WebLog Journal of Agricultural and Crop Sciences

Research Article
Published: 25 Jul, 2026

Effect of Gamma Radiation of Cesium (Cs137) on Morphological Changes of Sunflower During Two Seasons

El-Hefny A. M[1], Abd El-Rahman Abd El-Raouf Ahmed[2]*, Mahenor Arabiy Ebrahim[2], Osama Anwar Abd El-Hameed[2], Rasha S. Ahmed[2] and Sara Abd El-Rahman Abd El-Raouf[3]

[1]Natural Products Research Department, National Center for Radiation Research and Technology, Egyptian Atomic Energy Authority, Cairo, Egypt

[2]Agricultural Engineering Research Institute, Agriculture Research Center, P.O. Box 256, Dokki, Giza, Egypt

[3]Rural Sociology and Agricultural Extension Department, Agricultural Faculty, Ain Shams University, Egypt

WebLog Open Access Publications
Article ID : wjacs.2026.g2501
Author : Abd El-Rahman Abd El-Raouf Ahmed

OPEN ACCESS

***Correspondence:**
Abd El-Rahman Abd El-Raouf Ahmed, Agricultural Engineering Research Institute, Agriculture Research Center, P.O. Box 256, Dokki, Giza, Egypt, Tel: +201004314922;
E-mail: abdo_aaaa2000@yahoo.com

Received Date: *01 Jun 2026*
Accepted Date: *23 Jul 2026*
Published Date: *25 Jul 2026*

Citation:
El-Hefny A. M, Abd El-Rahman Abd El-Raouf Ahmed, Arabiy Ebrahim M, Anwar Abd El-Hameed O, Ahmed RS, Abd El-Rahman Abd El-Raouf S. Effect of Gamma Radiation of Cesium (Cs137) on Morphological Changes of Sunflower During Two Seasons. WebLog J Agric Crop Sci. wjacs.2026.g2501. https://doi.org/10.5281/zenodo.21740601

Abstract

This research was studied different gamma radiation doses were applied to sunflower seeds to determine their effects on some plant characteristics. sunflower (*Helianthus annuus* L.) seeds which were irradiated with 0, 5, 10, 15, 20, 25, and 30 Gy of gamma radiation in a cesium (Cs137) before cultivation in two seasons. The morphological changes of sunflower plants such as plant length, leaf area, stem diameter, (chlorophyll (a), (b) and total chlorophyll and total coronoids pigments), (leaf, disc, full plant of fresh weights) were measured. Obtained results were as follows:

Leaf area of plant and plant length: It shows that increasing the dose from 5 to 25 Gy led to increases the leaf area of plant and plant length from (4287.1 to 7284.2 cm^2), and (213.3 to 237 cm), then the leaf area and length of plant decrease to (5387.1 cm^2), and (217 cm) at a dose of 30 Gy in the first season. In the second season, the leaf area and length of plant ere increased from (3735.4 to 5377.4 cm^2), and (192 to 225.6 cm), then decreases to (4274.1 cm^2), and (215 cm) at a dose of 30 Gy., compared to untreated sample (control) which was (3720.1 and 3584.2 cm^2) and (193.3 and 187.6 cm) for first and second seasons, respectively. These results indicate that the leaf area and length of plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

Fresh full plant weight and fresh discs weight/plant: It shows that increasing the dose from 5 to 25 Gy led to increases the fresh full plant weight and fresh discs weight/plant from (475.6 to 861.6 g), and (233.7 to 299.9 g) then the fresh full plant weight and fresh discs weight/plant decreases to (669.6 g), and (256.8 g) at a dose of 30 Gy in the first season. In the second season, the fresh full plant weight and fresh discs weight/plant increases from (354.6 to 744.2 g), and (149.0 to 266.6 g) then decreases to (549.1 g), and (214.4 g) at a dose of 30 Gy., compared to untreated sample (control) which was (347.2 and 302.8 g), and (129.0 and 120.7 g) for first and second seasons, respectively. These results indicate that the fresh full plant weight and fresh discs weight/plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

Keywords: Morphological Changes; Growth Parameters; Sunflower; Gamma Radiation (Cesium-137)

