, differential respiratory process due to ATP formation and changes in membrane structures have all been reported as some of the effect of deterioration, though these are less comprehended (Kerter *et al*.1997).

Spano *et al.* (2006) reviewed the effects of membrane alteration resulting from deterioration. The authors suggested that lipid oxidation of cell membrane might be the actual cause of loss of

viability in seeds. Other research works have reported on phospholipids changes and suggested that oxidative degradation of cell membrane lipids was connected with seed aging (Kerter *et al.* 1997). Ching & Schoolcraft, (1968) reported that seed deterioration due to ageing with time results in depletion of vigour and germinability. The authors further reported that deterioration of seeds is mostly as a result of alterations in biochemical constitution and loss of electrolytes during imbibition. Abdul-Baki & Anderson, (1973) reported that deteriorative changes observed in seeds under storage was as a result of interactions of various biochemical processes such as denaturation of biomolecules such as protein, carbohydrates etc., accumulation of harmful substances and loss of membrane wholeness.

Kalpana and Rao (1991) reported that deteriorative effects due to ageing culminated in depreciation in germination and vigour during storage under ambient conditions. The authors attributed this to changes in physiological properties of seeds, moisture content fluctuations, alterations in biochemical makeup and increment in leaching of electrolytes.

As stated earlier, groundnut kernels are known to store poorly and deteriorate rapidly when stored just like other oil crops. This deterioration is as a result of various factors such as genotype, amount of water content, relative humidity, temperature, duration of storage, containers and modification of storage environment, seed treatments (such as irradiation) and pests.

2.2.1 *Effect of storage on Groundnut seed viability*

Groundnut seeds have been well reported to store poorly with its seeds being short lived and known to lose viability quickly under ambient conditions. Lantican, (1984), emphasised on the importance

of viability of seeds after storage and good field emergence as determinants of crop yield. In line with the above-mentioned report, studies on influence of storage periods and environments on quality of groundnut seeds are collated and presented here. Impacts of temperature and relative humidity on viability of groundnut seeds have been reported by Nautiyal & Zela, (1991). The authors observed that high storage temperature, relative humidity and moisture content are the main elements culpable for the rapid decrease in viability of stored seeds and that high temperature brings about the fracturing of seed coat and cotyledons, thereby exposing the seeds to microbes and insects. Similar observations by Singh & Singh (1992), stated that moisture content and temperature of the storage environment are the main factors affecting seed storability. 2According to Boakye-Boateng & Humes (1975), groundnut and other leguminous crops rapidly lose their viability when stored unless the seeds are stored below 12% moisture in moisture-proof containers and kept under refrigeration.

Parmil and Khatra (1984) stated that seeds of *Arachis hypogaea* stored in jute containers at a temperature of 11°C recorded maximum percentage of germination when compared to seeds stored in plastic bin at ambient temperature. The authors further disclosed that vigour and germination proportion of groundnut seeds decreased in storage as a result of ageing.

Nautiyal & Joshi (1991) observed that percentage of germination and vigour of summer groundnut seeds could be kept at a satisfactory level for a period greater than or equal to eight months by reducing the moisture content through the use of calcium chloride. Nautiyal and Ravindra (1996) reported a 50% loss of viability in groundnuts seeds stored for five months. The authors further stated the cause of this to be an interacting effect of unfavourable storage conditions due to high humidity, temperature and pests. Narayanaswamy (2003) reported that moisture content range of

8-9.53% could be utilised in storing peanut seeds for two-third of a year with no significant depreciation in viability under ambient storage circumstances. Rashmireddy *et al.* (2006) investigated the effect of source of origin and storage location on performance of stored groundnut seeds. The authors reported a gradual depreciation in germination percentage as storage period advances in samples studied.

Sastry *et al.* (2007) investigated the effect of different storage conditions (varied temperatures and moisture contents) on performance and survivability of groundnut seeds. The authors reported a gradual loss in seed viability for all treatments. The authors also reported that seed deterioration was faster at temperatures of ≥50 °C and moisture content of ≥10.1% when compared to other treatments. They further reported a total loss of viability within 10 days in the varied storage conditions used in their study. The authors further suggested that drying groundnut seeds to MC around 3% could increase the survival of seeds at high temperature. Vasudevan *et al.* (2014) investigated the impact of modified storage environmental conditions on seed quality of *Arachis hypogaea*, and reported that germination percentages (93 to 44.67%), Vigour index (2688 to 325), shoot length (11.25 to 4.29 cm), root length (13.28 to 5.23 cm), seedling length(24.53 to 9.53 cm) and speed of germination (20.85 to 15.32) reduced while moisture content (5.7 to 6.16%) and seed infection (0 to 17.80%) increased as storage period progressed irrespective of modified environment and packing materials.

Sharaanapa *et al.* (2018) reported on the sensitivity of groundnut seeds to storage factors such as high temperature, moisture content and light. The authors also reported higher moisture content of seeds stored as kernels over unshelled groundnut seeds after nine months. The authors further

compared kernel and pods storage in groundnut and reported that, pods showed best result in terms of preserving seed qualities due to protection offered by shell and that seed coat of kernels is very thin and delicate such that seed quality loss is more pronounced.

Narayanaswamy (1993) reported that storing pods of peanut genotypes; JL-24 as well as TMV-2 in polyethylene package showed significantly greater viability and emergence percentage, radicle length, vigour and minimal electrical conductivity values when compared to seed of pods stored in cloth bag for 16 months. The authors further reported that pods in polythene bags were less prone to fluctuations in moisture content all through the period of storage.

Sujatha *et al.* (2018) reported that seeds stored as pods showed significantly higher germination percentages and seedling vigour indexes (50.88% & 842) over kernel (44.05% & 770) at the conclusion of the storage period under ambient condition. The seeds stored as pods retained germination per cent (70.00 %) above quality requirements for up to half a year. The authors attributed this to the fact that pods provided protection to the seeds against microbial attack which is common under unfavourable storage conditions. Kernels may get damaged during shelling that hasten the seed deterioration and also makes kernels susceptible to microflora and insect attack.

Norden (1981) investigated the effect of source of origin and storage environment on lifespan of shelled groundnut and observed that storing kernels at temperature range of 17-23 °C conserved the kernels from depreciation for four years, after which viability declined. The author also reported that kernels with high MC (8.11%) had depreciated survival time, while those with low MC (2-6%) increased life cycle of seeds.

Rao *et al.* (2002) investigated the impact of shell and low moisture content on longevity of groundnut seed stored under three storage conditions. The authors reported high moisture contents of 5.6% for shelled and 5.9% for unshelled seeds in cultivars: ICGS 76 and JL 24 prior to storage.

Narayanan & Prakash, (2014) investigated the influence of seed enhancement techniques on storability of groundnut kernels and reported a decreased in germination percentages as a result of the influence of storage period and packing materials.

2.2.2 *Effects of storage factors on seed deterioration*

Singh, (1987) investigated the effect of prevailing temperature and amount of water vapour in the air (RH) on the viability of soybean seeds. The authors reported that seed samples kept at 30°C exhibited reduced germination percentage compare to samples kept at 20°C. The lowest germination percentage was reported in samples stored for almost two months at 30°C and 85 per cent RH.

Balamurugan *et al.* (1989) investigated the effects of MC and storage container (cloth bag) on performance of seeds of *Helianthus annuus* stored for 20 months under ambient condition. The authors reported that seeds with MC of eight per cent were able to maintain viability, vigour and root length to acceptable standards for up to ten months. However, these parameters were reported to decreased as storage period advanced.

Gao-Ping *et al.* (1996) investigated the impact of temperature (–4, 0, 4°C and room temperature) on maintenance of vigour in soybean varieties stored for about eight years. The authors reported faster reduction in seed vigour at room temperature when compared to samples of lower temperatures.

Nkang & Umar (1997) investigated the influence of stage of harvest, temperature and RH on storage properties of varieties of *Glycine max*. The authors reported that temperature and RH ranges of 25 to 30 °C and 55-66 % were found to be ideal for maintaining seed quality of soybean.

2.3 *Gamma radiation*

Gamma rays is a type of electromagnetic radiation possessing between ten to hundreds kilo electron volts with high penetrability than other forms of radiation (Kovacs and Keresztes, 2002). Radiation with gamma has been successfully utilised in the preservation of agricultural crops and other food items as a result of its' effect in eliminating pests and preventing sprouting (Hyun-Pa *et al.* 2006; Maity *et al.* 2008) When compared with other physical methods of sterilization and preservation, irradiation has been reported to be fast, easy, more effective, environmentally safe due to its' high and faster penetrability through the biomolecules (Bao *et al.* 2005; Vidya Kumari, 2013).

Gamma radiation has been employed in mitigating agricultural issues such as losses occurring after harvesting and lack of genetic diversity encountered in breeding for superior traits (Emovon, 1996; Andress *et al.* 1994). It has also been reported to be a feasible and effective nonchemical option for eradicating diseases during postharvest (Hallman, 2011). There is also a growing

potential in its use as a seed enhancer due to its' positive effect on germination, seedling growth, vigour and consequently yields (Melki & Dahmani, 2009; Maity *et al.* 2005; Zaka *et al.* 2002) especially when applied in low doses.

The biological impact of gamma-rays is founded on the interaction of gamma rays on biomolecules such as water which constitute a larger proportion of cell structures, to produce unhindered radicals (Kovacs and Keresztes, 2002). Ashraf *et al.* (2003) reported that the free radicals produced possess the ability to modify either positively or negatively important components and processes of plant cells which affect forms, activities and functions of plants depending on level or rate of exposure.

2.4 *Effect of gamma irradiation on seed germination*

Pathak & Patel, (1988) reported that treating cultivars of upland rice with 50, 100, 150 and 200 Gy doses of gamma rays did not results in considerable reduction in germination percentages of these rice cultivars.

Retamal *et al.* (1990) investigated the effect of gamma radiation doses (0, 100, 200, 300, 400 Gy) on the germination and leakage of electrolytes in groundnut and reported a sharp decrease in germinability of groundnut seeds as the dose increases.

Al-Safadi & Simon, (1995) treated carrot seeds and carrot tissues with gamma radiation (5, 10, 50, 100, 200, 300, 400 Gy) to investigate the effect on genetic variations in carrot propagules. They reported that seed germination was most rapid with the 5 Gy dose, where 30% of the seeds had germinated on the 3rd day, 80% on the 4th day, and 88% on the 5th day. Only 20% of the control seeds germinated at day 5 after the test, but by the 7th day levels had reached 90%. Some

stimulation was also observed at the 10 Gy dose. Higher doses delayed seed germination especially at the 400 Gy dose, at which no germination was observed until the seventh day after irradiation. No further seed germinated at 10 days after the test.

Singh & Singh, (2005) reported changes in germination percentages as a result of treatment with gamma irradiation doses of 50, 100, 250 and 500 Gy in seeds of *Oryza sativa*. The authors further reported that speed and percentages of germination were stimulated by low irradiation doses.

Mokobia and Anomohanran, (2005) irradiated maize, okra and groundnut seeds with radiation doses of 150, 300, 500, 700, 900 and 1000 Gy. The authors reported a significant reduction in germination percentages due to increasing doses. The authors further reported that 150 Gy had less impact on germination percentages of maize and okra. However, it resulted in considerable loss (≈10%) in germination percentages of groundnut.

Miranda *et al.* (2009) investigated the effects of low gamma doses (0, 1, 2.5 and 5 Gy) on quality of rice seeds. The authors reported that germination percentages were significant for all doses except 2.5 Gy. The authors further reported that percentage and speed of germination where high at 5 Gy compared to those of non-irradiated control.

Wiendl *et al.* (2013) also reported that low doses (25, 50, 75, 100, 125, 150 and 200 Gy) of gamma radiation treatment in tomato seeds impacted a stimulatory effect on parameters associated with germination but there was a gradual decrease in germinability as the dose increases.

Marcu *et al*. (2013) treated lettuce seeds with gamma radiation doses (2,5,15,30 and 70 Gy) to study dose-dependent effect on lettuce seeds and seedlings. The authors reported that germination percentages increased up to 30 Gy. The authors further reported an increment in germination percentages in seeds for the first four doses (2&5 Gy (8%), 15 Gy (10%) and 30 Gy (25%)). The authors also reported that germination percentage was found to decreased by 8.34% at 70 Gy, when compared with control samples. They also reported an increasing pattern in germination index at doses up to 30 Gy, as observed in germination percentages. There were significant stimulatory effects on germination index of seed samples treated with 2 Gy (45%) ,5 and 15 Gy (52%), and 30 Gy (75%) when compared with non-irradiated samples. Samples treated with 70 Gy had 5% reduction in germination index when juxtaposed with those of control.

Aparna *et al.* (2013) treated groundnut seeds with gamma radiation doses of 0.70, 0.90, 1.10, 1.30, 1.50, 1.70, 1.90, 2.10 and 2.30 kGy and reported that there was continual decrease in percentage, speed and peak value of germination as radiation doses increased. The authors further reported that non-irradiated seed samples had highest germination percentage (95%) while the lowest value was obtained at 2.30 kGy (20%). The authors also reported a lethal dose 50 (LD_{50}), in which there is 50% reduction in viability of seeds tested at 1.50 kGy.

Ahuja *et al.* (2014) reported the effect of very low (0.0082, 0.0164. 0.0328, 0.0656, 0.1312, 5 Gy) to relatively high (25, 100, 500 Gy) gamma radiation dose on groundnut seeds in terms of its' stimulatory effect on germination. The authors reported an increase in germination percentages (10 – 25%) and vigour indexes (22 – 84%) for doses up to 5 Gy when compared to the non-irradiated control.

Bishnoi & Chandra, (2014) reported on the effect of radiation doses (0, 0.1, 0.2, 0.5, 1.0, 3.0, 5.0, 10.0 and 15.0 kGy) on seed viability of *Arachis hypogaea* L. The authors further reported decrease in germination percentages of groundnut seeds as the radiation dose increased with control having the highest (98%) and 1 kGy having the lowest (40%). They further reported that doses from 3 kGy to 15 kGy resulted in total loss of viability.

Yadav *et al.* (2015) investigated the effects of gamma irradiation on viability of maize (*Zea mays*) varieties (HQPM 1 and HM 4). The authors reported that an increase in radiation dose culminated in depreciation in germination percentages of the maize cultivars. The authors further reported that HQPM 1 had significantly higher germination percentages compared to HM 4. The authors also observed that for both varieties, germination percentage was slightly constant up to 200 Gy. However, there was a reduction of 12.5% and 14.4% for HM 4 and HQPM 1, respectively at 300 Gy. The highest decrease, HM 4 (50%) and HQPM 1 (33.3%) for both varieties was obtained at 2 kGy.

Kharade *et al.* (2015) investigated the impact of mutagenesis on variations in seed quality of *Arachis hypogaea*, using radiation dose of range 200-400 Gy with 100 Gy intervals. The authors reported that germination percentage decreased after irradiation and the effect was more intense with increasing irradiation doses. The authors further reported significant reductions in germination and seedling parameters due to increased doses compared to the control.

Beyaz *et al.* (2016) investigated the effect of gamma radiation (0, 50, 100, 150, 200 and 250 Gy) on some physiological parameters of seeds of *Lathyrus chrysanthus* Boiss. The authors reported contradictory observations compared to previously mentioned works. They observed an increase in germination percentage and seedling growth as radiation dose increases till it got to the maximum (62.4%) at 150 Gy dose and began decreasing as the dose further increased.

Suradkar, (2017) investigated the impacts of gamma radiation on response and performance of groundnut cultivars using irradiation dose of 0.1, 0.15, 0.20 and 0.25 kGy on two varieties of groundnut viz. TAG-24 and AK-159. The authors reported that germinability in variety, TAG-24 was increasing up to dose 0.20 kGy but suddenly dropped down at high doses. However, in the case of variety AK-159, there was a decreasing pattern as radiation dose increased. The results further enforced the claims of earlier works on varietal responses of groundnut seeds to radiation doses.

Hussain *et al.* (2017) irradiated sunflower seeds with gamma rays using doses between 5-50 Gy with 5 Gy intervals and reported 34 and 26% increase in germinability at 5 and 40 Gy over control. Though there was a subsequent relative decline in germinability as radiation doses increased after the two doses mentioned above.

Kuzin *et al.* (1975) suggested that the stimulatory impacts of low radiation doses on parameters associated with germination could be ascribed to stimulatory synthesis of ribonucleic acid or protein molecules occurring during the nascent phase of the germination process.

Luckey, (1980) & Korystov and Narimanov, (1997) attributed this stimulatory effect to a phenomenon termed “hormesis”. The authors further explained the term to be incitement by low radiation dose conferring a beneficial effect and high dose having an inhibitory or toxic effect.

Krishnaswamy and Seshu, (1989) suggested that, the invigorating effects of low radiation doses on physiological parameters could be ascribed to its’ impacts on absorption of oxygen and activities of dehydrogenases through the provision of energy to the developing embryo and the entire metabolic process. The authors attributed the inhibiting effect of high radiation doses to significant loss of electrolytes as a result of increased membrane permeability.

Salter & Hewitt, (1992) reported that high radiation doses bring about oxidative trauma leading to formation of reactive oxygen species, which interact with biomolecules including amino acids, lipids, Ribonucleic acid and Deoxynucleic acid resulting in disruptions of cell metabolic processes.

Inhibiting impacts of high gamma doses on germination has been proposed to include reasons such as alterations in processes involving cell and tissue structures, severance and dissolution of seed membranes and formation of free radicals leading to metabolic abnormalities in germinating seeds, these reasons are proportional to dose concentration (Lokesha *et al.* 1994).

