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Effects of X- Ray, Gamma Ray and UV Light on some Morphological Characteristics and Yield Components of the Second Generation Sorghum (*Sorghum bicolor* (L.) Moench)

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Abstract

Sorghum is considered as one of the most important crops in Sudan economically and nutritionally. The objective of this research was to study the effects of X-ray, Gamma-ray and UV light on some morphological and yield components of the second generation of sorghum (*Sorghum bicolor* (L.) Moench). The first generation samples of sorghum seeds were brought from the Center of Biosciences and Biotechnology, University of Gezira. Some of the first generation sorghum seed samples were irradiated by two dose of X-rays (33.4 and 200.2 sec.), and two doses of gamma rays (200 CGY and 800 CGY), while the dose of ultra violet (UV) that used for general sterilization purposes against microorganisms was also used. The samples were planted in The Experimental Farm, University of Gezira. Vegetative growth parameters included, (plant weight, plant shoot length, number of fibrous roots/plant, number of leaves/plant, length of larger leaves, number of tillers/plant) and yield parameters included, (number. of heads/plant number of seeds/head and mean weight of seeds). The data were subjected to the appropriate statistical analysis. The results of this study revealed that, all treatments showed varying effects on all vegetative growth and yield parameters. There were some correlations (e.g. between number of roots and weight, number of roots and number of tillers, and also between plant weight and plant length). The F_2 did not showed similarity to the F_1 in most of the tested parameters. All irradiated groups, did not showed hypothetical high yield components (the production in the control (1643.02 kg\ha), LX (3299.45 kg\ha), HX (1086.54 kg\ha), LG (1108.76 kg\ha), HG (1917.54 kg\ha) and UV (1385.14 kg\ha). The research recommended further studies concerning the flour quality and resistance to diseases and pests in the irradiated sorghum.

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DEDICATION

To my family

ACKNOWLEDGEMENTS

I would like to thank those who contributed one way or another to the realization of this work: staff and colleagues of Center of Biosciences and Biotechnology, University of Gezira.

Chapter One

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is a cereal crop that is usually grown under hot and dry conditions. Sorghum might be originated from the headwaters of the Niger River in Africa. Archaeological evidence suggested that the practice of sorghum domestication was introduced from Ethiopia to Egypt about 3000 B.C. Now about 80 % of sorghum cultivation is found in the African and Asian regions, however, the world sorghum production is still dominated by the USA, India, Nigeria, China, Mexico, Sudan and Argentina (FAO, 1995).

Sorghum, the world's fourth major cereal in terms of production, and fifth in acreage following wheat, rice, maize and barley, is a staple food crop of millions of poor people in semi-arid tropics (SAT) of the world. It is mostly grown as a subsistence dry land crop by resource limited farmers under traditional management conditions in SAT regions of Africa, Asia and Latin America, which are frequently drought-prone and characterized by fragile environments. India grows the largest acreage of sorghum in the world followed by Nigeria and Sudan, and produces the second largest tonnage after the US. In most of the regions of India, it is cultivated both as a rainy- and post rainy-season crop. The yield and quality of sorghum produced worldwide is affected by a wide array of biotic and a biotic constraints (ICRISAT, 2004; Nadia *et al*., 2009).

Sorghum and maize are the most popular cereals consumed by adults and infants in Africa, south of the Sahara. Sorghum is a major source of protein and calories in the diets of large segment of the populations of Africa and Asia (Yousif and Eltinay, 2001).

Sorghum is the most important cereal crop in Sudan. It occupies about 40-48% of the total area used for the main field crops, and the average consumption is about 96% of the total production, which is about 3,32 million tonnes. It is evident that sorghum has become the staple food for the vast majority of the Sudanese people. The allocation of the farm area of sorghum crop has been dropping, while the yields per hectare have been increasing. The biggest sorghum crop the world produced in the last 40 years was in 1985, with 77,6 million tons harvest that year (Almodares and Hadi, 2010).

The quantity of sorghum produced by countries is measured each year. This made them tallied against the food security situation in the country. Research on the economic benefit of the different cereal grain crops has found that sorghum proved to be a major income earner for some countries including Sudan. Sudan is a leading country in sorghum production in Africa and the area which is allocated for it is the largest among the other crops. The crops which constitute the main food of the Sudanese Sorghum in the top and other several crops such as millet, wheat, and maize. Generally plants are affected by radiation - and this is reflected on vegetative growth, yield and quality of grains (Asiedu *et al*. 1993).

1.2 The Objective

The objective of this study was to investigate the effects of X- ray, Gamma ray and UV light on some morphological characteristics and Yield components of M_2 generation of sorghum (*Sorghum bicolor* (L.) Moench).

Chapter Two

Literature Review

2.1. Sorghum

2.1.1 Scientific classification

Kingdom: Plantae
Phylum: Angiosperms
Class: Monocots
Order: Poales
Family: Poaceae
Genus: *Sorghum*
Species: *bicolor*, (Dahlberg, 2000)

Sorghum bicolor, commonly called sorghum and also known as Dura, Jowari, or Milo, is a grass species cultivated for its grain, which is used for food, both for animals and humans, and for ethanol production. Sorghum originated in northern Africa, and is now cultivated widely in tropical and subtropical regions. *S. bicolor* is typically an annual, but some cultivars are perennial. It grows in clumps that may reach over 4 m high. The grain is small, ranging from 3 to 4 mm in diameter. Sweet sorghums are sorghum cultivars that are primarily grown for foliage, syrup production, and ethanol; they are taller than those grown for grain (Mutegi *et al*., 2010).

2.1.2 Seedling Development:

There is a relatively wide range in planting dates for sorghum in the southeastern United States, mainly because sorghum germination is closely linked to soil temperature. For good stand development, it is important to ensure that the soil temperature at the 2" depth is at least 65°F. Cold soils result in poor germination (Carmi *et al*., 2006).

The shoot (coleoptile) emerge from the ground and first leaf breaks through the tip. The mesocotyle grows during this period and a node is formed at the base of the coleoptile just below ground level. Secondary roots begin to grow from this node, 3 to 7 days after the plant emerges from the soil. Seedlings get the nutrients through these roots. The cultivated sorghums mature in 100 to 140 days depending on the variety. The right time to harvest sorghum is at the physiological stage of the plants or when the seed moisture content is below 25%. The sorghum root system consists of 3 types of roots, which are primary roots, secondary or adventitious roots and brace or buttress roots. Permanent adventitious roots of sorghum are another type of roots develop from the second internode and above. These roots are branched laterally interlacing the soil vertically. These roots mainly supply nutrients to the plant (Purseglove, 1972).

Plants in the 4th to 6th-leaf stage will tiller when the average daily temperature (as opposed to the daily high) is below 65 F. The cooler the average daily temperature is during the 4 to 6-leaf stage, the more plants will tiller. Normal planting dates will allow the plant to tiller, thus compensating for extreme differences in plant population. Frequently, tillering ability is not taken into consideration at planting time and the result is many grain sorghum fields are planted at populations that are too high.

Tillering is the most important factor in grain sorghum's tremendous ability to compensate for environmental changes and management inputs. Most grain sorghum hybrids possess the ability to tiller. Environmental conditions and management factors have a limited effect on the plant's ability to initiate tiller, but they do influence tiller development. While sorghum usually initiates tillers, environmental conditions determine how many of the tillers actually produce a head. Hot dry conditions suppress tiller survival while cool temperatures promote tiller survival. Cool fall conditions can result in extremely high tillering rates and delayed sorghum maturity (Hancock, 2009).

As planting date is delayed, plant populations need to be increased in order to compensate for reduced tillering to maintain maximum yields. The increase in planting rate will be gradual until the planting date becomes extremely late, such as is the case in a double crop or late replant situation. Under extremely late planting situations, where only main heads and no tillers are produced, it may be necessary to double the normal seeding rate (Jaiyesimi and Vanderlip, 1979).

The Brace roots of sorghum develop from the root primordia of the basal nodes above the ground level. They are stunted, thick, and above ground level. These roots provide anchorage to the plant. Sorghum shoot system consists of stem, leaves, nodes, and internodes during the vegetative stage. Leaves nodes develop at of one in 3 to 6 days. The plant remains in vegetative stage for 30 to 40 days during which all leaves (12 to 18) are formed. The stem of sorghum consists of many alternating nodes and internodes. It ranges from slender to very strong, 0.5 to 5 cm in diameter near the base. The length of stem varies between 0.5 to 4 m depending on the variety. A bud is formed at each node. At time, these buds develop tillers. About 6 to 10 days before flowering, the boot forms a bulge in the sheath of the flag leaf (uppermost leaf). This stage is called boot leaf stage. Sorghum usually flowers 55 to 70 days (Wang and Fields, 1978).

The first growth stage (GS_I) is characterized by vegetative growth. The plant develops its vegetative structures, leaves and tillers, which ultimately support grain formation and growth. The more leaves formed, the longer maturity (e.g., more time is required from planting to harvest) and greater its potential to produce forage and grain. Early-maturing hybrids typically produce 15 leaves per plant, while medium- and late-maturing hybrids produce 17 and 19 leaves each. On average, kernels weigh about 25 grams per 1,000 seed but can range from 13 to 40 grams per 1,000 seed. The base temperature or lower temperature limit of sorghum development is 50 degrees F, while the upper limit is 100 degrees F (Thomas *et al.*, 2013).

The flowering structure (inflorescence) in sorghum is called as panicle or head, which starts developing from 30 to 40 days after germination. Two days after the emergence of the inflorescence, the flowers begin to open. The maximum flowering takes place on 3rd or 4th day. It takes 6 days for the whole inflorescence to complete flowering. The sorghum grain matures in 30 to 35 days after fertilization. Sorghum seeds are spherical in shape but somewhat flat on one side. The seeds vary in color - red, brown, white, yellow, or cream and are with a dull or pearly luster. Uptake of nutrients also mostly cease at this stage. So, if there are problems like bird damage etc. it is advantageous to harvest the crop at this stage. As the seed moisture at this stage will be around 25 to 35%, proper drying of the seeds is important. Physiological maturity can be determined by the dark spot on the seed (Rooney and Serna-Saldivar, 1991). The global productivity of sorghum and other grain crops is presented in Table (2.1).

Table (2.1) The average of production and productivity of some grain crops in the world

Loss in Production (in million metric tons)	Area (Million ha)	Production (Million MT)	Average Yield (kg/ha) (World)	Crops
3.2	**145**	**705**	**4859**	**Maize**
26.3	**153**	**608**	**3970**	**Rice**
*****	**218**	**624**	**2869**	**Wheat**
*****	**57**	**155**	**2720**	**Barley**
8.9	**44**	**60**	**1357**	**Sorghum**

Source: SCPC (2002).

2.1.3 Uses

Sorghum has been, for centuries, one of the most important staple foods for milions of poor rural people in the semi-arid tropics of Asia and Africa. For some impoverished regions of the world, sorghum remain a principal source of energy, protiens, vitamins, and minerals. Sorghum grows in harsh Environment where other crops do not grow well, just like other staple foods, such as cassava, that are common in impoverished regions of the world. It is usually grown without application of any fertilizers or other inputs by a multitude of small- holder farmers in many countries (U.S Grain Council, 2005).

The reclaimed stalks of the sorghum plant are used to make a decorative millwork material marketed as Kirei board. Sweet sorghum syrup is known as molasses in some parts of the U.S., although it is not true molasses. In China, sorghum is fermented and distilled to produce maotai, which is regarded as one of the country's most famous liquors. Sorghum was ground and the flour was the main alternative to wheat in northern China for a long time. In India, where it is commonly called jwaarie, jowar, jola, or jondhahlaa, sorghum is one of the staple sources of nutrition. An Indian bread, jowar rotti or jolada rotti, is prepared from this grain. In some countries, sweet sorghum stalks are used for producing biofuel by squeezing the juice and then fermenting it into ethanol.

Sorghum is also used as wheat substitutes in gluten-free recipes and products. Fermentation of the production was carried out using the hydrolysate of sorghum grain as the fermentation medium with no supplementation *Saccharomyces cerevisiae* was used as fermentative agent to produce ethanol (FAO, 1995).

2.1.4. Economics of Production and Markets:

The global production of sorghum till 2013 is presented in table (2.2). The world average annual yield for the 2010 crop was 1.37 tons per hectare. The most productive farms of sorghum were in Jordan, where the nationwide average annual yield was 12.7 tons per hectare. The nationwide annual average yield in world’s largest producing country, the U.S.A, was 4.5 tons per hectare (Carter *et al.*, 2013).

The cost of grain sorghum production is about the same as for similar grain-yield production levels for corn. Therefore decisions to grow grain sorghum depend primarily on relative yield potential compared to corn, and the ability to obtain markets.

Table (2.2): Global Sorghum production, marketing and growth rate.

Growth Rate	Production (1000 MT)	Market Year
221.17 %	4400	**1988**
-59.09 %	1800	**1989**
-16.67 %	1500	**1990**
124.00 %	3360	**1991**
20.54 %	4050	**1992**
-40.74 %	2400	**1993**
54.17 %	3700	**1994**
-33.78 %	2450	**1995**
71.43 %	4200	**1996**
-30.48 %	2920	**1997**
65.41 %	4830	**1998**
-49.59 %	2435	**1999**
13.35 %	2760	**2000**
61.96 %	4470	**2001**
-34.45 %	2930	**2002**
77.13 %	5190	**2003**
-47.98 %	2700	**2004**
58.33 %	4275	**2005**
1.22 %	4327	**2006**
15.53 %	4999	**2007**
-22.60 %	3869	**2008**
8.35 %	4192	**2009**
-37.26 %	2630	**2010**
-20.57 %	2089	**2011**
104.45 %	4271	**2012**
-11.03 %	3800	**2013**

Source: (Carter *et al*., 2013)

Since market outlets for grain sorghum are not established in most areas of Minnesota and Wisconsin, local elevators will probably not buy it. On-farm utilization as feed is the most likely alternative available to most growers (Thomas *et al*., 2013). The factors affecting the production of sorghum can be summarized as:

1. Selection of forage Sorghum (all types)
2. Seedbed preparation and planning practices and dates
3. Fertilizer requirement
4. Water management
5. Weed control
6. Sorghum diseases
7. Sorghum insects
8. Nematodes
9. Preharvest desiccants for Sorghum
10. Harvesting forage Sorghum
11. Drying and storage of forage sorghum
12. Marketing strategies

2.1.5 Nutritional value of the dried seeds

Considering the nutritional value of the dried seeds of sorghum per 100g, it contains energy 1.418 kJ (339 k cal), carbohydrate 74.63 g, dietary fiber 6.3 g, fat 3.30 g, protein 11.30 g and ash 3.08 g in addition to 14 g moisture and volatile matter. These percentage are relative to US recommendations for adult (NRC, 1996; Leder and Schusterne, 2000).

2.2 Gamma radiation

Gamma radiation, also known as gamma rays, and denoted by the Greek letter γ, refers to electromagnetic radiation of high frequency and therefore high energy per photon. Gamma rays are ionizing radiation, and are thus biologically hazardous. They are classically produced by the decay from high energy states of atomic nuclei (gamma decay), but are also created by other processes (Villard, 1900).

Natural sources of gamma rays on Earth include gamma decay from naturally occurring radioisotopes, and secondary radiation from atmospheric interactions with cosmic ray particles. Gamma rays are produced by a number of astronomical processes in which very high-energy electrons are produced, that in turn cause secondary gamma rays by the mechanisms of Bremsstrahlung, inverse Compton scattering and synchrotron radiation. A large fraction of such astronomical gamma rays are screened by Earth's atmosphere and must be detected by spacecraft (L'Annunziata, 2007).

Gamma rays typically have frequencies above 10 exahertz (or $>10^{19}$ Hz), and therefore have energies above 100 keV and wavelengths less than 10 picometers (less than the diameter of an atom). However, this is not a hard and fast definition, but rather only a rule-of-thumb description for natural processes (Dendy and Heaton, 1999).

All ionizing radiation causes similar damage at a cellular level. Gamma rays and neutrons are more penetrating, causing diffuse damage throughout the body (e.g. radiation sickness, cell's DNA damage, cell death due to damaged DNA, increasing incidence of cancer) rather than burns. External radiation exposure should also be distinguished from internal exposure, due to ingested or inhaled radioactive substances, which, depending on the substance's chemical nature, can produce both diffuse and localized internal damage. The most biological damaging forms of gamma radiation occur in the gamma ray window, between 3 and 10 MeV (NCRP, 1987).

2.3 Ultraviolet (UV)

Light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than X-rays, in the range between 400 nm and 10 nm, corresponding to photon energies from 3 eV to 124 eV. It is so-named because the spectrum consists of electromagnetic waves with frequencies higher than those that humans identify as the color violet. These frequencies are invisible to humans, but visible to a number of insects and birds. UV light is found in sunlight (where it constitutes about 10% of the energy in vacuum) and is emitted by electric arcs and specialized lights such as mercury lamps and black lights. It can cause chemical reactions, and causes many substances to glow or fluoresce. A large fraction of UV, including all that reaches the surface of the Earth, is classified as non-ionizing radiation (Hockberger, 2002).

The higher energies of the ultraviolet spectrum from wavelengths about 10 nm to 120 nm ('extreme' ultraviolet) are ionizing, but due to this effect, these wavelengths are absorbed by nitrogen and even more strongly by dioxygen, and thus have an extremely short path length through air. However, the entire spectrum of ultraviolet radiation has some of the biological features of ionizing radiation, in doing far more damage to many molecules in biological systems than is accounted for by simple heating effects (e.g. sunburn). These properties derive from the ultraviolet photon's power to alter chemical bonds in molecule, even without having enough energy to ionize atoms (Klose *et al*., 1987).

An overexposure to UV radiation can cause sunburn and some forms of skin cancer. However, the most deadly form – malignant melanoma– is mostly caused by the indirect DNA damage (free radicals and oxidative stress). This can be seen from the absence of a UV-signature mutation in 92% of all melanoma. In humans, prolonged exposure to solar UV radiation may result in acute and chronic health effects on the skin, eye, and immune system. Moreover, UV can cause adverse effects that can variously be mutagenic or carcinogenic. UV rays are the highest energy, most dangerous type of ultraviolet light. The WHO classified all categories and wavelengths of ultraviolet radiation as a Group 1 carcinogen. This is the highest level designation for carcinogens and there is enough evidence to conclude that it can cause cancer in humans (Davies *et al*., 2002).