Wi *et al.* (2007) were in agreement with earlier works and reported that gamma radiation applied in low doses confers a stimulatory effect on plant growth by altering the flagging of interacting networks of hormones in plant cells or by raising the reductive capacity of cells to surmount environmental stresses such as variation of light intensity and temperature during seedling growth.

The authors further reported that increasing damages to chromosomes as a result of upsurge in radiation dose may be accountable for decrease in germination.

2.5 *Effect of gamma radiation on seedling growth*

Growth and development of plants involves an array of physiological phenomena through which morphological entities emerge and develop as growth takes place, and changes in pattern of growth will consequently have an effect either positive or negative on growth and yield (Jan *et al.* 2012). The use of gamma radiation on seed or other propagules has been found to impart obvious effects on growth of plants by various researchers.

Charbaji & Nabulsi, (1999) irradiated explants and shoot tips of two cultivar and root stocks of grapevine using doses of 0, 2, 5 and 7 Gy. The authors reported that shoot lengths of the two cultivars irradiated with 7 Gy were significantly greater than the control, and those of the root stocks were not significantly different from those of the control samples. However, the rootstocks subjected to 2 and 5 Gy exhibited lower shoot lengths compared to the control. Root lengths for both varieties treated with 2 and 7 Gy were also higher compared to the control samples for both varieties.

Miranda *et al.* (2009) investigated the effects of low gamma doses (0, 1, 2.5 & 5 Gy) on quality of rice seeds. The authors reported that irradiation doses of 1 and 2.5 Gy had no significant effect on lengths of seedling shoot. However, in the case of 5 Gy, higher shoot growth was observed and recorded compared to control. The authors reported significant differences in root lengths between seeds irradiated and 0 Gy (control).

Marcu *et al.* (2013) treated lettuce seeds with gamma radiation doses (2,5,15,30 and 70 Gy) to study dose-dependent effect on lettuce seedlings. The authors reported that root lengths were positively affected by radiation doses 2, 5,15 and 30 Gy, as it increased from 33 to 83%, as the doses increased. However, it fell by 21% in seeds treated with 70 Gy compared to the control samples. The authors also reported that the doses 2-30 Gy had positive impact on lengths of shoot of lettuce, as it increased by 34% for seeds treated with 2,5 and 15 Gy, and 57% for those irradiated with 30 Gy compared to samples of non-irradiated seeds. Dose 70 Gy had a negative effect on shoot lengths, as it was 35% less than those of control samples.

Aparna *et al.* (2013) reported on the inhibitory impacts of high radiation doses on seedlings parameters of groundnut seeds. The authors treated seeds with doses between 0.70-2.30 kGy with intervals of 200 Gy, and observed stunted growths with very short radicle and plumule for doses treated with high doses. The negative impacts on radicle and plumule lengths were more evident in seeds treated with 2.10 and 2.30 kGy. At a dose of 2.30 kGy, plumule growth was totally suppressed. The authors also reported that all doses had negative effects on lengths plumule (4.14-1.21 cm) and radicle (3.22-0.98cm) compared to the control with radicle and plumule lengths of 3.89cm & 4.14 cm, respectively.

Bishnoi and Chandra (2014) observed a decrease in both root and shoot length of groundnut seedlings with increasing radiation dose when the seeds were exposed to 0.1, 0.2, 0.5, 1.0, 3.0, 5.0, 10.0 and 15.0 kGy of gamma rays. Control(non-irradiated) had the highest of length for root (10.5±2.0 cm) and shoot (25.0±0.8 cm), while 1.0 kGy had the lowest length for root (0.9±0.1 cm) and shoot (4.3±0.6 cm).

Ilyas & Naz (2014) investigated the effect of gamma irradiation on morphological characteristics of turmeric (*curcuma longa* L**.** cv. F1-F11). The authors reported an initial decrease in root length of seedlings at 10 Gy and a subsequent increase up to 70 Gy when compared to the control. The authors further reported a decrease in root lengths of seedlings after 70 Gy.

Yadav *et al.* (2015) reported an improvement in seedling length, weight and vigour index at radiation doses below 200 Gy for seed of maize cultivars used in their study. However, the aforementioned parameters were observed to decreased at and above 200 Gy.

Kharade *et al.* (2015) reported that seedling parameters of *Arachis hypogaea* such as radicle and plumule lengths, and vigour index were significantly subdued at high radiation dose compared to control samples after treatment with radiation doses of 0.20, 0.30 and 0.40 kGy.

Beyaz *et al.* (2016) investigated the impact of radiation doses (0, 0.05, 0.10, 0.15, 0.20 and 0.25 kGy) on physiological parameters of Caley pea (*Lathyrus chrysanthus* Boiss) sown in test tubes. The authors reported increase in seedling growth parameters from control to 0.150 kGy and a further decrease in these parameters as the dose surpassed 0.150 kGy. The highest shoot (1.2 cm) and root lengths (2.9 cm) were recorded for 0.15 kGy treated sample. There was an increment of 61% in root length for seeds irradiated with 0.15 kGy (2.9 cm) compared to non-irradiated seed samples (1.8 cm).

Suradkar (2017) studied gamma sensitivity of groundnut (*Arachis hypogaea* L.) using doses of 0.10, 0.15, 0.20 and 0.25 kGy on two varieties of groundnut viz. TAG-24 and AK-159. The author

reported 15% and 5% increase in root length and seedling height, respectively from control at a dose of 0.10 kGy, however these parameters decreased as the radiation dose increases.

Alterations in the forms and structures of seed parameters reported above has been reported to be dependent on radiation intensity and duration (Jan *et al.*, 2012).

2.6 *Effect of gamma irradiation on seed storability*

Seed storability refers to the safe guarding of quality properties of a seed for a long time with minimum deterioration of the properties. Previous works on the effects of irradiation on stored agricultural crops are collated and presented below;

Wang *et al.* (1983) investigated the impacts of radiation doses on seeds of *Oryza sativa* stored for a year. The authors reported that there was considerable reduction in percentage of germination of irradiated samples treated with doses above 0.5 kGy. Pathogen infectivity was greatly reduced at doses greater than or equal to 1 kGy for the period for which the seeds were stored.

McDonald & Nelson (1986) reported that signs and symptoms of ageing in seeds includes late commencement of germination process, retardation in growth and development and increased sensitivity to deteriorating factors in the prevailing environment. Continuous reductions in germinability and speed of germination process are part of alterations in physiological properties that has been observed to occur in seed during ageing. The degree of decline or reduction has been reported to be associated with initial level of deterioration for a seed lot (Ram and Wiesner, 1988).

Lin (1988) reported significant reduction in germination percentages as storage period advanced. The author also reported that loss of vigour was related to reduction in seed viability, and decrease in seed vigour occurred at a faster rate than that of viability. The author further reported a high correlation between leaching of seed electrolytes and loss of viability and vigour. The author concluded by attributing the loss of vigour and viability during storage to membrane deterioration as a result of high moisture content in the storage environment.

Jang *et al.* (2005) investigated the effect of low dose gamma radiation (1, 4, 8, 16 and 32 Gy) on physiological parameters of radish seeds stored under room and cool temperature (10 ^{o}C) for a year. The authors reported that germination percentage decreased for non-irradiated seeds after a year of storage, irrespective of the temperature. However, germination percentage increased for the irradiated seeds till it got to the maximum at 8 Gy and started decreasing as the irradiation dose progresses. Root length increased as the dose increases at room temperature, however a rising and falling pattern was observed for seeds stored at 10 ℃ until 8 Gy, but increases as the dose increases further. The authors further reported that for room temperature stored seeds, there was an increase in weight as the irradiation dose increases, with 16 Gy having the highest weight of 14.7±2.8 mg. for seeds stored at 10 ^{o}C.

Vidya Kumari (2013) treated some rice varieties with gamma radiation doses (0.05, 0.10, 0.15, 0.20 kGy) in order to study gamma irradiation effect on their storability. The author reported that doses of 0.05 and 0.10 kGy had the upper hand in terms of positive influence exerted on most of the parameters studied throughout the course of the study. High doses were found to have

deleterious effect on the parameters measured. The author further reported on the superior performance of seeds irradiated with the two aforementioned doses in the field evaluation.

Zanzibar & Sudrajat, (2016) investigated the impact of gamma rays on the quality and storability of *Magnolia champaca* L. seeds. The authors reported that irradiated seeds, both with and without storage in refrigerator (4°C and 40-50% relative humidity) for 3 months, showed significant increases in percentage, index, value and mean time of germination when compared to non-irradiated seeds. The authors observed a declining trend in the values of the aforementioned parameters as a result of increase in radiation doses.

2.7 *Effect of gamma radiation on seed health and moisture*

Gamma radiation has been used in prolonging the shelf life of food products, including agricultural produce. It mainly acts by decontaminating the produce against both micro-organisms and insect pests that are mostly responsible for degradation of these produce. The efficiency and impact of irradiation as a method of eliminating pests have been documented in various works. Some of these works are collated and presented.

Tilton, (1974) reported that 0.5 kGy was adequate for controlling all stored product insect pests. The author also reported that this dose was able to prevent reproduction of these insect pests, rather than going for a high dose that will result in acute mortality and probable changes in sensory attributes of stored produce. The author further reported that the use of the aforementioned dose

did not eliminate insect pests instantly but it significantly reduced their feeding, thereby reducing their damaging activities to a minimum.

El Kady & Hekal, (1991) investigated the effect of gamma irradiation and resistance of packaging films for disinfesting and preventing insect pests on pulses. The authors reported that cowpea seeds irradiated with 0.4 kGy dose packed in polyethylene bags were able to completely eliminate insects at the end of the storage period.

Diop *et al.* (1997) reported a 97% mortality rate of cowpea weevil population at 0.05 kGy when stored 20 days after irradiation. The authors stated that application of low radiation doses in controlling insect pests does not instantly eliminate these pests, thereby allowing them to continue their destructive activities, though the doses becomes effective in eliminating the pests with time.

Hooshmand & Klopfenstein, (1995) treated wheat, maize and soybean seeds of different moisture content (9, 13 and 17%) with gamma radiation (5,7.5, 10 and 20 kGy) and reported a non-significant relationship between the factors. Though the authors stated that MC could be one of the determining factors contributing to the efficacy of gamma radiation in eradicating micro-organisms and their toxins.

Wilkinson & Gould, (1998) reported on the importance of moisture content in irradiation procedure by moderating the effects of changes due to radiolytic reactions during and after irradiation.

Ashaye (2006) treated seeds of three cowpea varieties (Ife brown, kano white and drum) with three low radiation doses(5,10 & 15 Gy) and stored at temperatures of 27±1 °C for ambient conditions

and 18 ^{0}C with the aim of investigating the influence of irradiation doses and temperatures on water activity and MC in cowpea seeds. The author reported an adjoining increase in moisture for both irradiated and control cowpea seeds with both samples exhibiting the triphasic sigmoidal curve occurring in all but a few food items. The author further reported that MC of irradiated cowpea seeds was higher compared to those of control, irrespective of the temperature. The author suggested that the above phenomenon could be due to the weakening of intermolecular bonds by gamma rays.

Yu & Wang (2007) conducted a study on the impact of radiation doses on equilibrium moisture content (EMC) modelling of *Triticum aestivum*. The authors reported that radiation doses had an effect on EMC of wheat at ambient temperature. The authors further reported an inverse relationship between EMC and radiation dose. They attributed this relationship to the alterations of carbohydrate granules and the water holding capacity of these granules as a result of different radiation doses.

Appiah (2001) observed while investigating the effect of gamma radiation on fungi population on cocoa beans that, the number of fungal colonies as well as the different species of fungi decreased with an increase in the radiation dose applied. The author further stated that 5 kGy dose was effective in eliminating fungi on or in non-mouldy beans while 8 kGy was able to completely destroy fungi population in mouldy beans.

Bishnoi and Chandra (2014) reported decrease in both moisture content and fungal load in groundnut seeds with increasing radiation dose when the seeds were irradiated at 0.1, 0.2, 0.5, 1.0,

3.0, 5.0, 10.0 and 15.0 kGy and then stored for 3 months. They further reported a complete inhibition of fungal growth at doses above 5 kGy.

Zarbakhsh & Rastegar, (2019) reported that the mechanisms involved in inactivation of microbes by irradiation is unclear, though findings from earlier works have suggested that hydroxyl radicals resulting from irradiation interact with microbial DNA by the removal of hydrogen atoms leading to breakdown of DNA structures and consequently disruptions in their functions.

CHAPTER THREE

3.0 MATERIALS AND METHODS

This study "Effect of low dose gamma radiation on quality and storability of groundnut seed (*Arachis hypogaea* L)" was carried out at the National Seed Testing Laboratory of the Ghana Seed Inspection Division, Pokuase from December 2018 to May 2019. Experimental design employed was Complete Randomised Design (CRD) with three replications.

3.1 Materials

3.1.1 *Crop variety and preparation*

Foundation Seeds of *Arachis hypogaea* cv. Chinese from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) used for the experiment was sourced from the Savannah Agricultural Research Institute (SARI), Ghana. The variety is quite popular in Ghana due to its' relatively early maturing trait (100 days), medium oil content (35%) and wide adaptability to various ecological zones. Two seed forms- shelled and unshelled were employed for the seeds to be irradiated. The seeds were packed in hermetic polyethene bags (700mm gauge) weighing 100 grams and 150 grams for shelled and unshelled groundnuts seeds respectively.

3.2 Methods

3.2.1 *Gamma radiation*

Seed irradiation was carried out at the Radiation Technology Centre of the Biotechnology and Nuclear Agriculture Research Institute (BNARI), Ghana Atomic Energy Commission (GAEC), Kwabenya, Accra.

The seeds were exposed to selected doses of gamma radiation (Table 3.1) with a Co^{60} source having doses rates of 70 $Gyhr^{-1}$ and 71 $Gyhr^{-1}$ for shelled and unshelled seeds, respectively. These dose rates were determined after a preliminary test using ethanol-chlorobenzene (ECB) as a dosimeter. The materials were placed on an adjustable metallic stool of height 70 cm from the ground and at a distance of 150 cm from the shroud bearing the source in order to achieved low absorbed dose application for the samples. Six packs of the groundnut were placed manually in the irradiation room as proposed with the source in its shielded position in the storage room.

The packs were rotated on their axis while they were irradiated to improve dose uniformity and reduce variation within the packs. After completion of irradiation, the source was moved to its shielded position, and the irradiated packs were replaced with a new batch for the next irradiation.

Table 3.1: Details of gamma irradiation of the seeds

Code	Irradiation dose (Gy)	Exposure time Shelled(S) (Min)	Exposure time Unshelled (US) (Min)
D0	0	0	0
D1	1	1	0.85
D2	2	2	1.7
D3	3	3	2.55
D4	4	4	3.4
D5	5	5	4.25

D=dose

Radiation doses of 0, 1.0, 2.0, 3.0, 4.0, 5.0 Gy were used for the experiment. These doses were selected because of their beneficial and non-deleterious effects on certain seed quality parameters (Wi *et al.,* 2007, Ahuja *et al.,* 2014; Hamtabu, 2016). The 0.0 Gy dose which was the control served as a reference point for comparison with the treated seeds. The exposure time was used to achieve the target irradiation doses as stated above.

3.2.2 *Data collected*

Observations on seed quality was recorded shortly after irradiation, and served as the reference point. Observations at 3 weekly intervals on storability characteristics of seeds were taken for five months based on the parameters listed below;

3.2.2.1. *Germination percentage (%)*

Germination tests were conducted with 50 seeds in four replicates using the between paper (BT) method at 25 ^{0}C and 90 % relative humidity as prescribed by ISTA (2005). Counting and evaluation was carried out on the 10th day after planting. Seeds were evaluated and graded as normal, abnormal and dead. The number of normal seeds that germinated were counted in the four replications and their averages were expressed as germination percentage. Germination percentage was calculated based on the formula stated below;

$$\text{Germination Percentage} = \frac{\text{Number of normal seeds}}{\text{Total number of seeds planted}} \times 100$$

3.2.2.2. *Speed of Germination*

This parameter is based on the germination test carried out. Daily germination counts from the four replicates were carried out until the 10th day after planting. Speed of germination was calculated based on the formula provided by Maguire, (1962). The parameter's unit is number of seedlings germinating per day.

$$\text{Speed of Germination} = \Sigma (n/t)$$

Where, n = Number of newly germinated seeds at time 't'

t = Days from sowing

3.2.2.3. *Peak value of germination*

Daily counts of newly germinated seeds were carried out until the 10th day after sowing. Peak value of germination was determined using the formula below (Czabator, 1962). The parameter's unit is maximum cummulative number of seedlings germinating per the number of days to reach this number.

$$\text{Peak Value} = \frac{\text{Cummulative number of seeds newly germinated on each day}}{\text{Number of days elapsed since initial imbibition}}$$

3.2.2.4. *Shoot length*

Ten seedlings with essential morphological structures were randomly selected from each replication on the 10th day after sowing and used to determine shoot length. Lengths of shoot was measured with the aid of a ruler from the collar region (between the hypocotyl and radicle) to the tip of the apical bud. Average shoot lengths were computed and expressed in centimetres.

3.2.2.5. *Root length*

Ten seedlings with essential morphological structures were randomly selected from each replication on the 10th day after sowing and used to determine shoot length. Lengths of root was measured with a ruler from the collar region (between the hypocotyl and radicle) to the tip of the primary root. Average root lengths were computed and expressed in centimetres.

3.2.2.6. *Seedling length*

Ten seedlings with essential morphological structures were randomly selected from each replication on the 10th day after sowing and used to determine seedling length. Lengths of seedlings was measured with a ruler from the tip of the primary root to shoot tip. Average seedling lengths were computed and expressed in centimetres.

3.2.2.7. *Vigour Index 1*

This parameter was deduced from germination percentages and seedling length, then computed using the formula below as suggested by Abdul-Baki and Anderson (1973).

Vigour Index I = Germination percentage (%) X Seedling length (cm)

3.2.2.8. *Pathogen infectivity (%)*

Incidence of pathogen infection was calculated based on number of infected seeds observed at three-week intervals throughout the storage period. Detection of pathogenic infection was determined using Agar plating. Seed samples were superficially sterilized in 4% bleach (Sodium

hypochlorite) solution for 30 seconds. Excess bleach on the seeds was then rinsed off using sterilised distilled water. The seeds were then dried on sterile blotter paper and placed on 9 mm sterile potato dextrose agar (PDA) plates that were amended with chloramphenicol antibiotic. Four seeds were placed in each petri dish containing PDA in three replicates per replicate of radiation doses. The plates were thereafter incubated at room temperature (25 ^{o}C-28 ^{o}C) for seven days. The small number of seeds used was as a result of the fairly large size of the kernels so as to maintain a fair distance between them when identifying fungal colonies that have infected the kernels. All fungal growths were identified with the aid of Illustrated Genera of Imperfect Fungi manual (Barnett & Hunter, 1972); and their frequencies of occurrence determined accordingly (ISTA, 1993).

Pathogen infectivity percentages were computed for each sample using the formula below;

$$\text{Pathogen infectivity (\%)} = \left(\frac{\text{Number of infected seeds}}{\text{Total number of seeds used}}\right) \times 100$$

3.2.2.9. ***Moisture Content (%)***

Moisture content (MC) of seed samples was determined using a WAGTECH PROJECTS AG62-100 programmable seed moisture analyser. About 100 grams of the seeds were poured into the moisture analyser and the MC of the sample was given by the analyser. This was carried out three times and the average computed.

3.2.3 *Field Evaluation*

The treatments were planted out in rows of 10 hills of three seeds each using a dimension of 60 cm×30 cm. This was done to ascertain the Distinctiveness, Uniformity and Stability (DUS) of the

groundnut variety. The hills were later thinned to two stands per hill. The evaluation measured the underlisted morphological characteristics of the variety using the controls as checks. These were as follows:

3.2.3.1 *Field emergence (%)*

Within two weeks (14) after planting, the number of seedlings emerging from the plot were counted and compared. The number of seedlings which emerged after planting was counted over the number of seeds planted and then expressed as percentage.

3.2.3.2 *Days to seedling emergence*

Within 7 days, visual observations were carried out on the number of days it took seedlings from respective treatments to emerge after germination.

3.2.3.3 *Days to 50% flowering*

Visual evaluation was carried out to determine the number of days for 50 % of the plants population to start producing flowers.

3.2.3.4 *Morphological characters*

Visuals of leaf colour, shape and petiole colour were taken between 60-70 days after planting.

3.2.4. *Statistical analysis*

The data generated were subjected to Analysis of Variance (ANOVA) to test the significance of various treatments evaluated in the experiment using GenStat. (12^{th} edition) and means were compared using Least Significant Difference (LSD) at probability level of 5%. Data transformations were carried out using appropriate transformation procedures where necessary.

Regression analysis was carried out to show relationships and trends between the factors and parameters.

CHAPTER FOUR

4.0 RESULTS

4.1 Seed quality parameters immediately after gamma irradiation

Seed quality tests were carried out about 24 hr after irradiating the groundnut seeds to check if there was an immediate effect of radiation treatments on qualities of the seeds. There was no significant effect of the treatments on each of the seed quality parameters measured except for moisture content which was influenced by seed forms and speed of germination which was influenced by interaction of radiation doses and seed forms.

Moisture content (MC) was significantly higher ($p<0.05$) in unshelled seeds than shelled seeds 24 hrs. after irradiation (Table 4.1). The highest MC value (6.86%) was observed in unshelled seeds and the lowest MC value (6.56%) was recorded in shelled seeds.

Table 4.1: Moisture content of groundnut seeds forms

Forms	Moisture content (%)
Shelled	6.560(1.610)
Unshelled	6.860(1.620)
Mean	6.710(1.620)
LSD (0.05)	0.010
S.e.d	0.005
CV (%)	1.0

Figures in parentheses indicate root transformed values

Seed forms and irradiation doses had significant ($p \leq 0.05$) effect on speed of germination (Table 4.2). The highest speed of germination was observed in shelled seeds treated with doses of 2 and 4 Gy and unshelled seeds of 3 and 4 Gy, which were significantly different from those treated with 2 Gy in unshelled, 3 and 5 Gy in shelled seeds and the control samples. The lowest speed values recorded for both seed forms occurred in seeds irradiated with 3 and 2 Gy for shelled and unshelled, respectively. The remaining doses in both forms were not significantly different ($p \geq 0.05$) from the aforementioned significantly higher doses (i.e. 2&4 in shelled and 3&4 in unshelled).

Table 4.2: Speed of germination in forms of groundnut seeds immediately after irradiation

	Speed of germination(No of seedlings germinating/day)	
	Forms	
Dose (Gy)	Shelled	Unshelled
0	8.270	8.870
1	8.500	8.630
2	8.930	8.130
3	8.170	9.030
4	9.130	8.970
5	8.170	8.700
Mean	8.530	8.720
LSD (0.05)	0.660	
S.e.d	0.390	
CV%	4.600	

4.2 Seed quality parameters of gamma radiated seeds during storage

Seed quality tests carried out during the period of storage were significant for the main effects (dose, forms and storage period) and their interactions for the following seed parameters: germination percentage (%), speed of germination, peak value of germination, root and shoot lengths, seedling length, vigour index, moisture content and pathogen infectivity(%). The results of these effects and their interactions are presented as follows:

4.2.1 Effect of Gamma radiation doses on parameters studied

4.2.1.1 Effect of gamma radiation doses on germination parameters

Germination percentages were significantly ($p<0.05$) higher during storage in irradiated seeds than in non-irradiated seeds (Table 4.3). The highest proportion was observed in seeds treated with 2 and 4 Gy of radiation which were significantly different from seeds treated with 0 and 5 Gy. The lowest germination percentage was observed in non-irradiated seeds, though it was not statistically different ($p\geq0.05$) from values recorded for seeds irradiated with 5 Gy. The remaining doses (i.e. 1 and 3 Gy were not statistically different ($p\geq0.05$) from 2, 4 and 5 Gy. There was a non-significant ($p=0.059$) and positively correlated non-linear relationship ($R^2 = 0.84$) between germination percentage and radiation dose (Figure 4.1).

Peak of germination was significantly ($p<0.05$) higher in irradiated seeds than in control (Table 4.3). The highest values observed in seeds treated with 2 and 4 Gy of gamma rays were significantly different from 0 and 5 Gy. The lowest value was observed in non-irradiated seeds, though it was not statistically different ($p<0.05$) from values recorded for seeds irradiated with 5 Gy. The doses 1 and 3 Gy were not statistically different ($p\geq0.05$) from 2 and 4 Gy.

Speed of germination were significantly ($p<0.05$) higher in seeds treated with gamma radiation than in control (Table 4.3). The fastest speed of germination were observed in seeds treated with 2 and 4 Gy which were significantly different ($p<0.05$) from the control and the 5 Gy. The lowest speed of germination was observed in non-irradiated seeds, though it was not significantly different ($p\geq0.05$) from values recorded for seeds irradiated with 5 Gy. The doses 1 and 3 Gy were not significantly different($p\geq0.05$) from 2 and 4 Gy.

Table 4.3: Influence of radiation doses on percentages, speed and peak value of germination

Doses (Gy)	Germination percentages (%)	Peak value of germination(max. cumm. no of seedlings/5days)	Speed of germination
0	84(1.162)	17.620	7.325
1	87(1.209)	17.994	7.596
2	88(1.229)	18.027	7.708
3	87(1.210)	18.004	7.617
4	88(1.229)	18.065	7.744
5	86(1.198)	17.815	7.642
Mean	87(1.206)	17.920	7.605
LSD (0.05)	0.031	0.238	0.176
S.e.d	0.016	0.120	0.089
CV %	6.3%	3.3	5.8

Figures in parentheses indicate arcsine transformed values

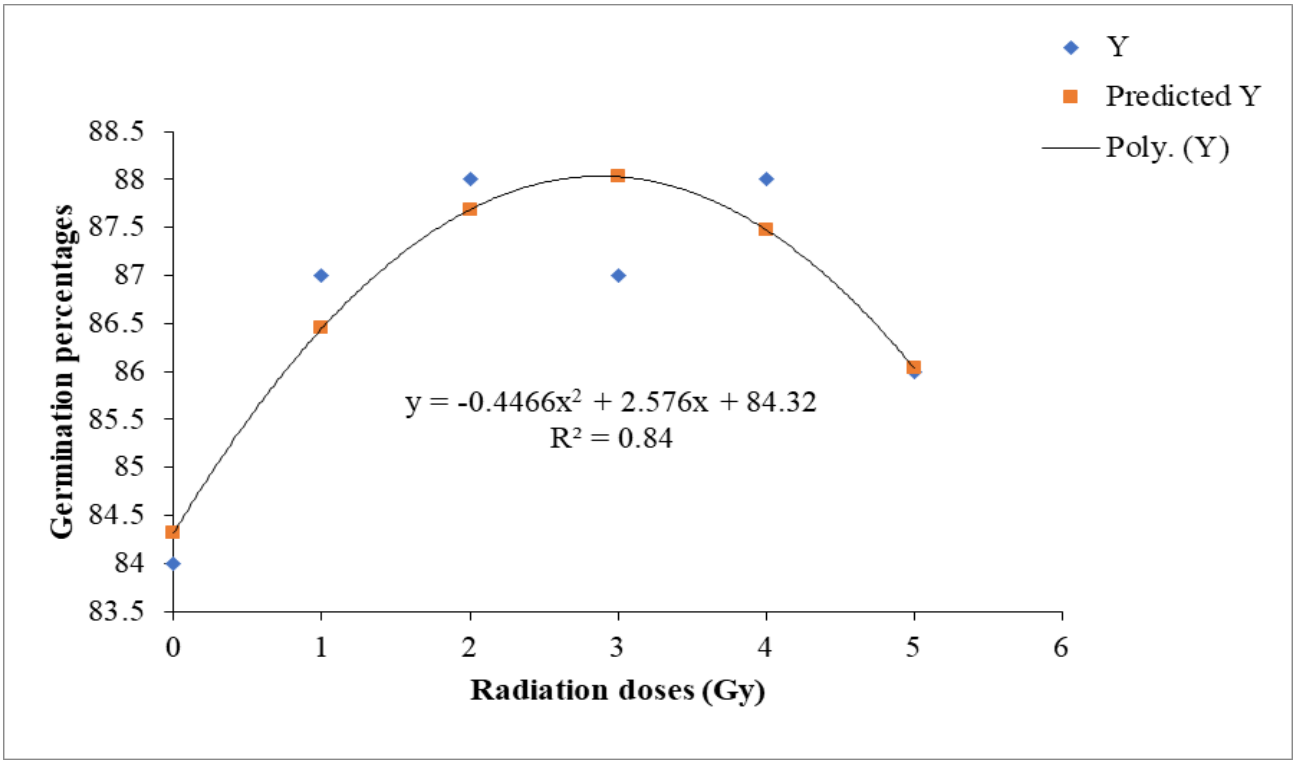

Fig. 4.1: Relationship between radiation doses and germination percentages

4.2.1.2 Effect of gamma radiation on vigour and seedling parameters

Root length was significantly lower ($p<0.05$) in seeds irradiated with 5 Gy than seeds treated with 2 Gy (Table 4.4). The highest root length value was observed in seeds treated with radiation dose of 2 Gy. While the lowest was observed in seeds irradiated with 5 Gy. Though, the low root length value was not significantly different ($p\geq0.05$) from the control and remaining doses (i.e. 1, 3 and 4 Gy).

Shoot length was significantly lower ($p<0.05$) in control than seeds irradiated (Table 4.4). There was no significant difference ($p\geq0.05$) among the irradiated seeds. The highest shoot length value was observed in seeds treated with 2 Gy (Table 4.4). The lowest value was observed in non-irradiated seeds.

Seedling length was significantly lower ($p<0.05$) in control than seeds irradiated (Table 4.4). There was a significant difference ($p<0.05$) between seeds treated with 2 and 5 Gy doses. However, these two doses were not significantly different ($p\geq0.05$) from seeds irradiated with 1,3 and 4 Gy. The highest seedling length value was observed in seeds treated with 2 Gy (Table 4.4). The lowest seedling length value was observed in non-irradiated seeds. There was a significant ($p=0.03$) and positively correlated non-linear relationship ($R^2 = 0.89$) between seedling length and radiation dose (Figure 4.2).

Seedling vigour index was significantly higher ($p<0.05$) in irradiated seeds than control (Table 4.4). There was a significant difference ($p<0.05$) between seeds treated with 2 and that of the control and 5 Gy dose. These two were also significantly different from each other. However, the 2 Gy dose was not significantly different ($p\geq0.05$) from seeds irradiated with 1, 3 and 4 Gy. The highest vigour index value was observed in seeds treated with 2 Gy (Table 4.4). The lowest value was observed in non-irradiated seeds. There was a significant ($p=0.045$) and positively correlated non-linear relationship ($R^2 = 0.87$) between vigour index and radiation dose (Figure 4.3).

Table 4.4: Influence of radiation dose on vigour and seedling parameters

Dose (Gy)	Root length (cm)	Shoot length(cm)	Seedling length(cm)	Vigour Index
0	14.03	5.27	17.55	1473
1	13.94	5.97	19.90	1736
2	14.64	6.27	20.91	1851
3	14.08	5.99	20.29	1762
4	14.12	6.12	20.40	1794
5	13.75	5.95	19.58	1689
Mean	14.09	5.93	19.88	1718
LSD (0.05)	0.77	0.34	1.288	123
S.e.d	0.39	0.17	0.65	62.60
CV (%)	13.80	14.20	16.20	17.80