2.4 X-rays

X-rays were discovered emanating from Crookes tubes, experimental discharge tubes invented around 1875, by scientists investigating the cathode rays, which are energetic electron beams that were first created in the tubes. Crookes tubes created electrons by ionization of the residual air in the tube by a high DC voltage of anywhere between a few kilovolts and 100 kV. This voltage accelerated the electrons coming from the cathode to a high enough velocity that they created X-rays when they struck the anode or the glass wall of the tube (Peter, 1995).

X–radiation (composed of X-rays) is a form of electromagnetic radiation. X- rays have a wavelength in the range of 10 to 0.01 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz ($30x10^{15}$Hz to $30x10^{18}$Hz) and energies in the range 120 keV to 120 keV. They are shorter in wavelength than UV rays. In many languages, X- radiation is called Rontgen radiation after one of its first investigators; Wilhelm Conrad Rontgen who had originally called them X-rays meaning an unknown type of radiation (Novelline, 1997).

As a result of Ivan Pulyui's experiments into what he called cold light, he is reputed to have developed an X-rays emitting device as early as 1881. Pulyui reputedly first demonstrated an X-ray photograph of a 13- year – old boy's broken arm and an X-ray photograph of his daughter's hand with a pin lying under it. The device became known as the Pulyui lamp and was mass – produced for a period; Reputedly, Pulyui personally presented one to Wilhelm Conrad Rontgen who went on the credited as the discoverer of X-rays (Dendy and Heaton, 1999). X-rays are usually used for diagnostic radiography and crystallography. As a result, the term X-ray is metonymically used to refer to a radiographic image produced using this method, in addition to the method itself. X-rays are a form of ionizing radiation and as such can be dangerous. X- rays span 3 decades in wavelength, frequency and energy. From about 0.12 to 12 keV they are classified as soft X-rays, and from about 12 to 120 keV as hard X-rays, due to their penetrating abilities (Sample, 2007).

The distinction between X-rays and gamma rays has changed in recent decades. Older literature distinguished between X- and gamma radiation on the basis of wavelength, now usually defined by their origin: X-rays are emitted by electrons outside the nucleus, while gamma rays are emitted by the nucleus (Charles,1961). Diagnostic X-rays (primarily from CT scans due to the large dose used) increase the risk of developmental problems and cancer in those exposed. X rays are classified as a carcinogen by both the WHO and the U.S. government (Berrington *et al*., 2004). The risk of x-ray is greater to unborn babies, so in pregnant patients, the benefits of the investigation should be balanced with the potential hazards to the unborn fetus (Stewart *et al*., 1956).

2.5 Mutation

In molecular biology and genetics, mutations are changes in a genomic sequence: the DNA sequence of a cell's genome or the DNA or RNA sequence of a virus. They can be defined as sudden and spontaneous changes in the cell. Mutation can affect organisms on structure, function, fitness, protein sequence or on inheritance ability. Mutations are caused by radiation, viruses, transposing and mutagenic chemicals, as well as errors that occur during meiosis or DNA replication (Burrus and Waldor, 2004; Aminetzach *et al*., 2005). There are two classes of mutations: spontaneous mutations (Sawyer *et al*., 2007) and induced mutations which can be caused by chemicals (e.g Hydroxylamine and Alkylating agents) radiation (e.g. Ultraviolet radiation (nonionizing radiation) (Kozmin *et al*., 2005), ionizing radiation (Gregory and Hebert, 1999) or Viral infections (Pilon *et al*., 1986).

2.6 Genetically modified foods

In genetics biotechnology, which refers to any technique that uses living organisms, an individual organism with beneficial characteristics, usually been selected to develop hybrid crops (FAO, 2004).

Genetically modified foods (GM foods) are foods derived from genetically modified organisms (GMOs). Genetically modified organisms have specific changes introduced into their DNA by genetic engineering techniques. These techniques are much more precise than mutagenesis (mutation breeding) where an organism is exposed to radiation or chemicals to create a non–specific but stable change. Other techniques by which humans modify food organisms include selective breeding; plant breeding, and animal breeding, and somaclonal variation. GM foods were first put on the market in the early 1990s. Typically, genetically modified foods are transgenic plant products: soybean, corn, canola, and cotton seed oil. Animal products have also been developed, although as of July 2010 none are currently on the market (Bob, 2010).

In 2006 a pig was controversially engineered to produce omega 3 fatty acids through the expression of a roundworm gene (Fiester, 2006). Researchers have also developed a genetically – modified breed of pigs that are able to absorb plant phosphorus more efficiently, and as a consequence the phosphorus content of their manure is reduced by as much as 60%.

Critics have objected to GM foods on several grounds, including safety issues, ecological concerns and economic concerns raised by the fact that these organisms are subject to intellectual property law (Lai, 2006).

Testing on GMOs in food and feed is routinely done using molecular techniques like DNA microarrays or qPCR. These tests can be based on screening genetic elements (like p35S, tNos, pat, or bar) or event – specific markers for the official GMOs (like Mon810, Bt11, or GT73). The array–based method combines multiplex PCR and array technology to screen samples for different potential GMOs, combining different approaches (screening elements, plant–specific markers, and event–specific markers). The qPCR is used to detect specific GMO events by usage of specific primers for screening elements or event–specific markers. A 5-digit Price Look–Up code beginning with the digit and indicates genetically modified food; however, the absence of the digit does not necessarily indicate the food is not genetically modified (King, 2003).

Food stuffs made of genetically modified crops that are currently available (mainly maize, soybean, and oil seed rape) have been judged safe to eat, and the methods used to test them have been deemed appropriate. However, the lack of evidence of negative effects does not meant that new genetically modified foods are without risk. The possibility of long–term effects from genetically modified plants cannot be excluded and must be examined. New techniques are being developed to address concerns, such as the possibility of the unintended transfer of antibiotic resistance genes (Key *et al*., 2008).

Growing genetically modified or conventional plants in the field has raised concern for the potential transfer of genes from cultivated species to their wild relatives. In the future, genetically modified plants may be equipped with mechanisms designed to prevent gene flow to other plants.

A controversy has arisen about whether certain genetically modified plants (which carry the Bt gene) could harm not only insect pests but also other species such as the monarch butterfly. The environmental effects of GM plants should be evaluated using science based assessment procedures, considering each crop to its conventional counterparts (FAO, 2004).

2.7 Previous work on irradiated sorghum

Some efforts were reviewed for some M.Sc. students who work on the effect of radiation on chemical, physical, morphological, nutritional and biochemical characteristics of *Sorghum bicolor*, e.g. Omer (2012); Dafalla (2012); Hamad (2011); Elsimet (2013) and Khalid (2013). Other irradiated crops like sesame, sunflower were also studied (Ahmed (2011); Omer (2012) and Dafalla (2012). Groundnuts and Jatropha are under investigations.

Some promising results were obtained from these efforts but the final confirmation of the safety was working on through more precise and intense researches.

Chapter Three

Materials and Methods

3.1 Materials

A sample of M_1 generation of sorghum seeds (*Sorghum bicolor*) was brought from Center of Biosciences and Biotechnology, Faculty of Engineering and Technology, University of Gezira, as a product of a running research. The sample was divided into six groups, tow groups were treated with low (LX) and high (HX) doses of X-ray (33.4 and 200.2 seconds, respectively) using X-ray device. Two groups were treated with low(LG) and high (HG) dose of gamma ray (200 and 800 CGY, respectively) using Co-60 device, at the Department of Radiation, National Cancer Institute, University of Gezira. The fifth group was treated with the ordinary used dose of UV(UV) light for sterilization purposes (for 30 minutes), at Food Microbiology Laboratory, Faculty of Engineering and Technology, University of Gezira, while the last group was used as a control.

3.2 Methods

3.2.1 Germination of sorghum samples

The six groups of sorghum seeds were planted with considerable distances between them in Complete Randomize Block Designed with three replication at the Experimental Farm, Faculty of Agricultural Sciences, University of Gezira, in July-October 2013. Each group was divided into four rows (the distance was 80 cm between rows and 100 cm between the plants with in the rows) i.e. the planted area for each treatment was 2.4X9 m = 21.6 m^2). The soil was prepared mechanically and the irrigation was derived directly from the main canal in the Farm, once a week. Weeding was done when requeried, no fertilizers nor pesticides were added throughout the experimental period.

3.2.2 Measuring of growth parameters and yield components

Samples of the growing sorghum (F_2) were submitted to some measurements (plant weight, shoot length, fibrous root/plant, number of leaves/plant, length of largest leaves and, number of tillers/plant). Three plant samples of each group were picked completely out of the soil every 10 days for a period of 60 days for such measurements as a replicate. After the complete maturation of sorghum heads, some of the productivity parameters were measured, (number of mature heads, seeds/head and mean weight of seed), based on three replications. The weight of plant and seeds were measured using an electrical balance, at the Food Analytical Laboratory, Faculty of Engineering and Technology, University of Gezira, while the length of plant shoot and leaves were measured using an ordinary scale ruler.

3.3 Statistical analysis

Microsoft office, excel 2007 was used to analyze the data obtained. Simple descriptive statistic (mean, standard error (SE), standard deviation (SD), maximum (Max) and minimum (Min) value and ANOVA single factor and two factors without replication tests (represented as f-stat, f-crit and *P-value*) were used to describe the observed variations between the control and the irradiated samples of sorghum. The difference will be significant whenever the critical (-crit) value is smaller than the statistical (-stat) value.