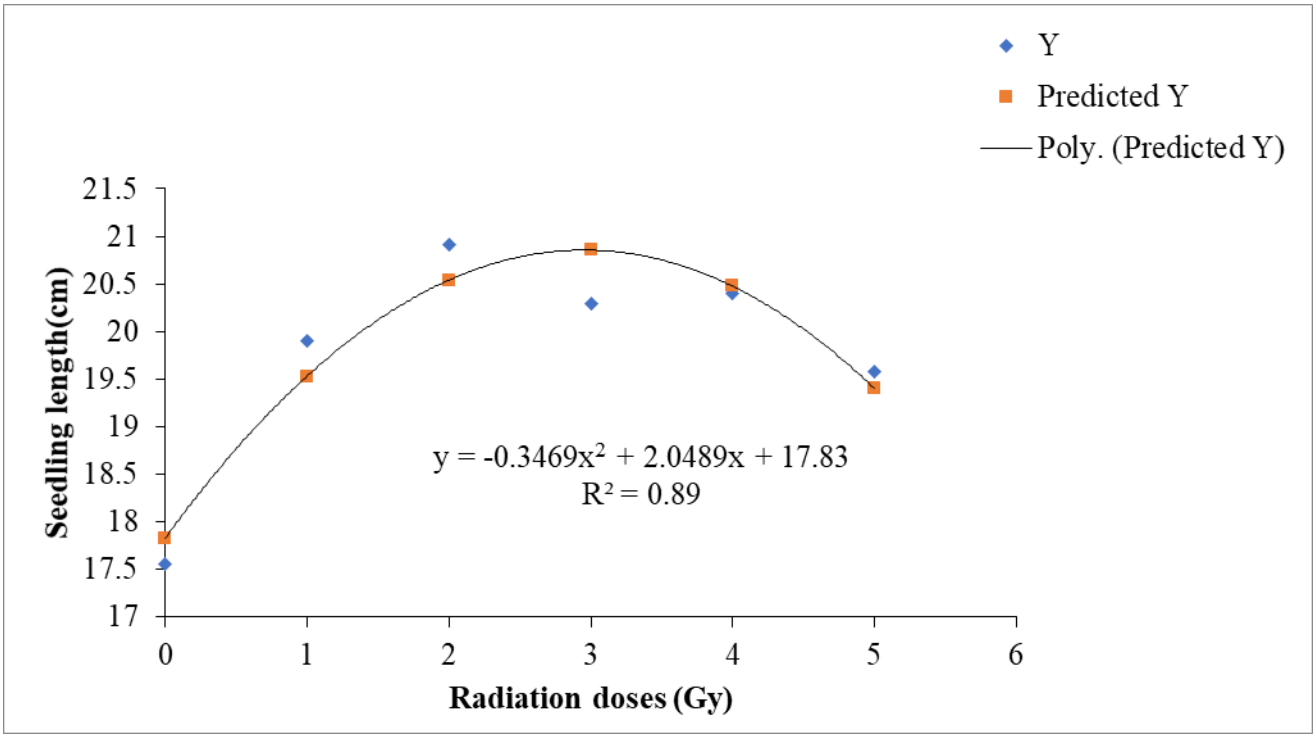

Fig. 4.2: Relationship between radiation doses and seedling length

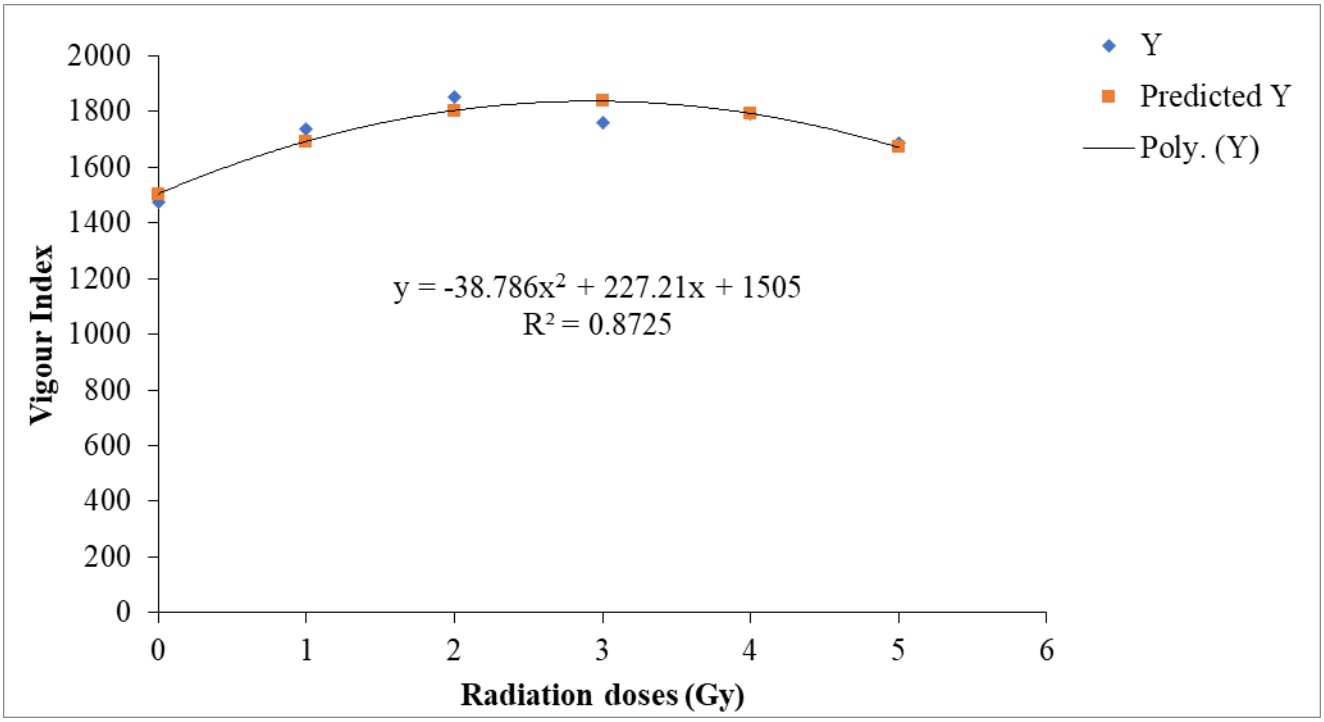

Fig. 4.3: Relationship between radiation doses and vigour index

4.2.2 Effect of storage periods on seed quality parameters studied

4.2.2.1 Effect of storage period on germination parameters

Germination percentages were significantly different ($p<0.05$) among the storage periods under investigation (Table 4.5). The highest germination percentage value observed at week 0 was significantly higher ($p<0.05$) than the subsequent storage periods (Table 4.5). Germination percentages at weeks 3 and 6 were not significantly different ($p\geq0.05$) from each other. However, these were significantly different($p<0.05$) from week 0 and other storage periods. The lowest values observed at 9^{th},15^{th}, 18^{th} and 21^{st} weeks were significantly different ($p<0.05$) from other storage periods. There was a relative decline in germination percentages as storage period progressed. There was a significant ($p=0.002$) and positively correlated linear relationship ($R^2 = 0.81$) between germination percentage and storage period (Figure 4.4).

Storage period had a significant effect ($p<0.05$) on peak value of germination as storage period progressed (Table 4.5). The highest value was observed at week 0 and was significantly different ($p<0.05$) from values of subsequent storage periods. Peak values at 3 and 6 weeks were not significantly different ($p\geq0.05$) from each other. However, these were significantly different($p<0.05$) from other periods. Peak value of germination was also similar for week 9 and 12, as they were not significantly different ($p\geq0.05$) from each other. However, these were significantly different ($p<0.05$) from other storage periods (Table 4.5). The lowest values were observed at 21 weeks after irradiation and were significantly different from the other periods as well.

Storage period had a significant effect ($p<0.05$) on speed of germination as storage period progressed (Table 4.5). The highest value was observed at week 0 and was significantly different

($p<0.05$) from the values from subsequent storage periods. Speed of germination values at 3, 6 and 9 weeks were not significantly different ($p\geq0.05$) from each other. Though, these values were significantly different ($p<0.05$) from those of other periods (Table 4.5). At 12 weeks, speed of germination value was significantly different ($p<0.05$) from other storage periods (Table 4.5). Speed of germination was also not significantly different ($p\geq0.05$) at 15 and 18th week of storage (Table 4.5). Though, the values for these periods were significantly different ($p<0.05$) from other storage periods. The lowest values were observed at 21 weeks during storage and was significantly different from the other periods of storage (Table 4.5).

Table 4.5: Influence of storage period on Percentage, Peak value and Speed of germination

Period(weeks)	Germination percentage	Peak of germination	Speed of germination
0	92(1.296)	19.214	8.625
3	89(1.239)	18.708	8.328
6	89(1.245)	18.533	8.156
9	83(1.151)	17.775	7.633
12	86(1.192)	17.592	7.581
15	83(1.154)	17.256	6.922
18	83(1.145)	16.653	6.239
21	82(1.141)	16.642	6.197
Mean	86(1.195)	17.800	7.460
LSD (0.05)	0.035	0.274	0.203
S.e.d	0.018	0.140	0.100
CV (%)	6.3	3.3	5.8

Figures in parentheses indicate arcsine transformed values

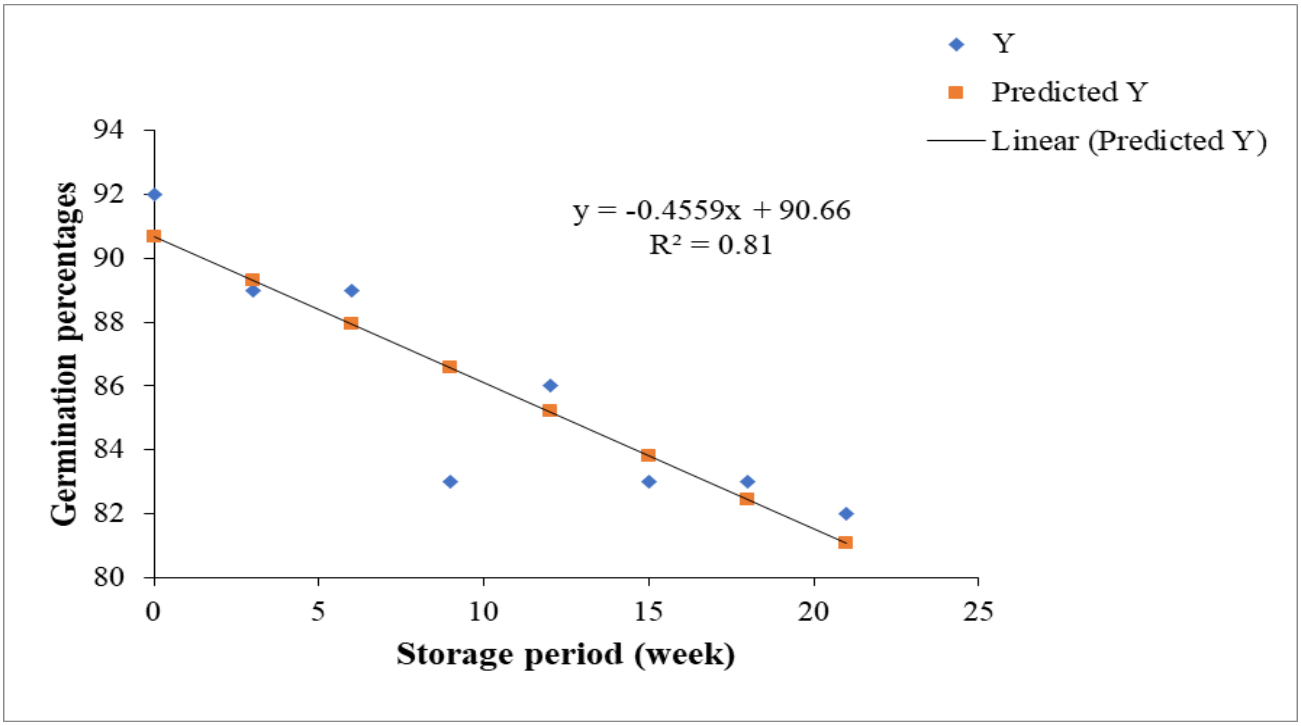

Fig. 4.4: Relationship between storage period and germination percentage

4.2.2.2 Effect of storage period on seedling length, vigour, moisture and seed health

There was a significant effect ($p<0.05$) of storage period on seedling length (Table 4.6). The highest seedling length values were observed at weeks 6 and 9 which were not significantly different ($p\geq0.05$) from each other. However, these were significantly different ($p<0.05$) from the other storage periods (Table 4.6). Seedling length observed at week 12 was not significantly different ($p<0.05$) from values obtained at week 0 and 15. However, they were significantly different ($p<0.05$) from the other storage periods (Table 4.6). At week 15, the value observed was not significantly different ($p\geq0.05$) from those of week 3 and 18. Though, it differed significantly ($p<0.05$) from the other periods (Table 4.6). The lowest seedling length value was observed at the end of the storage period (i.e. week 21), and it was significantly different ($p<0.05$) from the other

storage periods (Table 4.6). There was a non-significant ($p=0.059$) and positively correlated non-linear relationship ($R^2 = 0.68$) between storage period and seedling length (Figure 4.5).

Storage period had a significant effect ($p<0.05$) on vigour index (Table 4.6). The highest value observed at week 6 was significantly different ($p<0.05$) from values recorded in other storage periods (Table 4.6). Vigour index values observed at week 0 and 9 were not significantly different ($p\geq0.05$) from each other. However, these values were significantly different from values from other storage periods (Table 4.6). There was a significant difference in vigour index values recorded at week 12 and 18. However, these values were not significantly different ($p\geq0.05$) from vigour indexes observed at week 3 and 15 (Table 4.6). The lowest value for vigour index was observed at week 21 and it was significantly different ($p<0.05$) from the values from other storage periods (Table 4.6). There was a decrease in vigour index at 3 weeks but it increases at 6 weeks and subsequently start decreasing till the 21st week after irradiation (Table 4.6).

Moisture content was significantly higher ($p<0.05$) at the 18th and 21st week than at other storage period (Table 4.6). The lowest values observed at the 3rd, 6th, 9th, 12th and 15th weeks were significantly different ($p<0.05$) from week 0 and other periods of storage (Table 4.6). There was a decline in moisture content from week 0 up to week 9. Then it rose and fell again from week 12 to 15 and continued falling till the end of the storage period (Table 4.6).

Pathogen infectivity was significantly lower ($p<0.05$) at 0 week than at the end of the storage period (Table 4.6). Pathogen infectivity values were not significantly different ($p\geq0.05$) between weeks 0 and 3. However, these values were significantly different ($p<0.05$) from the values

recorded for other storage periods (Table 4.6). At week 12 and 18, infectivity values were not significantly different from each other. However, these values were significantly different ($p<0.05$) from other storage periods except week 9, 12 and 15 (Table 4.6). There was no significant difference ($p\geq0.05$) in values recorded at weeks 6 and 9 (Table 4.6). Infectivity value was lowest at the start of the storage period and then progressed to the maximum at the end of the storage period (Table 4.6). There was a highly significant ($p=0.000039$) and positively correlated linear relationship ($R^2 = 0.95$) between storage period and pathogen infectivity (Figure 4.6).

Fungal species such as *Aspergillus flavus, A. niger, A. versicolor; A. ochraceous* were identified during the tests and were more predominant than other fungal species. Other species such as *Botrydiplodia theobromae, Rhizopus spp and Penicillium spp* were also identified, although they were found to occur less than *Aspergillus spp.*

Table 4.6: Influence of storage period on seedling parameters, vigour, moisture and seed health

Storage Period (weeks)	Seedling length (cm)	Vigour Index	Moisture content (%)	Pathogen infectivity (%)
0	20.64	1901	6.71(1.61)	22.20
3	18.09	1606	6.62(1.60)	29.20
6	24.17	2153	6.59(1.59)	47.20
9	23.21	1930	6.48(1.59)	54.20
12	20.00	1725	6.63(1.60)	68.10
15	19.12	1601	6.54(1.59)	69.40
18	17.67	1563	6.94(1.62)	77.80
21	15.29	1258	6.93(1.62)	79.90
Mean	19.77	1717	6.68(1.607)	56.00
LSD (0.05)	1.49	142.5	0.0052	15.72
S.e.d	0.75	72.2	0.0026	7.97
CV (%)	16.20	17.8	0.7	60.40

Figures in parentheses indicate root transformed values

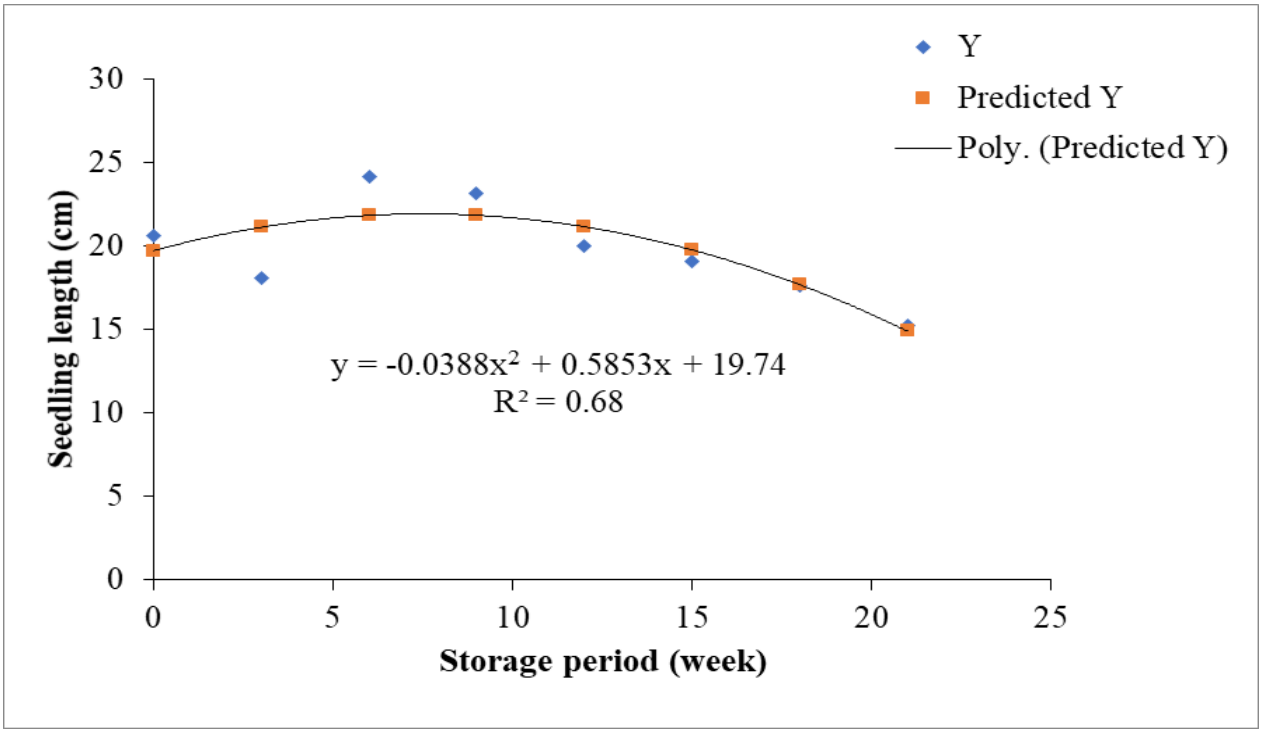

Fig. 4.5: Relationship between storage period and seedling length

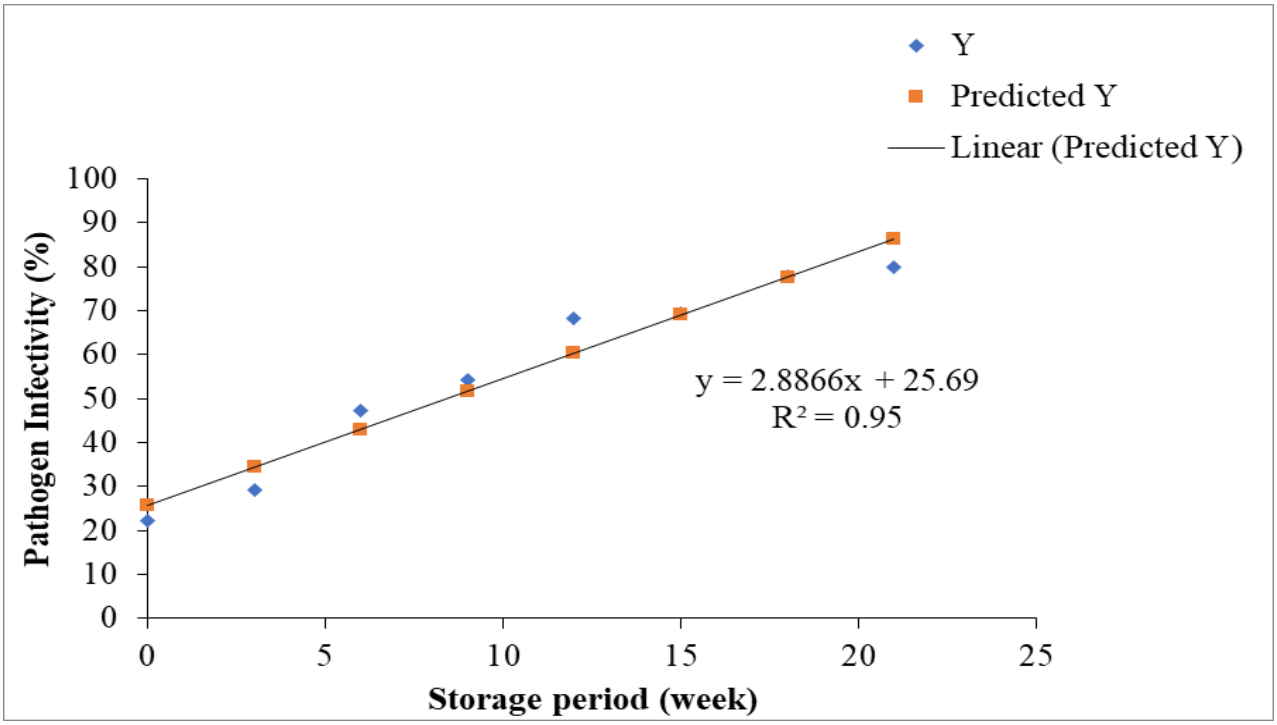

Fig. 4.6: Relationship between storage period and pathogen Infectivity

4.2.3 Effect of seed forms (shelled and unshelled) on parameters studied

Germination percentages, speed of germination, peak of germination, seedling length and vigour were all significantly ($p<0.05$) higher in unshelled than shelled groundnut forms (Table 4.7). Moisture content was significantly lower ($p<0.05$) in unshelled seeds than shelled groundnut seeds (Table 4.7).

Table 4.7: Influence of groundnut forms on germination parameters, Seedling length, vigour and moisture content

Forms	Germination percentage (%)	Peak of germination	Speed of germination	Seedling length (cm)	Vigour Index	Moisture content (%)
Shelled	85(1.18)	17.50	7.18	19.38	1650	6.70(1.61)
Unshelled	88(1.23)	18.34	7.98	20.16	1785	6.60(1.60)
Mean	87(1.21)	17.92	7.58	19.77	1718	6.65(1.61)
LSD (0.05)	0.018	0.14	0.10	0.74	71.30	0.003
S.e.d	0.009	0.069	0.05	0.38	36.1	0.0013
CV%	6.30	3.30	5.80	16.20	17.80	0.70

Figures in parentheses indicate arcsine and root transformed values

4.2.4 Interaction effect of irradiation dose by seed forms on root and shoot length and speed of germination.

4.2.4.1 Effect of irradiation doses by seed forms on root and shoot length on seedlings

Irradiation doses by forms of groundnut had a significant ($p<0.05$) effect on root length (Table 4.8). Root lengths were significantly higher ($p<0.05$) in irradiated seeds than in the controls of

both forms (Table 4.8). The lowest root length value was observed in non-irradiated shelled seeds and it was significantly different ($p<0.05$) from other treatments for both forms (Table 4.8). The highest value was observed in unshelled seeds treated with 2 Gy and it was significantly different ($p<0.05$) from the controls for both forms (Table 4.8). However, this value was not significantly different ($p\geq0.05$) from seeds treated with 2, 3 and 4 Gy for shelled and 1,4 and 5 Gy for unshelled forms. The root length value of non-irradiated unshelled seeds was not significantly different ($p\geq0.05$) from seeds treated with 1,2 and 5 Gy for shelled and 1,3, 4 and 5 Gy in unshelled forms.

Irradiation doses by seed forms had a significant ($p<0.05$) effect on shoot length (Table 4.8). Shoot lengths were significantly higher ($p<0.05$) in irradiated seeds than in controls of both forms (Table 4.8). The lowest shoot length value was observed in non-irradiated shelled seeds and it was significantly different ($p<0.05$) from other treatments of both forms (Table 4.8). The highest value was observed in unshelled seeds treated with 2 Gy and it was significantly different ($p<0.05$) from the controls of both forms (Table 4.8). However, it was not significantly different ($p\geq0.05$) from seeds treated with 2, 3 ,4 and 5 Gy for shelled and 1 and 4 Gy for unshelled. The shoot length value of non-irradiated unshelled seeds was not significantly different ($p\geq0.05$) from seeds treated with 1,2,3 and 5 Gy for shelled seeds and 1,3, 4 and 5 Gy in unshelled (Table 4.8).

Table 4.8: Influence of doses and forms on root and shoot length of groundnut seedlings

	Root length (cm)		Shoot length (cm)	
	Forms			
Doses (Gy)	Shelled	Unshelled	Shelled	Unshelled
0	11.38	13.20	4.88	5.66
1	13.82	14.05	5.92	6.02
2	14.22	15.06	6.09	6.46
3	14.45	13.70	6.08	5.91
4	14.48	14.07	6.21	6.03
5	13.97	14.09	5.99	5.90
Mean	13.72	14.03	5.86	5.99
LSD (0.05)	1.09		0.48	
S.e.d	0.55		0.24	
CV (%)	13.80		14.20	

4.2.4.2 Effect of irradiation doses by seed forms on speed of germination

Speed of germination was significantly higher ($p<0.05$) in the irradiated seeds than in control (Table 4.9) as influenced by the interaction between irradiation doses and forms of groundnut. The highest value was observed in unshelled seeds treated with 3 Gy and it was significantly different ($p<0.05$) from all other treatments except unshelled seeds treated with 2 and 4 Gy (Table 4.9). In shelled seeds, the highest speed of germination value was observed in seeds treated with 2 Gy.

This high value was significantly different ($p<0.05$) from the control and from seeds treated with 3 Gy. The lowest value for both forms was recorded in non-irradiated (control) shelled seeds. Though, the control was not significantly different ($p\geq0.05$) from shelled seeds treated with 3 and 5 Gy (Table 4.9).

Table 4.9: Influence of irradiation doses by seed form on speed of germination of groundnut seeds

	Speed of germination(No of seedlings germinating/day) Forms	
Doses (Gy)	Shelled	Unshelled
0	6.98	7.67
1	7.26	7.93
2	7.34	8.08
3	7.03	8.21
4	7.30	8.19
5	7.15	7.82
Mean	7.17	7.98
LSD (0.05)	0.25	
S.e.d	0.13	
CV (%)	5.80	

4.2.5 Effect of storage period by seed forms on parameters studied

4.2.5.1 Effect of storage period by seed forms on speed and peak of germination

Speed of germination was significantly higher ($p<0.05$) at 0 week in unshelled seeds than at 21st week in shelled seeds (Table 4.10). The highest values observed for week 0 in both shelled and unshelled groundnut forms were significantly different ($p<0.05$) from all treatments except in unshelled seeds at 3rd and 6th weeks of storage (Table 4.10). The lowest values were recorded for both forms at the 21st week (Table 4.10). The lowest value observed in shelled seeds was significantly different ($p<0.05$) from every other treatment except in shelled seeds at week 18. The lowest speed of germination value in unshelled seed was significantly different ($p<0.05$) from other unshelled values (Table 4.10). However, it was not significantly different ($p\geq0.05$) from shelled seeds at 15 and 18 weeks of storage. Speed of germination values at 3 and 6 weeks for shelled seeds and 9 and 12 weeks for unshelled were not significantly different ($p\geq0.05$) from each other. In unshelled seeds at 15th week, speed of germination value was not significantly different ($p\geq0.05$) from those of week 6 and 9 in shelled seeds but significantly different from every other treatment (Table 4.10). There was a decline in this parameter as the storage period progresses.

Peak value of germination was significantly higher ($p<0.05$) at 0 week in shelled and unshelled seeds than at 21st week in both seed forms (Table 4.10). The highest values observed for week 0 in both shelled and unshelled groundnut forms were significantly different ($p<0.05$) from all treatments except in unshelled seeds at 3rd and 6th weeks of storage (Table 4.10). The lowest values were recorded for both forms at the 21st week of storage (Table 4.10). The lowest value observed in shelled seeds was significantly different ($p<0.05$) from every other treatment. The lowest peak value of germination in unshelled seed was significantly different ($p<0.05$) from other unshelled

values (Table 4.10). However, it was not significantly different ($p \geq 0.05$) from shelled seeds at 12 weeks of storage. Peak value of germination at 3 weeks for shelled seeds and 3 and 6 weeks for unshelled were not significantly different ($p \geq 0.05$) from each other. In shelled seeds at 15th and 18th week, peak value of germination was not significantly different ($p < 0.05$) from each other. However, it was significantly different ($p < 0.05$) from every other treatment (Table 4.10). There was no significant difference ($p \geq 0.05$) in peak value of germination for shelled seeds at 6 weeks and unshelled seeds at 9th and12th week of storage. There was a decline in the peak of germination as the storage period progressed (Table 4.10).

Table 4.10: Influence of storage period by seed forms on speed and peak value of germination

	Speed of germination		Peak value of germination	
	Forms			
Period (weeks)	Shelled	Unshelled	Shelled	Unshelled
0	8.530	8.720	19.130	19.300
3	8.190	8.460	18.540	18.870
6	7.680	8.630	18.140	18.990
9	7.330	7.940	17.390	18.160
12	7.190	7.970	17.210	17.970
15	6.340	7.500	16.770	17.740
18	6.160	7.020	16.520	17.480
21	5.970	6.420	16.020	17.270
Mean	7.170	7.980	17.500	18.340
LSD (0.05)	0.290		0.390	
S.e.d	0.150		0.190	
CV (%)	5.800		3.300	

4.2.5.2 Effect of storage period by seed forms on Germination percentages and Moisture content

Germination percentages were significantly higher ($p<0.05$) at week 0 than at 21st week of storage irrespective of the seed forms (Table 4.11). The highest value was observed at the start of the storage period in both groundnut forms and were significantly different from other storage periods. Germination percentages in shelled seeds at 3 and 6 weeks of storage were significantly different from those of 9, 15 and 21 weeks. Also, germination percentages were significantly different at 0,3, 6 and 18 weeks from those of 9,12, 15 and 21 weeks in unshelled seeds. There was an increase in germination percentages at the 18th week of storage. However, this increase was not significantly different ($p\geq0.05$) from the values recorded for 3rd, 6th and 12th week but it was significantly different ($p<0.05$) compare to other storage periods (Table 4.11).

Moisture contents of the seeds were significantly higher ($p<0.05$) at the 21st week of storage in shelled seeds than at 0 week in unshelled seeds (Table 4.11). The lowest moisture content was observed at the 9th week of storage in unshelled seeds. The highest moisture content was observed at the 21st week of storage period in shelled seeds. Moisture contents at 0, 6, 9, 12 and 15 weeks of storage for shelled seeds and 3, 6, 12 weeks for unshelled seeds were not significantly different ($p\geq0.05$) from each other (Table 4.11).

Table 4.11: Influence of storage periods and seed forms on Germination percentage and Moisture content

	Germination percentage (%)		Moisture content (%)	
Period(weeks)	Shelled	Unshelled	Shelled	Unshelled
0	92(1.287)	93(1.306)	6.56(1.605)	6.86(1.618)
3	87(1.212)	91(1.267)	6.7(1.609)	6.55(1.599)
6	86(1.189)	92(1.301)	6.69(1.604)	6.48(1.596)
9	82(1.124)	85(1.177)	6.56(1.601)	6.40(1.591)
12	86(1.185)	87(1.199)	6.61(1.603)	6.66(1.605)
15	81(1.117)	86(1.190)	6.6(1.599)	6.47(1.595)
18	86(1.191)	91(1.269)	7.11(1.634)	6.77(1.610)
21	82(1.139)	83(1.142)	7.03(1.628)	6.83(1.615)
Mean	85(1.181)	86(1.232)	6.73(1.610)	6.63(1.604)
LSD (0.05)	0.049		0.007	
S.e.d	0.025		0.004	
CV%	6.3		0.7	

Figures in parentheses indicate arcsine and root transformed values

4.2.6 Effect of storage period by doses on shoot length(cm) of seedlings

There was significant difference ($p< 0.05$) in shoot length of seedlings among the treatments as influenced by radiation doses and storage periods (Table 4.12). The highest shoot length was observed at 2 Gy by 6^{th} week of storage and the lowest observed in the control (0 Gy) the 21^{st} week of storage (Table 4.12). At week 21 however there were no significant differences ($p>0.05$) in the seedling length across the doses

Table 4.12: Influence of storage periods and radiation doses on shoot length (cm) of seedlings

Doses (Gy)	Period (weeks)							
	0	3	6	9	12	15	18	21
0	5.75	5.57	6.27	5.80	4.90	4.73	4.81	4.29
1	5.59	5.39	7.71	6.66	6.09	5.98	5.54	4.81
2	6.71	5.41	8.28	7.61	6.61	5.69	5.32	4.59
3	6.68	4.79	6.93	7.03	6.23	6.31	5.34	4.68
4	6.03	5.51	7.59	7.34	6.25	6.19	5.49	4.57
5	6.40	5.75	6.19	7.36	5.93	6.04	5.31	4.59
Mean	6.19	5.40	7.16	6.96	6.00	5.82	5.3	4.59
LSD(0.05)					0.9585			
S.e.d					0.4859			
CV%					14.2			

4.2.7 Interaction effect of dose by storage period, by seed forms on root length (cm) of seedlings

There was a significant difference($p<0.05$) in root length of seedlings as influenced by the interactions among doses, forms and period of storage (Table 4.13). The highest root length was observed at 6^{th} week of storage in unshelled seeds treated with 2 Gy of irradiation was significantly different from those of shelled seeds treated with 1 Gy at 15^{th} week of storage.

Table 4.13: Influence of Irradiation dose, storage periods and groundnut forms on root length (cm) of groundnut seedlings

Dose (Gy)	Forms	Period (weeks) 0	3	6	9	12	15	18	21	Mean forms	Mean doses
0	S*	11.81	12.86	12.44	12.53	11.01	9.38	10.90	10.08	11.38	24.58
	US	15.03	13.14	16.82	14.54	11.85	12.67	11.55	9.96	13.20	
1	S	13.39	15.05	18.64	15.17	15.14	9.28	11.90	11.99	13.82	27.87
	US	12.72	12.27	17.31	15.91	13.30	16.5	13.95	10.43	14.05	
2	S	15.84	12.04	19.18	16.64	14.47	12.67	11.74	11.15	14.22	29.29
	US	15.45	13.21	19.46	18.85	16.38	13.86	13.07	10.24	15.07	
3	S	16.03	12.98	16.36	15.87	15.35	15.52	12.48	11.04	14.45	28.15
	US	15.12	10.78	15.96	16.92	13.70	13.91	12.41	10.80	13.70	
4	S	14.35	11.25	19.37	17.83	14.96	14.89	12.79	10.45	14.49	28.56
	US	13.77	14.47	16.03	16.4	14.19	14.02	12.83	10.87	14.07	
5	S	13.98	15.23	16.24	16.24	13.88	14.67	11.15	10.38	13.97	28.06
	US	15.89	11.62	15.19	18.08	13.77	13.51	13.63	11.01	14.09	
Mean period		14.45	12.91	16.92	16.25	14.0	13.41	12.37	10.70		
LSD (0.05)						3.074					
CV %						13.8					

****S=Shelled, US=Unshelled***

4.3 Field evaluation

Days to germination of groundnut seeds planted in the field for assessment was similar for both seed forms and doses (Table 4.14). However, field emergence percentages for the doses and groundnut forms were quite different. The non-irradiated controls of both forms had the same number of plants emerging (Table 4.14). 100 % emergence was observed in 3 and 5 Gy for shelled

seeds and 2, 4 and 5 Gy for unshelled. The other doses and form were almost similar in their emergence percentage with those that had 100% emergence (Table 4.14). Days to 50% flowering were between 26 and 27 days (Table 4.14).

There were no differences in the morphological evaluation of the irradiated seeds (Plate 1-12, in Appendix III). The parameters (leaf shape and colour, petiole colour) assessed were quite the same with no differences in their colour or shape.

Table 4.14: Emergence percentages and days to emergence of irradiated forms of groundnut seeds

	Days to germination		Field emergence%		Days to 50% flowering	
Doses (Gy)	Shelled	Unshelled	Shelled	Unshelled	Shelled	Unshelled
0	4	4	96	96	26	26
1	4	4	96	93	26	26
2	4	4	96	100	27	26
3	4	4	100	96	26	27
4	4	4	96	100	26	26
5	4	4	96	100	26	26

CHAPTER FIVE

5.0 DISCUSSION

5.1 Seed quality analysis immediately after irradiation

Moisture content was significantly higher in unshelled seeds (6.86%) than shelled seeds (6.56%) immediately after exposure (Table 4.1). This observation is similar to findings of Rao *et al.* (2002), who reported lower moisture content of 5.6 for shelled and 5.9% for unshelled seeds in two groundnut varieties prior to storage. The lower moisture content observed in shelled groundnut seeds could be as a result of loss of moisture through direct exposure of kernels to environmental factors prevalent at the time of the year.

Seed forms and irradiation doses had significant effects on speed of germination (Table 4.2). Shelled seeds treated with doses of 2 and 4 Gy and unshelled seeds of 3 and 4 Gy gave the highest speed of germination and were significantly different from the lowest group including control, 2 Gy in unshelled seeds and 3 and 5 Gy in shelled seeds. The above observations in the current study agree favourably with the research findings of Singh & Singh, (2005), who reported that the speed of germination of rice was stimulated by low irradiation doses. This was attributed to a phenomenon termed "*Hormesis"* according to Luckey, (1980) and Korystov & Narimanov, (1997) who both described it as an incitement of beneficial effects by low radiation doses on plants.