The regression analysis was also used to describe the relation between the observed increase in the growth parameters in accordance to the intervals of the test periods. R^2 (the correlation coefficient; which reflects the status of homogeneity), intercept (the expected value corresponding to day zero), x-coefficient (the constant rate of increase/day) and the standard error in X variable (SE-X) and in Y variable (SE-Y).were also obtained.

Chapter Four

Results and Discussion

4.1 Effect of radiation on the weight of sorghum plants

Table (4.1) showed the effect of X-ray, gamma ray and UV light on the weight (g) of sorghum plants (the second generation). The weight of the control samples increased from 0.47 to 230 g during a period of 60 days, with a constant rate of increase (X-coeff.) of 5.43 g/day, while in LX samples, it increased from 0.16 to 200 g, with a constant rate of increase of 3.92 g/day, whereas, in HX samples it increased from 0.14 to 193 g, with a constant rate of increase of 3.35 g/day. In UV samples, the weight of the sorghum plant increased from 0.14 to 219 g, with a constant rate of increase of 4.95 g/day, while those of LG and HG samples, the weight of the sorghum plants increased from 0.24 to 205 g, with a constant rate of increase of 4.32 g/day, and from 0.27 to 200 g with a constant rate of increase of 4.03 g/day, respectively. In comparison, there was slightly increase in plant weight in gamma ray treated samples, although the HX score a highest rate of increase (6.47 g/day). It was clear that, most of the plant weight was water. A similar research conducted by Khalid (2013), who found that, the moisture content was high in gamma rays treated samples followed by UV and then X-rays treated samples. The weight of the control and LG sorghum samples showed great homogeneity (R^2=0.93) in their increase during the test period followed by HG (0.91), UV (0.90), HX (0.83) and LX (0.72) samples.

Ahmed (2013), found that, after 50 days, the weight in the F_1 control *Sorghum* samples reached 140 g (lighter than F_2, which was 213 g), LX reached 125 g (heavier than F_2, which was 115 g), HX samples reached 220 g (lighter than F_2, which was just 60 g), UV samples reached 166 g (lighter than F_2, which was 180 g), LG samples, reached 180 (heavier than F_2, which was 150 g) and HG samples reached 210 g (heavier than F_2, which was 130 g).

Table (4.1) The weight (g) of the control and irradiated samples of sorghum (M2) plants during a period of 60 days from germination

HG	LG	UV	HX	LX	Control	Period (days)
0.27	0.24	0.14	0.14	0.16	0.47	10
1.37	1.30	2.57	1.89	1.16	2.27	20
3.06	1.81	4.88	5.67	4.11	9.64	30
30	43.33	110	38.33	34.33	130	40
130	150	180	60	115	213	50
200	205	219	193	200	230	60
The response of the different parameters studied for the different radiation doses						
0.798	0.825	0.892	0.713	0.802	0.887	R Square

80.364-	84.195-	87.07-	67.290-	77.967-	92.45-	Intercept
4.03	4.328	4.95	3.35	3.92	5.43	X-Coeff.
39.44	38.6	33.48	41.26	37.80	37.74	SE-Y
1.013	0.991	0.859	1.06	0.97	0.97	SE-X

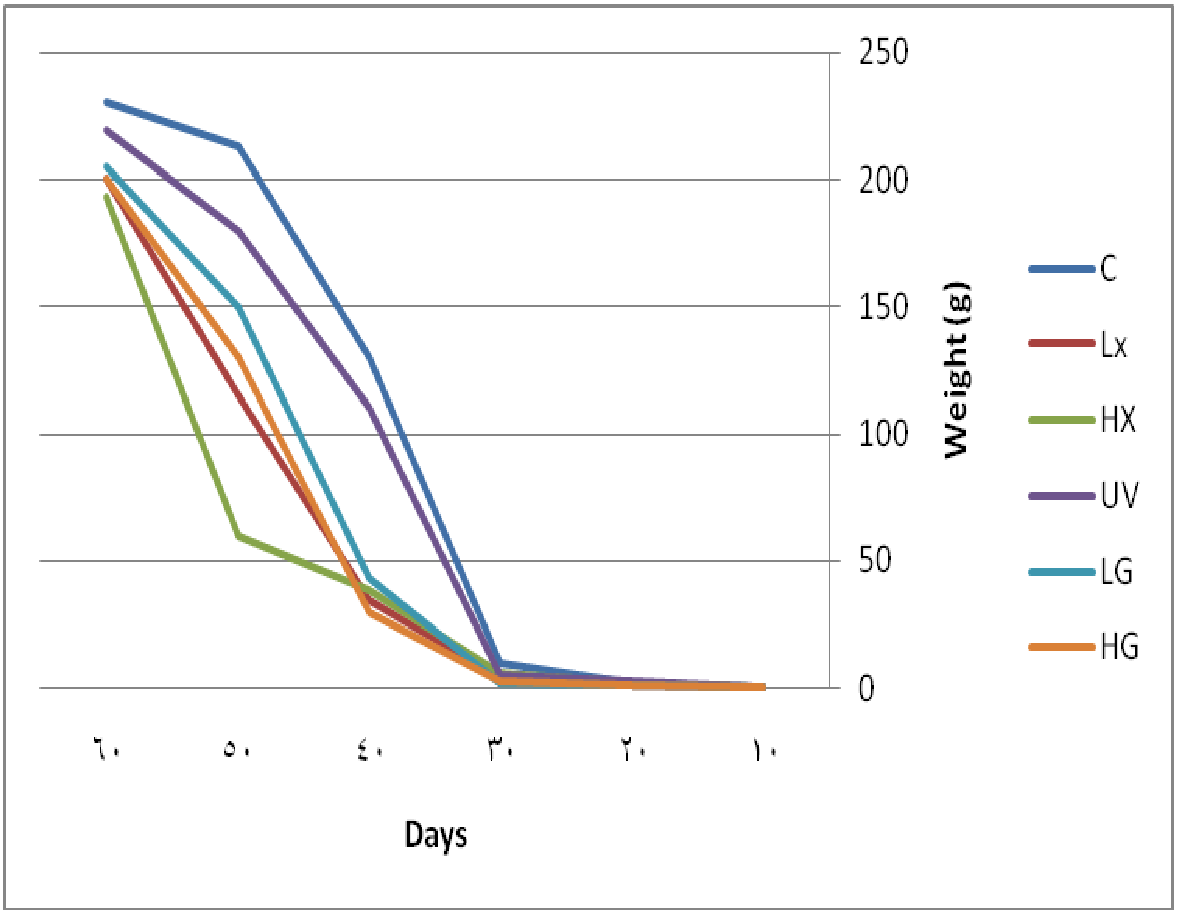

Figure (4.1) The weight (g) of the control and irradiated samples of sorghum (M2) plants during a period of 60 days from germination

4.2 The effect of radiation on the length of sorghum plants

The plant length in the control samples increased from 14 to 124 cm during a period of 60 days, with a constant rate of increase of 2.67 cm/day, while in LX samples it increased from 10 to 109.33 cm, with a constant rate of increase of 2.0 cm/day, whereas, in HX samples it increased from 8 to 104 cm, with a constant rate of increase of 2.01 cm/day. In UV samples, the length of the sorghum plants increased from 8 to 119 cm, with a constant rate of increase of 2.4 cm/day, in LG samples it increased from 10 to 123cm with a constant rate of increase of 2.29, the length of the sorghum plant in HG increased from 11 to 104 cm, with a constant rate of increase of 1.87cm/day(table 402). In comparison, there was a slight increase in plant length in the control samples over all irradiated samples, while the HX and HG showed the shortest samples.

The length of LG sorghum samples displayed great homogeneity (R^2=0.948) in their increase during the test period followed by LX (0.960), HX (0.968), HG (0.965), control (0.882) and lastly UV (0.951) samples.

Ahmed (2013), found that, after 50 days, the length in the M_1 control *Sorghum* samples reached 111.17, LX reached 113.33, HX samples reached 93.33, UV samples reached 93, LG and HG samples, reached 102.83 and 102.5 cm, respectively, while the result of M_2 were relatively shorter than M_1 (the differences ranged between 5.5 in HX to 23 cm in LX samples).

The length of stem varies between 0.5 to 4 m depending on the variety (Wang and Fields, 1978). The observed length in both control and irradiated sorghums, in this study remained within this limit.