5.2 Seed quality analysis during storage period

5.2.1 Effect of Irradiation doses on physiological and seedling parameters studied

Germination parameters serve as indices of performance of a seed lot under field conditions. Germination percentages were significantly higher during storage in irradiated seeds than in

controls (Table- 4.3). There was an increase of 5.83% in germinability at 4 Gy compared with the control (0 Gy). The highest percentage values were observed in seeds treated with 2 and 4 Gy of radiation and were significantly different from seeds treated with 0 and 5 Gy. The remaining doses (i.e. 1 and 3 Gy) were not statistically different from 2, 4 and 5 Gy for germination percentages. The above observations were similar to the findings of Ahuja *et al.* (2014), who reported increase of 10-25% in germination percentages at lower doses close to 5 Gy in irradiated groundnut seeds. Hussein *et al.* (2017) also, reported a 34% and 26% increase in germination percentage of sunflower seeds at 5 and 40 Gy respectively, and subsequent decrease as the doses increases between the two doses. The slight decrease in germination at 5 Gy when compared to the other doses in this study may be attributed to the detrimental effect of an increase in radiation doses. Ahuja *et al*. (2014) reported a decrease of 15% in germination percentages as doses approached 5 Gy in groundnut seeds. The above observations were backed by a non-significant($p \geq 0.05$) positive non-linear correlation co-efficient, $R^2=0.84$ (Figure 4.1). The above correlation co-efficient implies that germination percentage increased up to a certain dose (2 Gy), then it declined as the doses further increased. Inhibitory impacts of high gamma doses on germination has been proposed to include reasons such as alterations in processes involving cell and tissue structures, severance and dissolution of seed membranes and formation of free radicals leading to metabolic abnormalities in germinating seeds, these reasons are proportional to dose concentration (Lokesha *et al.* 1994).

Parameters such as speed and peak value of germination evaluate the efficiency of a seed lot in terms of time taken to complete the total process of germination. Peak of germination and Speed of germination were significantly higher in irradiated seeds than in non-irradiated seeds (Table 4.3). The highest values for both peak and speed of germination observed in seeds treated with 2

and 4 Gy of gamma rays were significantly different from those of 0 and 5 Gy. The remaining doses (i.e. 1 and 3Gy) were not statistically different from 2, 4 and 5 Gy for peak and speed of germination. These observations were similar to the findings of Wiendl *et al.*(2013), who irradiated tomato seeds with low radiation doses (25- 15 Gy with a 25 Gy interval and 150-200 Gy with 50 Gy interval) and reported a stimulatory effects on germination parameters for the doses closer to the control (0 Gy) and a gradual decrease in these parameters as doses increases.

The stimulatory and inhibitory effect of low and high doses respectively had been explained by various authors in different crops throughout the years (Thapa, 1999; Jan *et al.* 2012). The invigorating effects of low radiation doses on physiological parameters could be ascribed to its' impacts on absorption of oxygen and activities of dehydrogenases through the provision of energy to the developing embryo and the entire metabolic process. The authors attributed the inhibiting effect of high radiation doses to significant loss of electrolytes as a result of increased membrane permeability (Krishnaswamy & Seshu, 1989).

Gamma irradiation has also been reported to bring about oxidative trauma leading to formation of reactive oxygen species, which interact with biomolecules including amino acids, lipids, RNA and DNA resulting in disruptions of cell metabolic processes (Salter & Hewitt, 1992), though these are dependent on the intensity of exposure (Lokesha *et al.* 1994).

Root length was significantly lower in seeds irradiated with 5 Gy than seed treated with 2 Gy, though both treatments were not significantly different from the other treatments (Table 4.4). There was a 4.4% increase at 2 Gy and 2% decrease at 5 Gy when compared with the non-irradiated

control. There was a slight decrease (0.6%) of root length at 1 Gy. It however increases to the maximum at 2 Gy and then decline with further irradiation. These results were similar to findings of Ilyas & Naz (2014), who reported a decrease of 20% compared to non-irradiated sample in the root lengths of turmeric (F1-F11) at 10 Gy and a subsequent increase till it got to the maximum (30%) at 70 Gy and started decreasing from 70 Gy.

Shoot length was significantly lower in control than seeds irradiated. There was no significant difference among the irradiated seeds. There were 13.4, 19.2, 14, 16, and 12.9% increase in shoot lengths at 1, 2, 3, 4 and 5 Gy, respectively. These observations were similar to findings of Marcu *et al.* (2013), who reported that doses 2-30 Gy had positive impact on lengths of shoot of lettuce, as it increased by 34% for seeds treated with 2,5 and 15 Gy, and 57% for those irradiated with 30 Gy compared to samples of non-irradiated seeds.

Seedling vigour index and seedling length were significantly higher in irradiated seeds than control. There was also significant difference in both parameters between seeds treated with 2 and 5 Gy doses but these two doses were statistically similar to the mean of remaining doses. There were 13, 19, 15.6, 16.2 and 11.5% increases in seedling lengths and 17.8, 26, 19.6, 21.8 and 14.66% increases in vigour index at 1, 2, 3, 4 and 5 Gy, respectively. These observations were similar to findings of Yadav *et al.* (2015), who reported an improvement in seedling length and vigour of maize at lower doses(<0.2kGy) of gamma rays and the decrease of these characters beyond the stated dose. The above observations were backed by a significant ($p<0.05$) positive non-linear correlation co-efficient, $R^2=0.89$ for seedling length (Figure 4.2) and $R^2=0.87$ for vigour index (Figure 4.3).

The stimulatory effect of low dose gamma rays on growth of seedlings may be ascribed to its' action in inducing growth stimulation by altering the flagging of interacting networks of hormones in plant cells or by raising the reductive capacity of cells to surmount environmental stresses such as variation of light intensity and temperature during seedling growth (Wi *et al*. 2007).

A rise and fall pattern were observed in the germination and seedling parameters studied in the present research work as influenced by increasing radiation doses. This phenomenon was in accordance with earlier works by Jang *et al*. (2005) who reported similar rise and fall in germination and seedlings parameters of irradiated radish seeds stored for 12 months.

5.2.2 Effect of storage period on parameters studied

Germination percentages, speed of germination and peak value of germination were significantly different among the storage periods under investigation (Table 4.5). Germination percentages help in providing information about the viability of a seed lot. Peak value of germination is the point of the distribution in a germination process in which the highest number of seeds germinating occurred. Speed of germination is an indirect but accurate index used in evaluating viability and vigour. Estimates of these parameters could be reasonably applied with some degree of accuracy to seeds undergoing natural ageing to forecast the storage potential of seeds (Vidya Kumari, 2013). Speed and peak value of germination are based on germination test and are thus, influenced by germination percentages to some extent.

For these germination parameters, there was a relative decline in their values as the storage period progressed, though germination percentage increased at the 12^{th} week but declined after this

period. The progressive reduction in germination parameters as the storage period increases has been reported to be as a result of a phenomenon known as ageing (Ram & Wiesner, 1988). Ageing in seeds leads to loss of germination and vigour during storage due to alterations in physiological makeup of seeds, moisture content variations and increment in leaching of electrolytes (Kalpana & Rao, 1991). These observations in the present study were in agreement with findings of Parmil & Khatra (1984) and Vasudevan *et al.* (2014), who reported that germination parameters decreases with increase in ageing of groundnut seeds. The above observations were backed by a highly significant ($p<0.05$) positive linear correlation co-efficient, $R^2=0.80$ (Figure 4.4). This implies that as the storage period advances, the lower the germination percentage, hence reduction in seed quality of groundnut seeds. The increase at the 12^{th} week of storage could be as a result of recovery in the inbuilt repair mechanisms of the seeds to the stress caused by effect of irradiation.

There was significant effect of storage period on vigour and seedling length (Table 4.6). The means of seedling lengths and vigour decreased after the third week of storage and then increased at the 6^{th} week of storage and subsequently decreases till the end of the storage period (Table 4.6). The decreasing trends in the means of these parameters observed in the present study were in conformity with the findings of Vasudevan *et al.* (2014) who reported progressive reductions in seedling length and seed vigour as storage period advances irrespective of the treatments in their study, and they attributed this to deterioration due to ageing. The observations from the results of the present study were also similar to those of Gao-Ping *et al.* (1996), who reported a fast decline in vigour for soybean seeds stored at room temperature. Lin (1988) also reported decline in vigour of maize seeds with increasing length of storage. The author further reported that loss of vigour was more rapid than loss of viability when seed are stored. The author attributed the loss of vigour

during storage to seed membrane deterioration due to high moisture content and leakage of electrolytes. The above observations on seedling length were backed by a slightly high non-significant ($p \geq 0.05$) positive non-linear correlation co-efficient, $R^2=0.68$ (Figure 4.5). This implies that as the storage period advances, there was an increase in seedling length up to a point, then it declines after this.

Moisture content was significantly higher at the 18th and 21st week than at other storage period (Table 4.6). A reducing trend was observed from the 3rd, 6th and 9th week with an increase at 12th and further decrease at the 15th week. The fluctuating pattern observed in moisture content of the seeds during storage could be attributed to the changes in relative humidity of the environment due to changes in seasonal pattern from dry harmattan and then rainy during the period of storage. These observations were similar to the findings of Narayanaswamy (1993), who reported that groundnut seeds stored for 16 months were prone to variations in moisture content in the two groundnut cultivars used in their study.

Pathogen infectivity was significantly lower at 0 week than at the end of the storage period (Table-4.6). Infectivity value was lowest (22%) at the start of the storage period and then progressed till it got to the maximum (79.9%) at the end of the storage period. This phenomenon was similar to findings of Vasudevan *et al.* (2014), who reported an increase in seed infection from 0 to 17.8 % of groundnut seeds stored for ten (10) months. The above observations were backed by a highly significant ($p<0.05$) positive linear correlation co-efficient, $R^2=0.95$ (Figure 4.6). This showed that as the storage period advances, the higher the incidence of pathogen infectivity, hence reduction in seed quality of groundnut seeds. The increase in seed pathogen infectivity during storage in the

present study could be as a result of latent infestation or infection brought from the field or in the process of handling of the seeds which were then brought to fore as a result of increase in relative humidity of the environment or fluctuation in seed moisture content as was observed in the present study.

5.2.3 Effect of groundnut forms on physiological parameters studied

Percentage, speed and peak value of germination, seedling length and vigour were all significantly higher in unshelled than shelled groundnut forms during the storage period (Table 4.7). There was an increase of 4.34, 4.02 and 8.2 % for germination percentage, seedling length and vigour index in unshelled from shelled seeds (Table 4.7). These observations were similar to the findings of Sujatha *et al.* (2018), who reported that seeds stored as pods (unshelled) recorded significantly higher seed germination and seedling vigour Index (50.88% & 842) over kernel (44.05% & 770) stored under ambient condition for twelve months.

Moisture content was significantly lower in unshelled seeds than shelled groundnut seeds (Table 4.7). The high moisture content could be attributed to the presence of the pods which help to reduce moisture absorption.

The superior performance of unshelled seeds to shelled seeds (Table 4.7) could be attributed to the fact that the pods provide a sort of protection to the seeds against deteriorating factors (high humidity, pest, mechanical damages etc.) while shelled seeds may get damaged during shelling that hasten deterioration of seeds and also makes kernels susceptible to other biotic and abiotic attack (Sujatha *et al.* 2018).

5.2.4 Interactive effect of doses and forms on physiological parameters studied

Interactive effect between doses and forms of groundnut on root and shoot lengths were significantly higher in irradiated seeds than in controls of both forms (Table 4.8). Root lengths of shelled seeds irradiated with 3 Gy and unshelled seeds treated with 5 Gy were significantly different from the controls of both forms. Shoot lengths of shelled seeds irradiated with 2 Gy and unshelled seeds treated with 3 Gy were significantly different from both forms of non-irradiated seeds. These observations were similar to the findings of Charbaji & Nabulsi (1999), who reported differences in shoot and root lengths of different forms of grapevine rootstocks irradiated with 0, 2, 5 and 7 Gy gamma radiation doses.

Speed of germination was significantly higher in the irradiated seeds than in control due to the influenced of the interaction between doses and forms of groundnut (Table 4.9). The highest values were observed in shelled seeds (7.34) irradiated with 2 Gy and unshelled seeds (8.21) treated with 3 Gy, and were significantly different from non-irradiated seeds of both forms. The difference in the dose that impacted the high speed of germination in the forms of groundnut seeds could be attributed to the presence or lack of shell in the forms as seeds stored in pod had a higher irradiation dose rate compared to shelled seeds. The differential response of the different forms to radiation dose have been explained as one of the factors that influence the effect of irradiation on plant growth and development (Kim *et al.*, 2009).

5.2.5 Interactive effect of storage period and forms on physiological parameters studied

Speed and Peak value of germination exhibited similar response across the storage period (Table 4.10). The above parameters were significantly higher at 0 week in shelled and unshelled seeds than at 21st week in shelled seeds. The highest values for speed of germination observed at 0 week

in both shelled (8.53) and unshelled (8.72) groundnut forms were significantly different from seeds at the 21st week after irradiation. The highest values for peak of germination observed at 0 week in both shelled (19.13) and unshelled (19.30) groundnut forms were also significantly different from seeds at the 21st week after irradiation. Peak of germination at 0 and 3 weeks of storage in shelled seeds was significantly different from those at the end of the storage period. The value in unshelled seeds at 0 week was significantly different from those of 9, 12, 15,18 and 21 weeks. There was decreasing trend in these parameters as storage period advances with shelled seeds having lower values across the storage period. The above observations in the present study were similar to findings of Vasudevan *et al.* (2014), who reported decrease in speed of germination of groundnut seeds as storage periods advances. Vasudevan *et al.* (2014) attributed the decrease to the deteriorative effect of ageing of the seeds.

Germination percentages were significantly higher at week 0 than at 21st week irrespective of the seed forms (Table 4.11). Germination percentages in shelled seeds at 3, 6 and 18 weeks of storage were significantly different from those of 9, 15 and 21 weeks. Germination percentages were also significantly different at 0,3, 6 and 18 weeks compare to those of 9,12, 15 and 21 weeks in unshelled seeds. There was a progressive decline (from 92 and 93% in shelled and unshelled, respectively) in germination parameters as the period advances except in germination percentages which increases at the 12th and 18th week of storage. The observed decline in these parameters irrespective of forms was similar to findings of Kalpana & Rao (1991), who reported losses in germination and vigour of pigeon pea during storage because of ageing due to changes in cellular physiology of seeds and fluctuation in moisture content. The unusual increase in germination percentages at the 12th and 18th week in the present study could be as a result of differences in

deterioration of individual seeds in the seed lot (Delouche, 1973) or probably from the residual beneficial effect of irradiation.

The amount of moisture in stored produce has been reported to be a determinant of conduciveness of storage environment for storage pests (Ranga Rao *et al*. 2010). Moisture contents of the seeds were significantly higher ($p<0.05$) at the 21st week of storage in shelled seeds than at 0 and 21st week in unshelled seeds (Table 4.11). The lowest moisture content was observed at the 9th week of storage in unshelled seeds. The highest moisture content was observed at the 21st week of storage period in shelled seeds. These observations were similar to findings of Sharanappa *et al.* (2018) who reported higher moisture content of seeds stored as kernels over unshelled groundnut seeds after nine months.

5.2.6 Interactive effect of storage period and Irradiation doses on all parameters studied

There was no significant difference in the interactive effect of storage period and doses on the parameters studied in the present study except for shoot length of seedlings (Table 4.12). There were significant differences among the treatments as influenced by radiation doses and storage periods. The highest value observed at a dose of 2 Gy by 6th week of storage was significantly different from the lowest observed in the control (0 Gy) at the end of the storage period. These observation were similar to findings of Vidya Kumari (2013), who reported that seeds irradiated with 50 Gy showed superiority over non-irradiated control and higher doses in positively influencing shoot lengths of rice seedlings during 9 months of storage.

5.2.7 Interactive effect of storage period, Irradiation doses and forms on all parameters studied

There was no significant difference in the overall interactive effects of the three factors under investigation on all the parameters studied in the present study except for root length of seedlings (Table 4.13). There was significant difference in root length of seedlings as influenced by the interactions among doses, forms and period of storage. The highest value (18.85 cm) observed at 6^{th} week of storage in unshelled seeds treated with 2 Gy of irradiation was significantly different from those of shelled seeds treated with 1 Gy at 15^{th} week of storage. The low root length value (9.28 cm) observed in shelled seeds treated with 1 Gy at 15^{th} week of storage could be attributed to several factors such as the reducing effect of ageing and exposure to various environmental factors on shelled seeds and differences of response in irradiated matrices (Kalpana & Rao, 1991; Kim *et al*. 2009; Sharanappa, *et al.* 2018). The high root length value observed in unshelled seed treated with 2 Gy at week 6 could be as a result of stimulatory effect of the irradiation dose on the irradiation matrix (unshelled) (Kim *et al*. 2004; Wi *et al*. 2007; Kim *et al*. 2009).

5.3 Field evaluation

Results from field evaluations in the present study showed little or no differences in the plant characteristics studied. Emergence percentage ranges from 93-100% (Table 4.14). The results from the field showed slight superiority of doses 2 to 4 Gy over the remaining doses (i.e. 0,1 and 5 Gy) and unshelled seed over shelled which was similar to results obtained in the laboratory studies, although germination percentages of other doses were quite high also. These observations followed the trend reported by Vidya Kumari (2013), who noted that doses 50-100 Gy performed better in terms of rice field emergence percentages compared to laboratory values. These observations may be ascribed to the stimulatory effect of the specific radiation doses.

Days to germination, days to 50% flowering and the morphological characters of the resulting plants were quite similar for all the irradiation doses and seed forms. These results indicate that low radiation doses in both groundnut forms had no impact on the plant morphology as it was probably too low for any significant changes to occur within the seed. These observations agree favourably with Habtamu, (2016), who reported that for significant mutation to occur in groundnuts seeds, a dose range of ≥100-450 Gy should be used.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Groundnut seed is known to lose viability and other related quality characteristics in storage as a result of effect of several biotic and abiotic factors. This study therefore shed light on the effect of low gamma radiation doses on the biotic and abiotic factors that affect storability of groundnut seeds and overall quality including physiological, sanitary and genetic seed quality of the groundnut variety used in this study. Findings from the current study suggest that:

Irradiation doses between 2-4 Gy had a positive effect on germination percentage, speed and peak of germination, seedling vigour and other seedling physiological characteristics through the storage period, with 2 Gy having a more pronounced effect on these physiological parameters.

On the effect of radiation doses on seed forms, a dose range of 2-4 Gy had a positive effect on both seed forms for physiological characters such as germination percentage, speed and peak value of germination, moisture content and seedling parameters during storage with unshelled seeds slightly outperforming and storing better than shelled seeds. However, the radiation doses used in the study did not improve the sanitary quality of groundnut seeds irrespective of the form in which they are stored as the doses were far too low to have an impact on pathogens.

The doses used in the study had no significant effect on the genetic quality of the seed, hence there was no change in the plant form compare to the non-irradiated samples.

There was a relative decline in germination and seedling parameters, moisture content and sanitary quality across the storage period irrespective of the dose and forms with shelled seeds declining more than seeds in pod.

6.2 RECOMMENDATION

1. Irradiating groundnuts seeds with low doses of 2-4 Gy prior to storage is recommended for maintaining physiological seed quality of groundnut seeds during storage for a period of 5 months.

2. Groundnut should be stored best in pods than kernels as they are better protected from biotic and abiotic stresses that occur during storage.

3. Further studies may be conducted to ascertain the impact of different irradiation doses especially on unshelled groundnuts in storage.

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APPENDICES

APPENDIX I

ANALYSIS OF VARIANCE OF MEANS OF PARAMETERS STUDIED

Analysis of variance (Mean squares) for seed quality parameters immediately after irradiation

Source of variation	D.f.	Germination percentage(%)	Speed of germination	Peak value of germination	Vigour Index
Dose	5	0.002298	0.2798	0.0983	151531
Form	1	0.003446	0.3403	0.2669	63706
Dose x form	5	0.006237	0.5563*	0.1796	69125
Residual	24	0.00699	0.1553	0.2711	85326
Total	35				

**significant at P=0.05*

Analysis of variance (Mean squares) for seed quality parameters immediately after irradiation

Source of variation	D.f.	Root length(cm)	Shoot length(cm)	Seedling length (cm)	Moisture content (%)	Pathogen infectivity (%)
Dose	5	7.313	1.3433	14.925	0.000104	402.8
Form	1	1.647	0.3025	3.361	0.0014591*	3042.8
Dose x form	5	4.414	0.8108	9.009	0.000122	611.1
Residual	24	4.519	0.83	9.222	0.000264	1562.8
Total	35					

**significant at P=0.05*

Analysis of variance (Mean squares) for seed quality parameters during storage

Source of variation	D.f.	Germination percentage(%)	Peak value of germination	Speed of germination	Vigour Index
Dose	5	0.030068**	1.3730*	1.1447**	830197**
Form	1	0.188108**	50.1668**	46.9642**	1305122**
Period	7	0.111775**	25.445**	23.0555**	2723561**
Dose x form	5	0.0073	0.4586	0.486*	80900
Dose x period	35	0.004426	0.2721	0.2331	86340
Forms x period	7	0.012183*	2.035**	3.2932**	114289
Dose x form x period	35	0.004359	0.2561	0.227	71607
Residual	192	0.005732	0.3479	0.1911	93958
Total	287				

**significant at P<0.05*

***significant at P<0.01*

Analysis of variance (Mean squares) for seed quality parameters during storage

Source of variation	D.f.	Root length (cm)	Shoot length (cm)	Seedling length (cm)	Moisture content (%)	Pathogen infectivity (%)
Dose	5	32.108**	5.7857**	66.78**	0.000186	884
Form	1	6.833	1.3122	43.87*	0.0033215**	8163
Period	7	147.72**	26.4639**	307.12**	0.0038204**	17028**
Dose x form	5	10.239*	1.7061*	14.91	0.000247	2499
Dose x period	35	4.957	1.0883*	9.39	0.000138	932
Form x period	7	5.398	0.7856	9.78	0.0010802**	3385
Doses x forms x period	35	5.802*	0.9232	9.1	0.000126	1526
Residual	192	3.643	0.7084	10.24	0.000127	3897
Total	287					

**significant at P<0.05*

***significant at P<0.01*

APPENDIX II

ANALYSIS OF VARIANCE OF REGRESSION ANALYSIS

Pathogen infectivity* period

	df	SS	MS	F	Significance F
Regression	1	3149.469	3149.469	115.0062	3.88E-05
Residual	6	164.3112	27.3852		
Total	7	3313.78			

Seedling length * period

	df	SS	MS	F	Significance F
Regression	2	40.43685	20.21842	5.240177	0.059289
Residual	5	19.29174	3.858348		
Total	7	59.72859			

Germination percentage*period

	df	SS	MS	F	Significance F
Regression	1	78.72	78.72	26.016	0.00222
Residual	6	18.15	3.026		
Total	7	96.88			

Vigour Index * dose

	df	SS	MS	F	Significance F
Regression	2	75550.64	37775.32	10.2661	0.045519
Residual	3	11038.86	3679.619		
Total	5	86589.5			

Seedling length *dose

	df	SS	MS	F	Significance F
Regression	2	6.241614	3.120807	13.24866	0.032435
Residual	3	0.706669	0.235556		
Total	5	6.948283			

Germination percentage *dose

	df	SS	MS	F	Significance F
Regression	2	9.497619	4.74881	7.7607	0.065189
Residual	3	1.835714	0.611905		
Total	5	11.33333			

APPENDIX III

PLATES OF PLANTS GOTTEN FROM IRRADIATED AND NON-IRRADIATED SEEDS

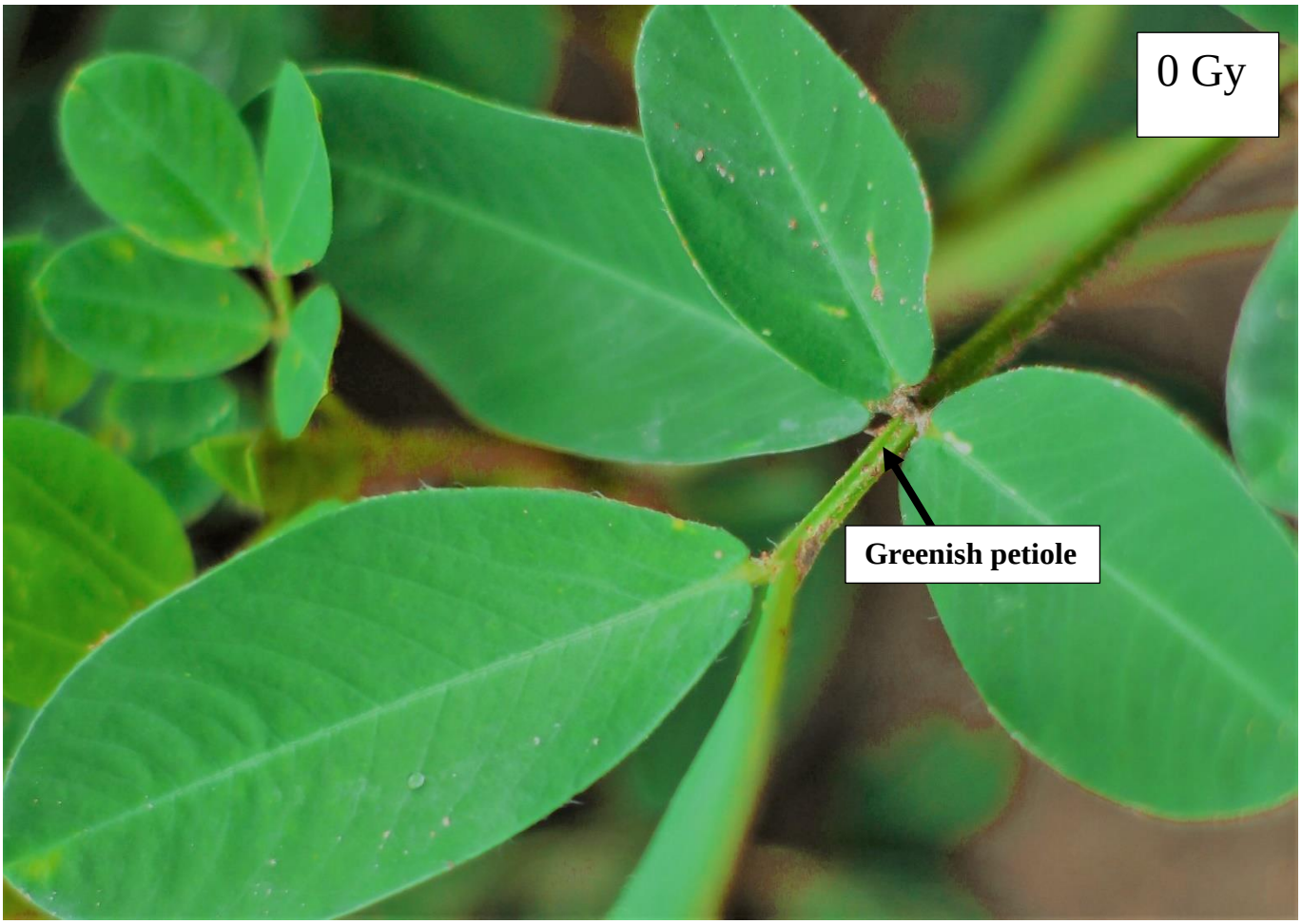

Plate 1: Leaf and petiole colour of groundnut plants of unshelled seed irradiated with 0 Gy

Plate 2: Leaf and petiole colour of groundnuts plant of unshelled seed irradiated with 1 Gy

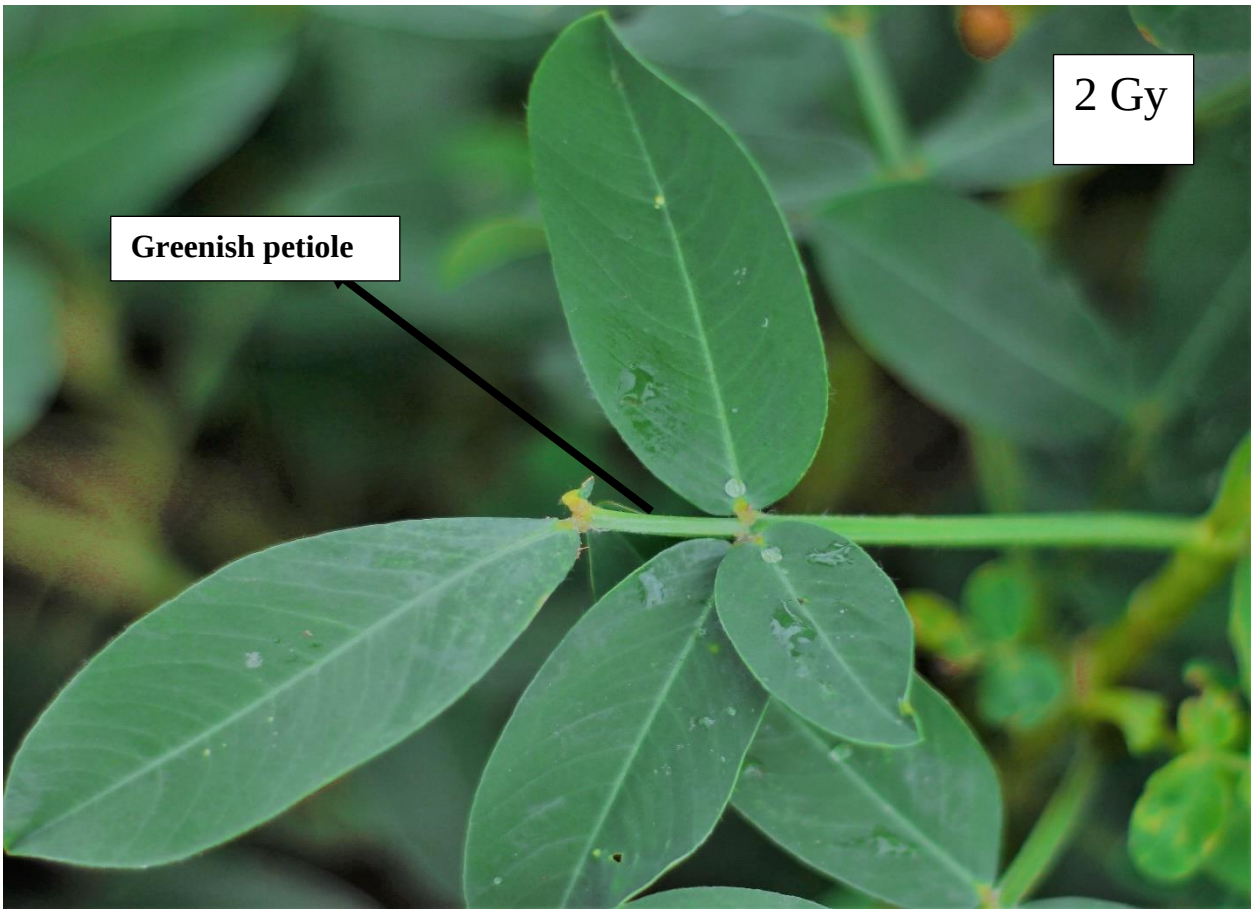

Plate 3: Leaf and petiole colour of groundnuts plant of unshelled seed irradiated with 2 Gy

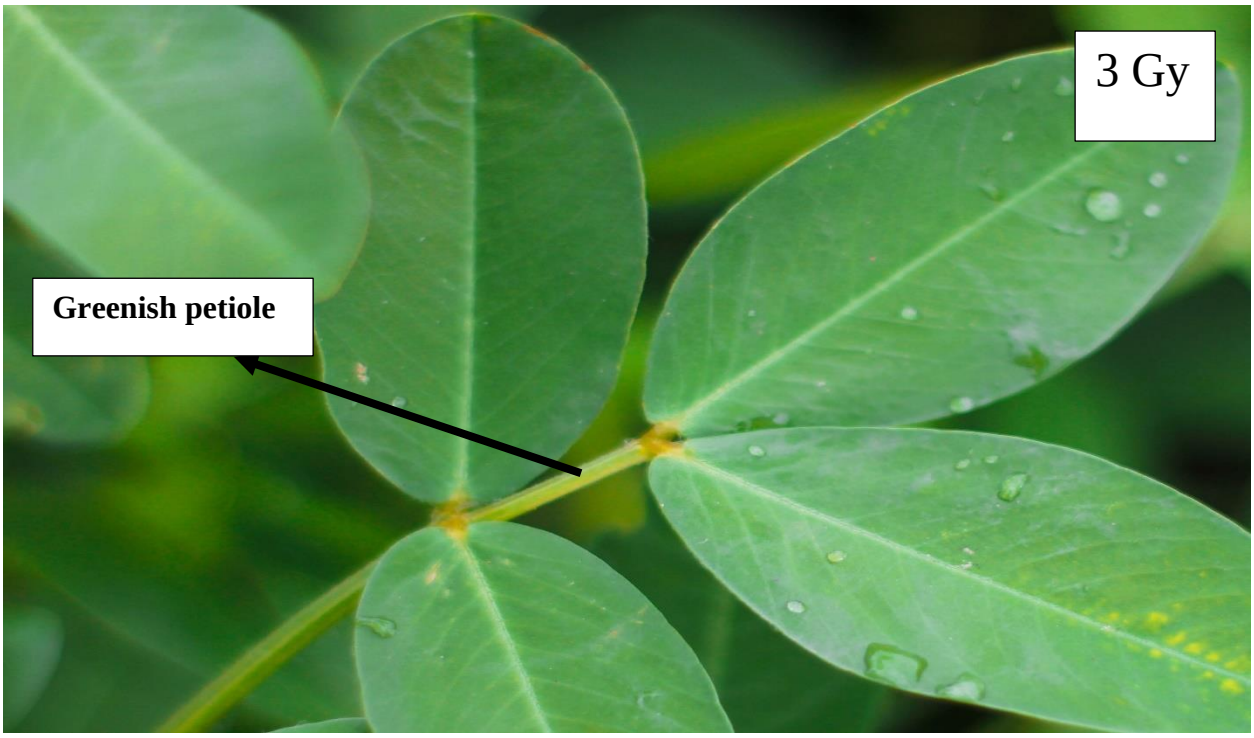

Plate 4: Leaf and petiole colour of groundnuts plant of unshelled seed irradiated with 3 Gy

Plate 5: Leaf and petiole colour of groundnuts plant of unshelled seed irradiated with 4 Gy

Plate 6: Leaf and petiole colour of groundnuts plant of unshelled seed irradiated with 5 Gy