Table (4.2) The length (cm) of the control and irradiated samples of sorghum plants (M2) during a period of 60 days from germination

HG	**LG**	**UV**	**HX**	**LX**	**Control**	**Period (days)**
11	10	8	8	10	14	**10**
26.33	24	28	25	23	28	**20**
31	29.33	32	29.67	29	35.33	**30**
57	61	79.67	63.67	62.67	82.33	**40**
80.67	92.67	109	87.67	89.67	104.67	**50**
104	123	119	104	109.33	124	**60**
The response of the different parameters studied for the different radiation doses						
0.965	0.948	0.951	0.968	0.960	0.882	**R Square**
13.735-	23.601-	21.955-	17.199	19.088-	22.78-	**Intercept**
1.868	2.293	2.416	2.005	2.086	2.671	**X-Coeff.**
6.91	10.44	10.44	7.06	8.21	19.03	**SE-Y**
0.177	0.268	0.268	0.181	0.210	0.488	**SE-X**

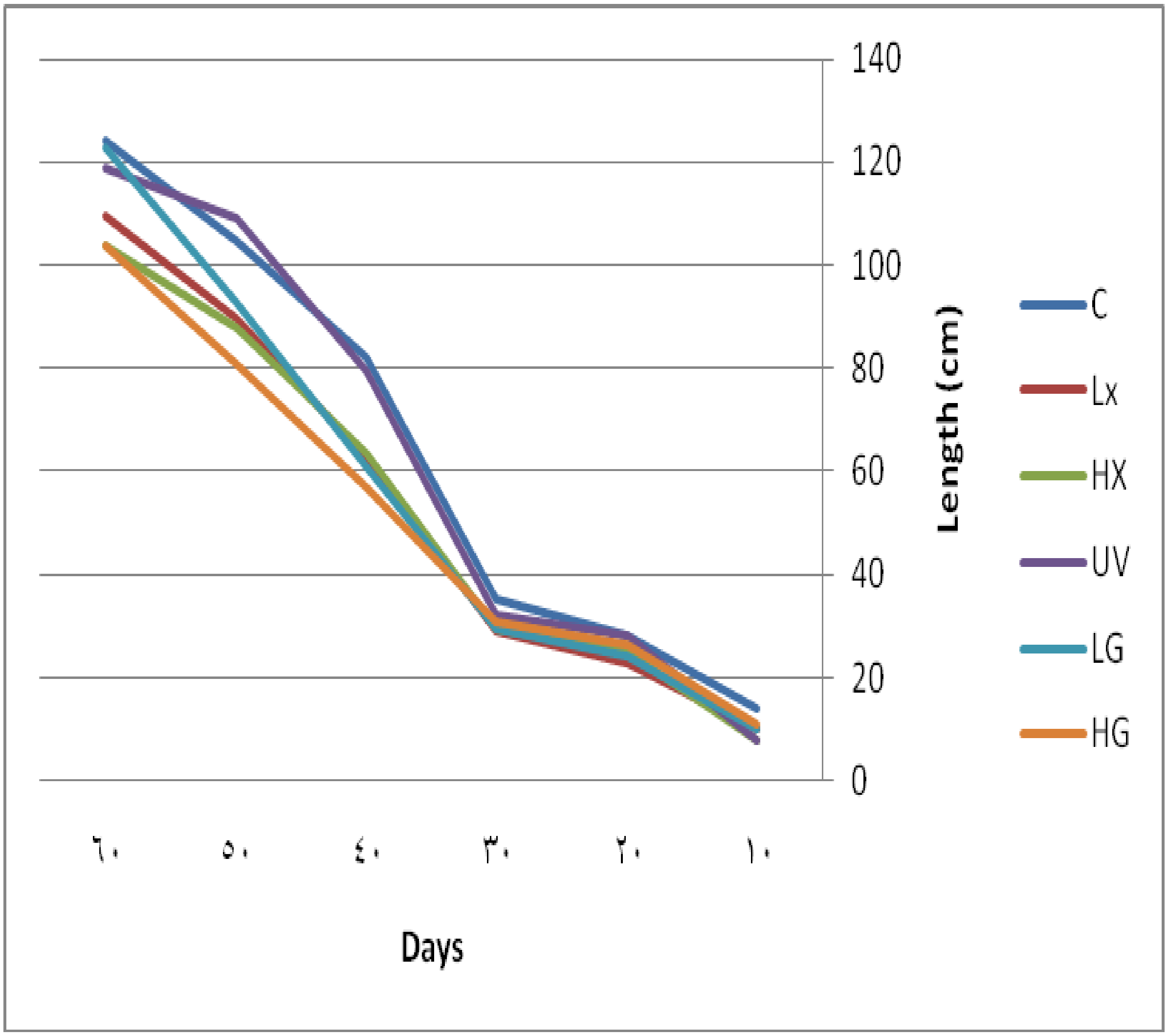

Figure (4.2) The length (cm) of the control and irradiated samples of sorghum plants (M2) during a period of 60 days from germination

4.3 Effect of radiation on the number of fibrous roots of sorghum plants

The Number of fibrous roots in the second generation of sorghum plants that were irradiated with X- and gamma rays and UV light were presented in (Table, 4.3). From 9 roots, the roots in the control sorghum plant increased to 60.67 roots/plant after the period of 60 days, with a constant rate of increase of 1.18 roots/day, while in LX samples it increased from 6 to 57.67 roots/plant, with a constant rate of increase of 1.11 roots/day, whereas, in HX samples it increased from 5 to 55 roots/plant, with a constant rate of increase of 1.08 roots/day. In UV samples, the fibrous roots increased from 5 to 58.33 roots/plant, with a constant rate of increase of 1.17 roots/day, while those of LG and HG samples, increased from 6 to 63 roots/plant, with a constant rate of increase of 1.21 roots /day, and from 7 to 56.33 roots/plant with a constant rate of increase of 1.0 roots/day, respectively.

In comparison, there was a clear increase in plant roots in gamma ray samples(LG), over the other samples, while LX samples showed slightly fewer roots/plant.

The number of roots of LX samples showed great homogeneity (R^2=0.956) in their increase during the test period followed by LG sorghum samples (0.960), then HX (0.921), HG (0.972) and control (0.862) and lastly UV (0.878) samples.

Ahmed (2013), found that, after 50 days, the number of fibrous roots in the M_1 Sorghum in the control reached 39 root/plant, LX samples reached 35.67, HX samples reached 44.33, UV samples reached 39.33 LG and HG samples reached 56.67 and 55.33 roots/plant, respectively, which were relatively fewer than M_2 samples (except in LG which was typical in both generations), and the differences ranged between 7 in HG to 22.33 in the control samples. This may be due to the sawing dates which met autumn in the M_2 while it met winter in M_1 generation.

Table (4.3) Number of roots/plant of the control and irradiated samples of sorghum (M2) during a period of 60 days after germination

HG	**LG**	**UV**	**HX**	**LX**	**Control**	**Period (days)**
7	6	5	5	6	9	**10**
20.17	19	24	20	18.17	21.33	**20**
23.33	21.33	24	21.67	22.33	26.67	**30**
42.33	46	55	47.33	45.33	61.33	**40**
48.33	56.67	61.33	54.67	53.67	61.33	**50**
56.33	63	58.33	55	57.67	60.67	**60**
The response of the different parameters studied for the different radiation doses						
0.972	0.960	0.878	0.921	0.956	0.862	**R Square**
2.098-	6.934-	3.020-	4.022-	4.923-	1.246-	**Intercept**
1.00	1.21	1.17	1.08	1.11	1.18	**X-Coeff.**
3.26	4.78	8.46	6.17	4.59	9.16	**SE-Y**
0.08	0.12	0.22	0.16	0.12	0.24	**SE-X**

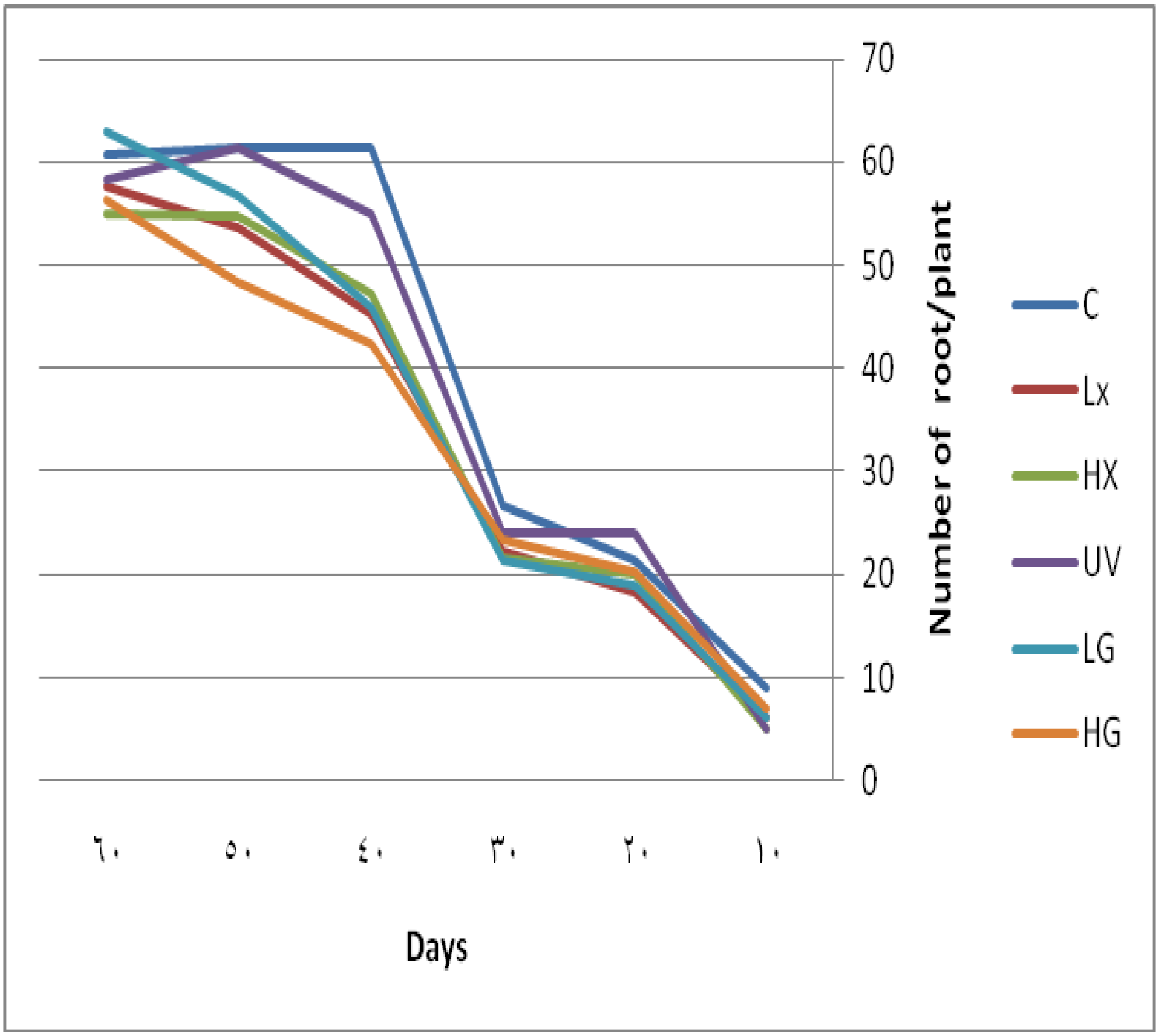

Figure (4.3) Number of roots/plant of the control and irradiated samples of sorghum (M2) during a period of 60 days after germination

4.4 Effect of radiation on the number of tillers/sorghum plant

The number of tillers in the second generation of sorghum plants irradiated with x-, gamma rays and UV light were presented in (Table, 4.4). From one main plant, the tillers in the control sorghum plant increased to 12 tillers/plant during the period of 60 days, with a constant rate of increase of 0.23 tillers/day, while in LX samples the increased to 10.33 tillers /plant, with a constant rate of increase of 0.19 tillers/day, whereas, in HX samples the increased to 9.67 tillers/plant, with a constant rate of increase of 0.19 tillers/day. In UV treated samples, the tillers increased to 13.33 tillers/plant, with a constant rate of increase of 0.25 tiller/day, while those of LG and HG samples, to 12 tillers/plant, with a constant rate of increase of 0.21 tillers/day, and to 9.67 tillers/plant with a constant rate of increase of 0.16 tillers/day, respectively.

In comparison, there was a slight increase in tillers/plant in UV and LG treated samples, over the other irradiated samples, while HG and HX samples showed slightly fewer tillers/plant. The number of tillers/plant showed relatively great homogeneity in all samples; in LG samples (0.956), HX (0.917), UV (0.984) HG (0.956) and LX (0.970), while that of the control samples was (0.989).

Ahmed (2013), found that, after 50 days, the number of tillers in the M_1 control sorghum increased to 8, in LX it increased to 6.33, in HX samples it increased to 6.67, in UV samples it increased to 7, while those of LG and HG samples were increased to 9.67 and to 7.67 tiller/plant, respectively. The number of tillers/plant were relatively few in M_1 than M_2 (except in gamma irradiated samples which were similar in both generations), and the differences did not exceed 4.

Sorghum plant, either control or irradiated, was started to form tillers after ten days of germination, and this observation was similar to Hancock (2009) who stated that, Sorghum plants in the 4 to 6-leaf stage will tiller when the average daily temperature is below 65 F.

Table (4.4) Number of tillers/plant of the control and irradiated samples of sorghum(M2) during a period of 60 days from germination

HG	**LG**	**UV**	**HX**	**LX**	**Control**	**Period (days)**
1	1	1	1	1	1	**10**
3.67	3	3	3	3.33	3	**20**
5.67	3.67	6	5.67	6	5.33	**30**
7	5.67	7	9	8	8	**40**
7.33	9	11	9.33	9.67	11	**50**
9.67	12	13.33	9.67	10.33	12	**60**
The response of the different parameters studied for the different radiation doses						
0.956	0.956	0.984	0.917	0.970	0.989	**R Square**
0.16	-1.78	-1.78	-0.29	-0.38	-1.45	**Intercept**
0.16	0.21	0.25	0.19	0.19	0.23	**X-Coeff.**
0.67	0.90	0.61	1.10	0.66	0.47	**SE-Y**
0.02	0.02	0.02	0.03	0.02	0.01	**SE-X**

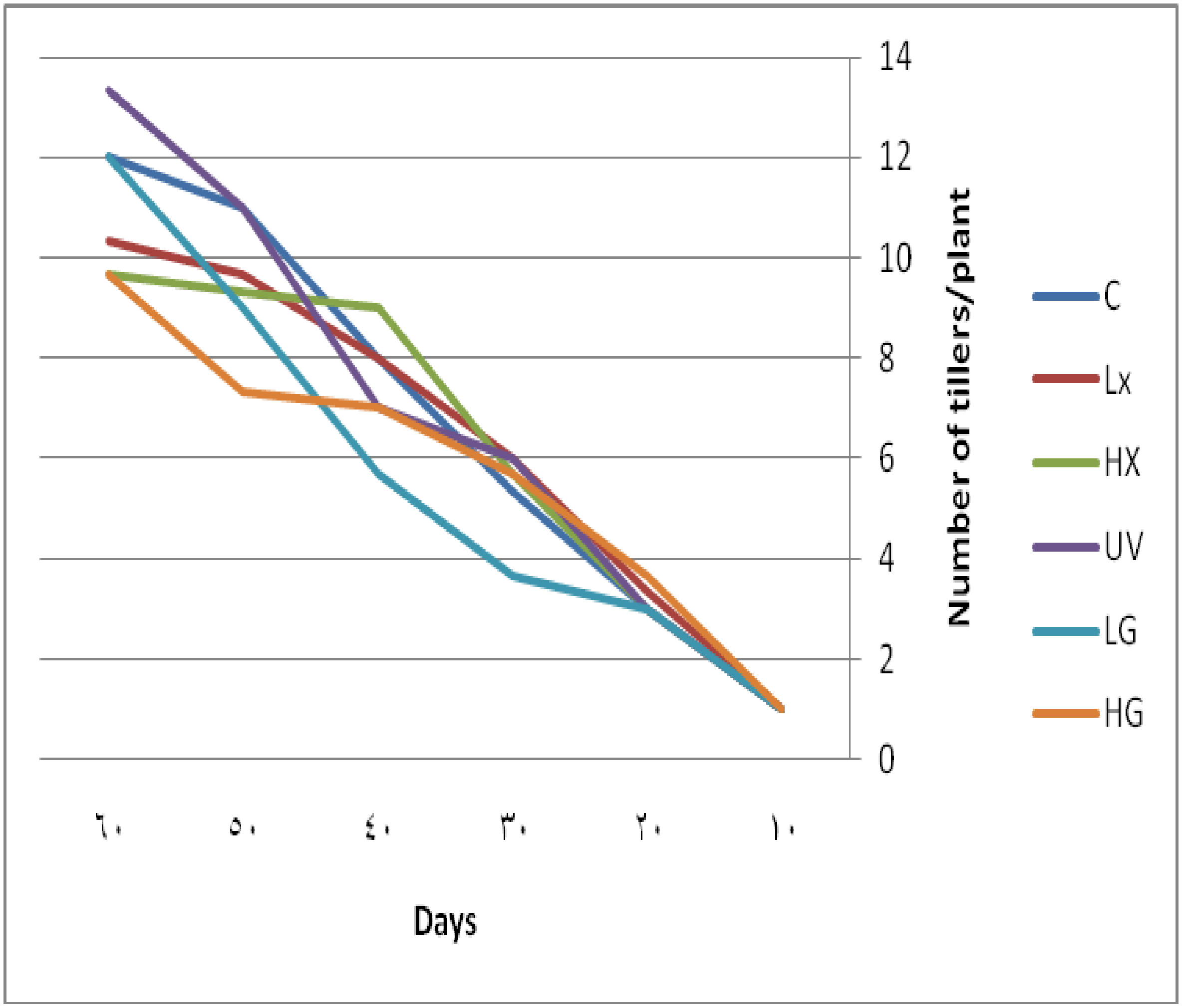

Figure (4.4) Number of tillers/plant of the control and irradiated samples of sorghum(M2) during a period of 60 days from germination

4.5 Effect of radiation on the number of leaves/sorghum plant

Table (4.5) showed the effect of x-ray, gamma-ray and UV light on the number of leaves in the second generation of sorghum plants. From four leaves/plant (except it was 5 in the control) at the 10th day from germination in all groups, the leaves in the control sorghum increased to 26 leaves/plant at the end of 60 days, with a constant rate of increase of 0.67 leaves/day, while in LX samples it increased to 14 leaves/plant, with a constant rate of increase of 0.20 leaves/day, whereas, in HX samples it increased to 20 leaves/plant, with a constant rate of increase of 0.41 leaves/day. In UV samples, the leaves increased to19 leaves/plant, with a constant rate of increase of 0.38 leaves/day, while those of LG and HG samples, were increased to 21 leaves/plant, with a constant rate of increase of 0.39 leaves/day, and to 18 leaves/plant with a constant rate of increase of 0.31 leaves/day, respectively.