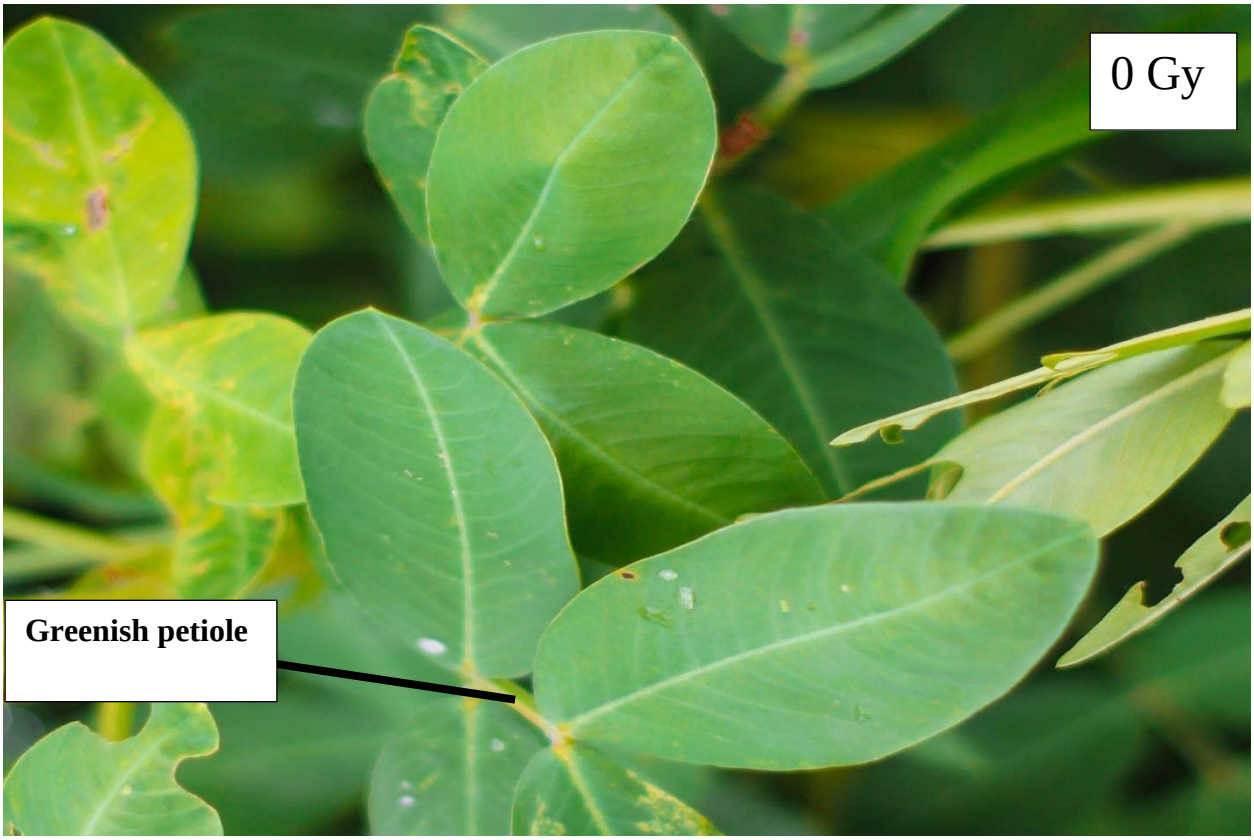

Plate 7: Leaf and petiole colour of groundnuts plant of shelled seed irradiated with 0 Gy

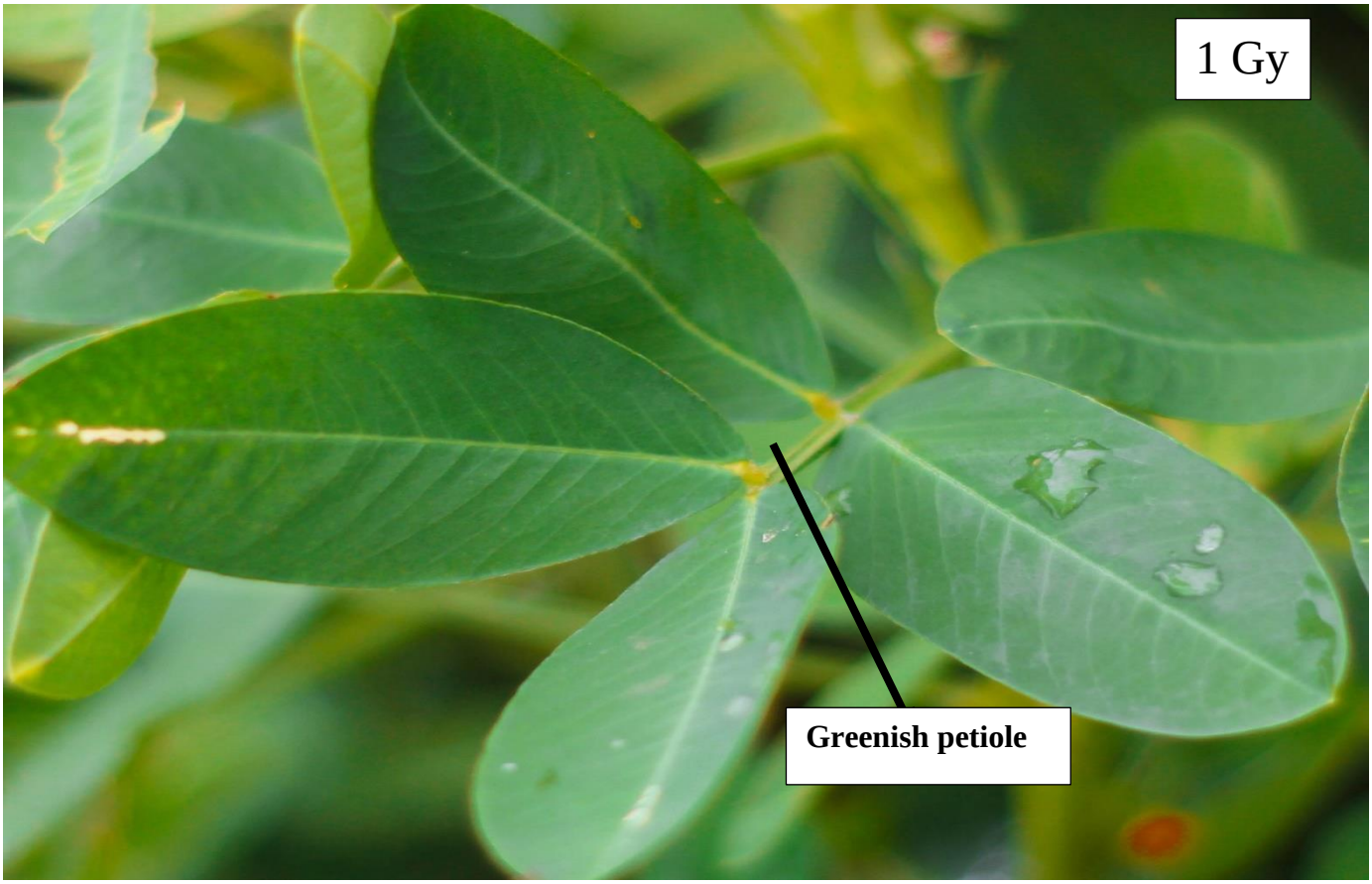

Plate 8: Leaf and petiole colour of groundnuts plant of shelled seed irradiated with 1 Gy

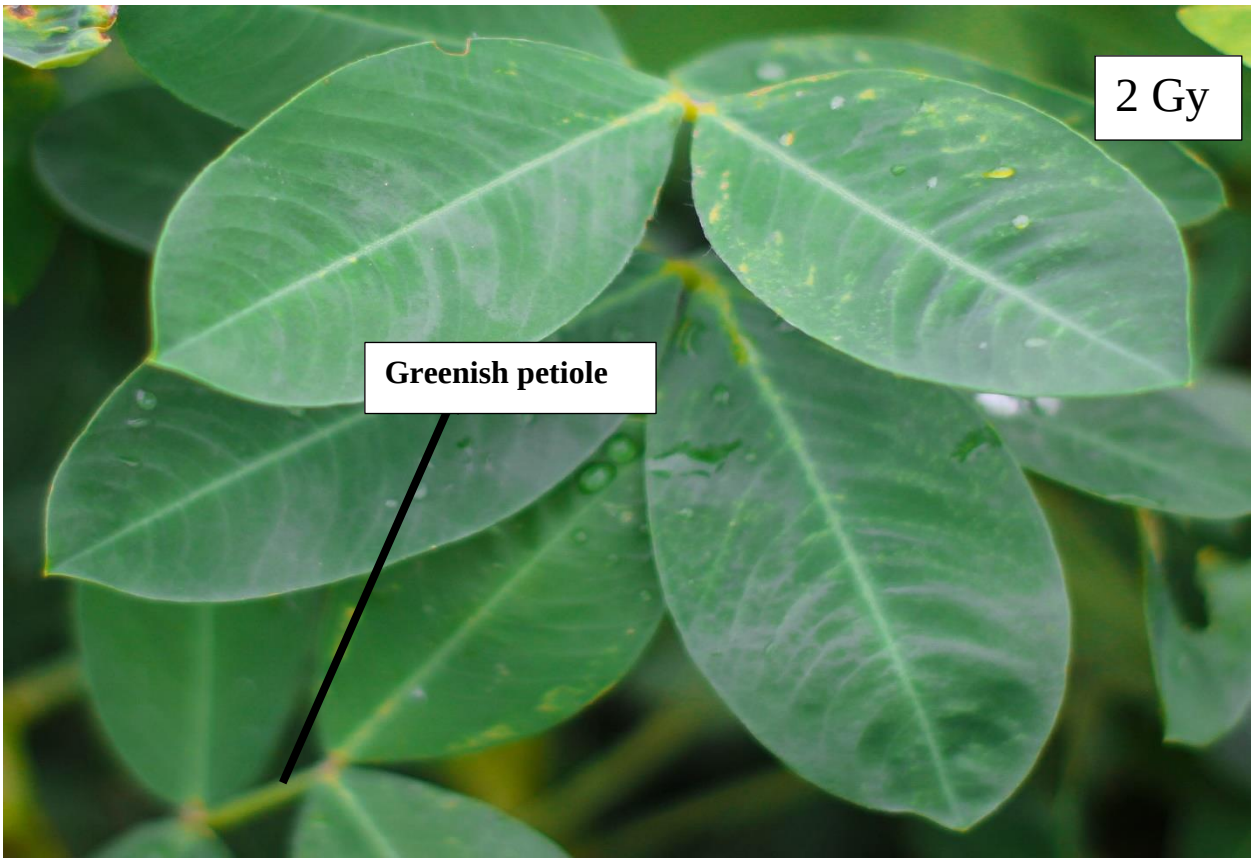

Plate 9: Leaf and petiole colour of groundnuts plant of shelled seed irradiated with 2 Gy

Plate 10: Leaf and petiole colour of groundnuts plant of shelled seed irradiated with 3 Gy

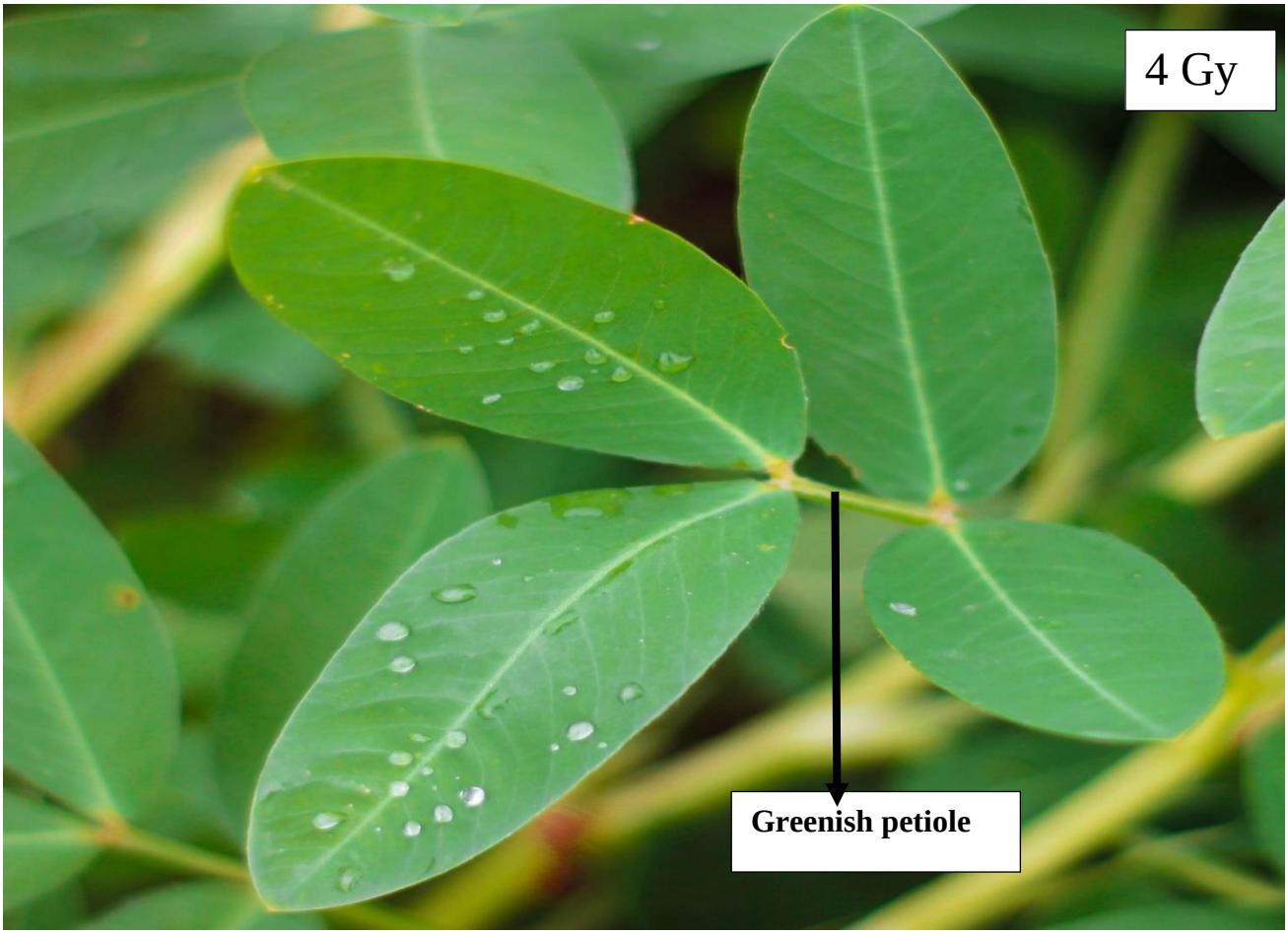

Plate 11: Leaf and petiole colour of groundnuts plant of shelled seed irradiated with 4 Gy

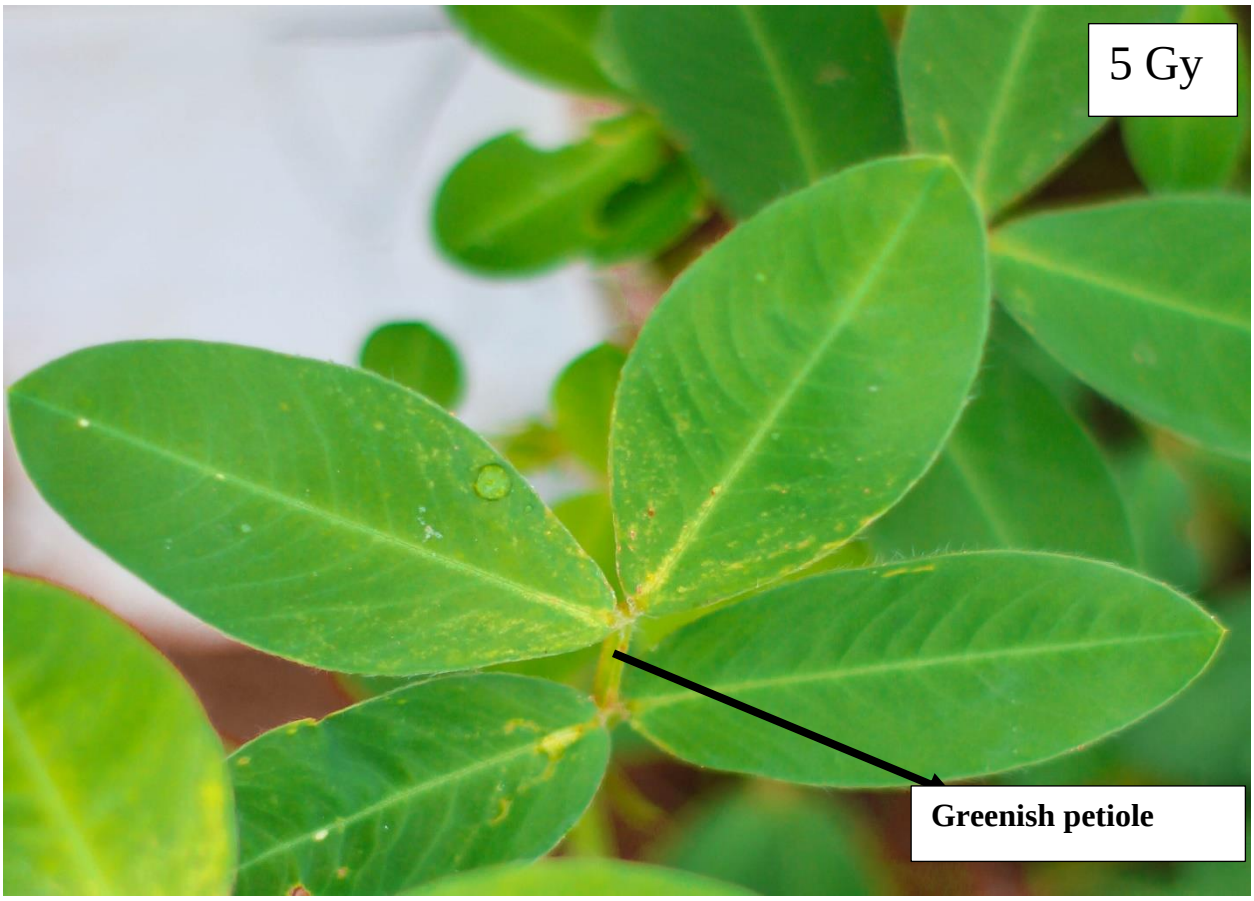

Plate 12: Leaf and petiole colour of groundnuts plant of shelled seed irradiated with 5 Gy