In comparison, the leaves/plant in all irradiated samples, by day 60, were less than the control (LX=14, HG=18 , HX=26 ,UV=25 , LG=21 and control =26). The count of leaves/plant showed high homogeneity (0.90 - 0.94), except in LX (0.88).

Ahmed (2013), found that, after 50 days, the number of leaves/plant in the M_1 control and treated sorghum fall within the normal range of leaves/plant (12 – 18) that was suggested by Wang and Fields (1978). The number of leaves/plant in this work (M_2) were seemed similar to that of M_1, except in the control and LG samples.

The plant remains in vegetative stage for 30 to 40 days during which all leaves (12 to 18) are formed. The stem of sorghum consists of many alternating nodes and internodes. Early-maturing hybrids typically produce 15 leaves per plant, while medium- and late-maturing hybrids produce 17 and 19 leaves each (Thomas *et al*., 2013).

Table (4.5) Number of leaves/plant of the control and irradiated samples of sorghum plants (M2) during a period of 60 days from germination

HG	**LG**	**UV**	**HX**	**LX**	**Control**	**Period (days)**
4	4	4	4	4	5	**10**
6	6	7	6	7	10	**20**
6	7	9	11	8	20	**30**
14	18	10	15	10	22	**40**
16	19	16	18	13	25	**50**
18	21	19	20	14	26	**60**
The response of the different parameters studied for the different radiation doses						
0.918	0.899	0.881	0.870	0.981	0.913	**R Square**
-0.13	-1.00	-1.47	-0.87	2.33	-2.87	**Intercept**
0.31	0.39	0.38	0.41	0.20	0.67	**X-Coeff.**
1.78	2.51	2.72	3.06	0.54	4.07	**SE-Y**
0.05	0.06	0.07	0.08	0.01	0.10	**SE-X**

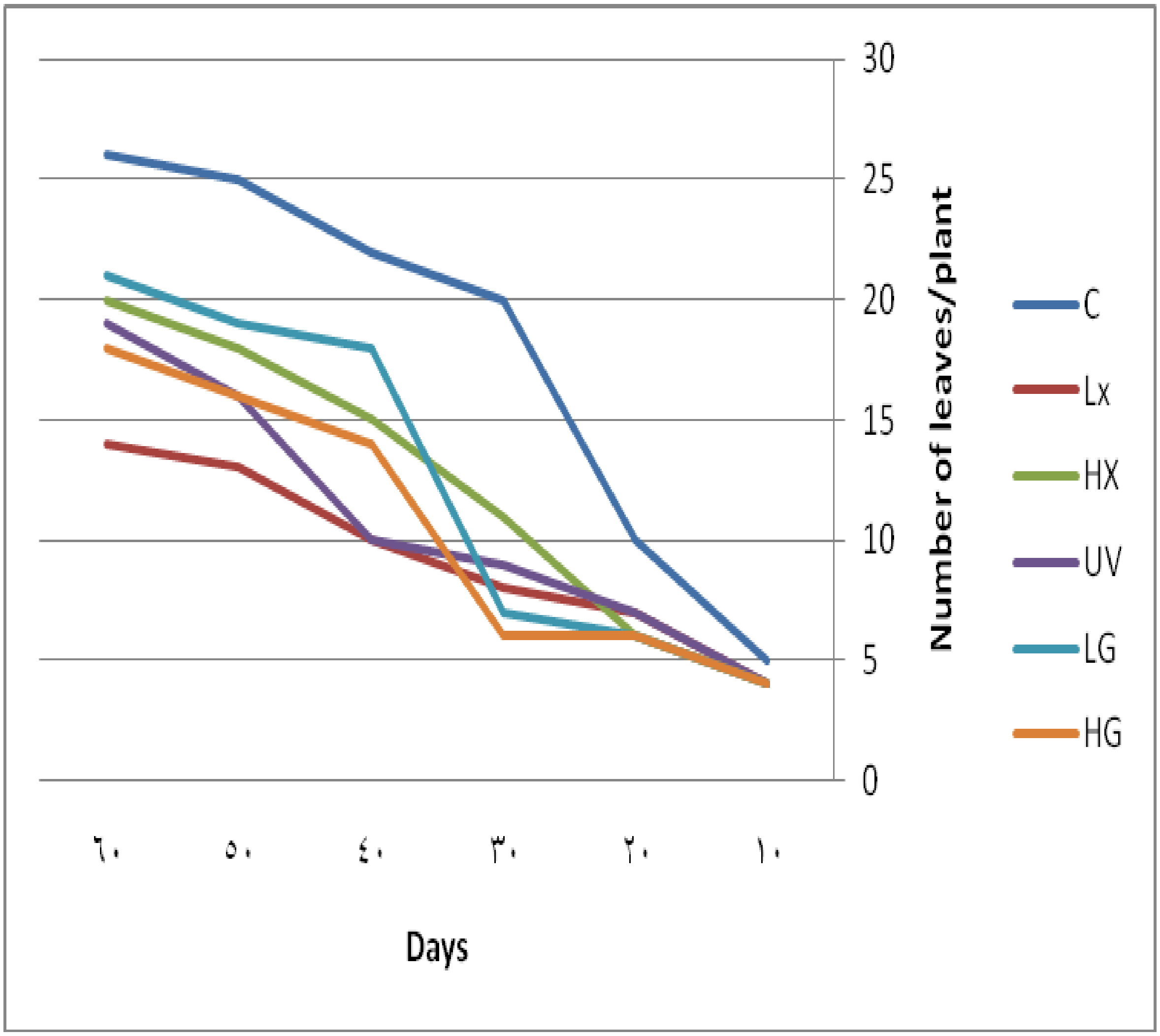

Figure (4.5) Number of leaves/plant of the control and irradiated samples of sorghum plants (M2) during a period of 60 days from germination

4.6 Effect of radiation on the length of the largest sorghum leaves

As was shown in Table (4.6), from less than 5 cm long at the 10th day in all groups, all irradiated samples except LG (39 cm), after 60 days, had relatively shorter leaves (HG= 30, HX= 26, LG= 39, LX= 30 and UV= 32 cm) than control (35 cm). All irradiated samples showed relatively low constant rate of increase in the length of the largest leaves than control (0.74 cm/day), which were LX (0.59) ,HX(0.52),UV (0.64), LG (0.72) and HG (0.54).

The levels of homogeneity followed the same order of the length of largest leaves (R^2 were 0.96 in HG, 0.96 in HX, 0.93 in LG, and 90 in UV) than in control (0.88) samples, while LX had the highest level of homogeneity 0.98.

It was clear that, the M_2 sorghum samples had shorter (the length of the taller leaves ranged between 22 in HG to 34 cm in control) taller-leaves than M_1, in which Ahmed (2013), found that, all irradiated samples, after 50 days, had relatively taller leaves (HG= 85, HX= 80, LG= 74, LX= 72 and UV= 70 cm) than control (67 cm).

The growth parameters data (for 60 days), were submitted to simple correlation analysis so as to determine the levels and types of correlation between each two of these parameters (Table, 4.7). It was obvious that, there were positive correlations (of about 0.65 and more) between plant weight and plant length (0.80), plant weight and number of tillers/plant (0.77), plant weight and number of leaves/plant (0.76), plant length and number of roots/plant (0.90), plant length and number of tillers/plant (0.87), plant length and length of largest leaves (0.87), number of roots/plant and number of tillers/plant (0.66), number of tillers/plant and the length of taller leaves (0.65) and number of roots/plant and length of taller leaves (0.99), which was the largest correlation value. Other small values of correlations were also observed and cannot be ignored in showing the correlation between all growth parameters.

Similar observations were also pointed in some of the growth parameters in M_1 sorghum as was reviewed by Ahmed (2013).

Table (4.6) The length (cm) of the largest leaves in the irradiated samples of sorghum (M2) during a period of 60 days after germination

HG	**LG**	**UV**	**HX**	**LX**	**Control**	**Period (days)**
2	3	4	3	3	3	**10**
8	7	8	6	6	8	**20**
9	8	11	12	12	13	**30**
15	20	29	20	19	34	**40**
22	27	30	26	27	34	**50**
30	39	32	26	30	35	**60**
The response of the different parameters studied for the different radiation doses						
0.961	0.935	0.896	0.957	0.982	0.878	**R Square**
-4.466	-7.866	-3.4	-2.8	-4.33	-4.733	**Intercept**
0.537	0.72	0.64	0.522	0.585	0.74	**X-Coeff.**
2.10	3.67	4.25	2.14	1.51	5.36	**SE-Y**
0.05	0.09	0.11	0.05	0.04	0.14	**SE-X**

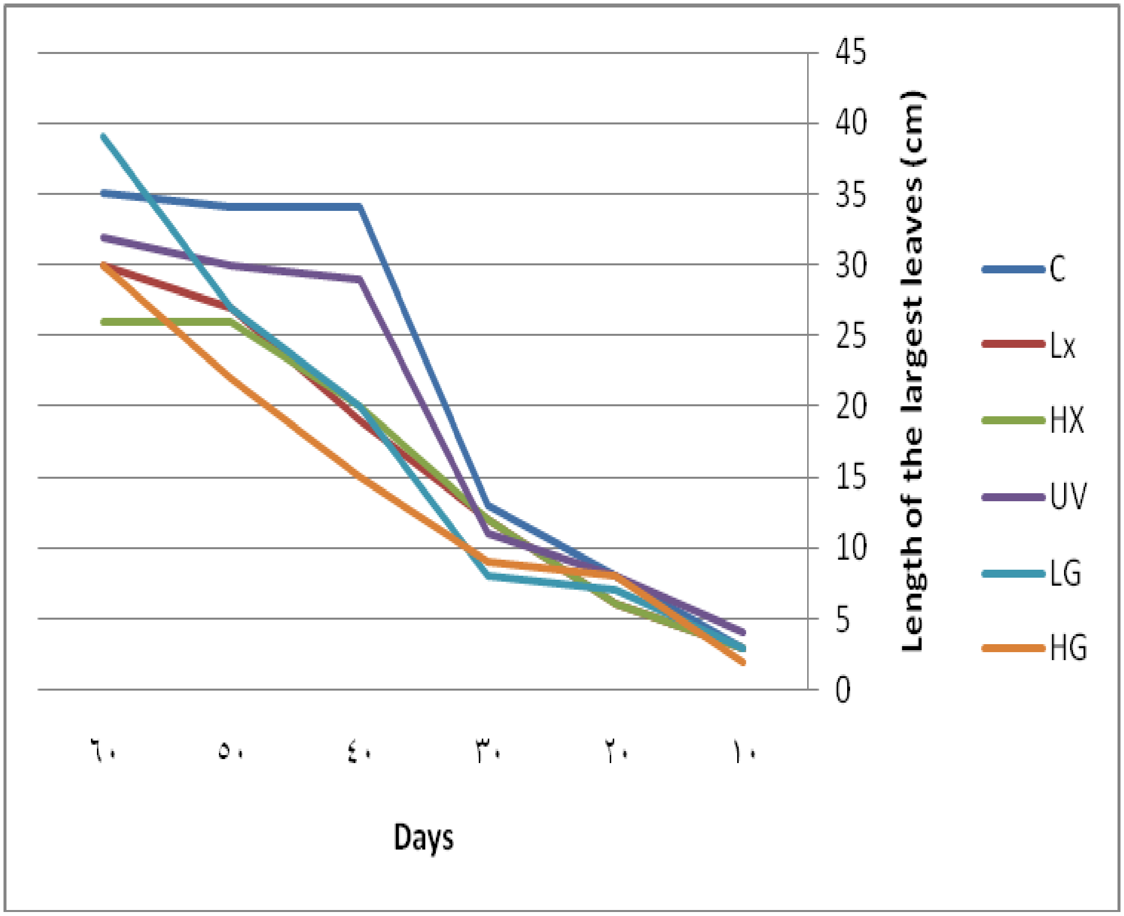

Figure (4.6) The length (cm) of the largest leaves in the irradiated samples of sorghum (M2) during a period of 60 days after germination

Table (4.7) The correlation between the growth parameters of the control and irradiated samples of sorghum plants after 60 days

HG	LG	UV	HX	LX	Control	Parameter
200	205	219	193	200	230	**Plant weight (g)**
104	123	119	104	109.33	124	**Plant length (cm)**
56.33	63	58.33	55	57.67	60.67	**N roots/plant**
9.67	12	13.33	9.67	10.33	12	**No tillers/plant**
18	21	19	20	14	26	**No leaves/plant**
30	39	32	26	30	35	**taller leaves (cm)**

No. leaves/ plant	***No. tillers /plant***	***No. roots/plant***	***Plant length(cm)***	***Plant weight (g)***	
				0.801	**Plant length (cm)**
			0.903	0.536	**No roots/plant**
		0.656	**0.872**	**0.774**	**No tillers/plant**
	0.394	0.284	0.546	**0.764**	**No leaves/plant**
0.246	**0.649**	**0.986**	**0.873**	0.532	**largest leaves (cm)**

4.8 Effect of radiation on the yield of sorghum

After about 100 days (The cultivated sorghums mature in 100 to 140 days depending on the variety, as was stated by Purseglove (1972), all irradiated groups resulted in considerably fewer number of mature heads (LX=118, HX= 109, UV= 99, LG= 100 and HG= 80) than the control (186). All irradiated groups gave considerably higher number of seeds/head (LX= 1510, HX= 598, UV= 590, LG= 1090 and HG= 1100) than the control (530). In M_1 sorghum, the number of seeds/head deteriorated (LX= 654, HX= 839, UV= 884, LG= 850.67 and HG= 857 and control= 175.33) according to Ahmed (2013).

All irradiated groups gave relatively heavier seeds (LX= 0.040, HX= 0.036, UV= 0.041, LG= 0.038) than the control (0.036 g), except HG (0.034 g). In M_1 sorghum, the mean weights of seeds were deteriorated (LX= 0.036, HX= 0.03, UV= 0.034, LG= 0.036 and HG= 0.034 and control= 0.029 g). On average, individual sorghum seed weigh about 0.025 g, but it can range from 0.013 to 0.040 g (Thomas *et al*., 2013). The obtained seed weights in this work were similar to these ranges, except for UV samples.

The yield parameters in the second generation of irradiated sorghum plants can easily be evaluated (hypothetically). Each of the mean seed weight was multiplied by the count of seeds/head of each group to obtain the weight of each mature head (ignoring the non-seed portion of the head). The head weight of each group was also multiplied by the number of mature heads of each group to obtain the production of each group in the growing area, which were 3548.88 g/area for the control, 7127.2 for LX, 2346.55 for HX, 2394.81 for UV, 4142 for LG and 2992 g for HG per growing area. In F_2, the weight of each mature head (ignoring the non-seed portion of the head), was 19.08 g for the control, 20.40 g for LX, 21.52 g for HX, 24.19 g for UV, 41.42 for LG and 37.40 g for HG.

Since one feddan is equivalent to 4200 m^2, the productivity in 21.6 m^2 must be multiplied by 194.44 to be converted in terms of kg/feddan. The productivity of the groups in term of kg/ feddan were 690.07 for the control, 1385.77 for LX, 456.35 for HX, 465.68for UV, 805.37 for LG and 581.76 for HG. Since that one feddan is equivalent to 0.42 ha, the productivity in feddan must be divided by 0.42 to be converted to kg/ha. Giving 1643.02for the control (the least), 3299.45for LX, 1086.54 for HX (the highest), 1108.76 for UV, 1917.54 for LG and 1385.14 for HG, were the hypothetical production of sorghum in terms of kg/ha. The different treatments revealed significant difference in productivity parameters (f- 24.98; f-crit=3.29).

Although , LX production was about two folds that of the control and LG showed higher productivity than the control, but ANOVA analysis revealed that, the control and the irradiated samples did not differ significantly in their productivity parameters (f- 1.53; f-crit=2.90). This finding can be attributed to the advantages of the number of heads in the control samples, in addition to the relative similarity of seeds weight between control and 3 of the irradiated samples, except LX and UV.

Table (4.8) The mean production parameters of control and irradiated samples of sorghum plants (M2)

HG	LG	UV	HX	LX	Control	Parameter
80	100	99	109	118	186	**Number of heads**
1100	1090	590	598	1510	530	**Seeds/head**
0.034	0.038	0.041	0.036	0.040	0.036	**Seed weight (g)**
2.992	4.142	2.395	2.347	7.127	3.549	**Production kg/21.6 m^2**
581.76	805.37	465.68	456.35	1385.77	690.07	**Production kg/feddan**
1385.14	1917.54	1108.76	1086.54	3299.45	1643.02	**Production kg/ha**

ANOVA

F crit	*P-value*	*F*	*MS*	*Df*	*SS*	*Source of Variation*
3.29	4.39E-06	24.98	18501571	3	55504712	Rows
2.90	0.240596	1.53	1129979	5	5649896	Columns
			740611.6	15	11109173	Error
				23	72263782	Total

The average world productivity of sorghum was 1370 kg/ha and it reached 12700 kg/ha in the most productive farms in some countries (Carter *et al*., 2013). The productivity of the control (1643.02 kg/ha), although it was relatively high than the average rate of production (1370 kg/ha), but it depended on having zero lost (i.e. it was calculated including each single seed in the head). In the same condition, irradiated samples of sorghum gave high productivity than the control. It reached 1086.54 kg/ha in HX samples, 3299.45 kg/ha in LX samples, 1385.14 kg/ha in HG, while it was 1108.76 in UV samples.

It was also observed that, the mature heads were fewer in all irradiated samples in comparison to the control, but the seeds/head and the seeds weight were far more in the irradiated samples in comparison to the control which in calculations it over compensated the situations, which were reflected in the productivity of each treatment in kg/ha.

Chapter Five

Conclusions and Recommendations

5 .1 Conclusions

X-and gamma rays and UV light affected the morphology and yield components of sorghum compared to the control samples. Some of the treated samples resulted in very good vegetative growth parameters and yield components, heavier plant weight, more number of leaves, very strong growth roots, larger leaves and higher yield components, but a reduction in the plant height was also observed (this is a desired character that facilitate the harvesting method).

5.2 Recommendations

- Further studies should investigate adaptability and resistance to pests and diseases.
- More important molecular genetic tests should be used.
- More concern should be oriented to sorghum flour.
- GM sorghum should be compared with the irradiated samples.
- Edibility aspects of the irradiated products should be studied.

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