Introduction

Sunflower (*Helianthus annuus* L.) is recognized as one of the world's most important oilseed crops, making a substantial contribution to global agricultural economies [7, 18]. The seeds are valued for their nutritional and health benefits, being consumed directly or processed into vegetable oil, while the resulting byproducts are utilized as animal feed [19, 33]. Due to its diverse economic applications, sunflower ranks as the fourth most significant oilseed crop globally [8]. Morphological abnormalities, including misshapen and mottled leaves, were observed in plants treated with doses exceeding 100 Gy. However, these changes were temporary and resolved with leaf maturity, suggesting that they resulted from physiological stress rather than stable genetic mutations. No alterations in flower color or structure were detected in any treatment group. Overall, while lower doses (100–200 Gy) permitted moderate vegetative growth, higher doses (300–500 Gy) increasingly suppressed growth and survival, with 440 Gy identified as the threshold for 50% lethality. These findings indicate that gamma radiation doses near the LD50 may be suitable for inducing desirable traits—such as dwarf stature—in future mutation breeding programs [44]. Sunflower plants treated with a combination of biotic and abiotic inducers—specifically, an aqueous extract of *Chenopodium album* (6%) and low-dose gamma radiation (6 Gy)—demonstrated improved control of Fusarium root rot, a devastating disease caused by *Fusarium solani*. Disease incidence was reduced from 47.49% in untreated controls to 28.25% in treated plants. This combined treatment approach may serve as an environmentally friendly supplement for the management of soil-borne pathogens, particularly *F. solani* [2]. Due to its short wavelength, gamma radiation has a high penetrating power and is an example of ionizing radiation. This is released by some of the most popular breeding programs, such radio induced mutagenesis, to create genetic diversity that hardly occurs in nature [24].

El-Beltagi HS *et al.* (2023) evaluate the effects of gamma ray, UV-C, UV-A (ultraviolet) treatments as seed priming on the growth, yield, quality, and the storage ability of cauliflower heads. The seeds were exposed to the following treatments: 50 and 75 kGy (gamma ray), UV-C for 15, 30, 45 minutes, and UVA for 15, 30, 45 minutes. The results indicated that gamma ray, UV-C, and UV-A treatments enhanced the plant growth characteristics including plant height, leaf length, number of leaves, plant fresh weight, SPAD reading, and plant dry weight. Additionally, the cauliflower seeds treated with different treatments showed higher total yield, head diameter, and head weight than the control plants. The storage ability including weight loss, total soluble solids, and antioxidant capacity during refrigerated storage of cauliflower heads was not affected by the different treatments, however UVA treatment enhanced vitamin C and phenolic compounds compared to the control. Sevil and Ulakoglu (2019) studied different gamma radiation doses were applied to two sunflower varieties seeds to determine their effects on some plant characteristics in plants and to determine GR50 doses for effective mutation dose values in mutation breeding studies. The effect of gamma irradiation on the germination percentage and seedling height (cm) of two sunflower varieties was investigated at different doses (0, 50, 100, 150, 200, 250, 300, 400 and 500 Gy). Gamma radiation was applied to seeds from Cesium-137 (137Cs) source. The trial was conducted as a split-plot experimental design in three replications. As a result, germination percentages of sunflower varieties were not affected with increasing radiation doses. But, as parallel to increasing doses applied of gamma radiation dose seedling height (cm) were affected negatively. On the other hand, the doses that decrease growth by 50 percent (GR50) for AS508 and Nantio were found to be 148 Gy and 165 Gy, respectively. Díaz et al. (2018) studied the effect of 60Co gamma irradiation, in the sunflower crop, were irradiated achenes in the Transelektro LGI-01 in the Instituto Nacional de Investigaciones Nucleares. The response variables were: plant height, root length and volume, dry biomass. The results indicated that germination and sprouting decreased as the radiation increased, adjusting these to a quadratic model. Plant height, length, root volume and dry biomass decreased at high doses. From this investigation it was concluded, that doses of 100 and 200 Gy, have a stimulating effect on plant height and root length, being an important agent, to induce genetic variability in sunflower. Rifnas et al. (2022) conducted to determine the effective doses of gamma radiation for mutational breeding of sunflower (*H. annuus* L.) on vegetative growth performances. Sunflower seeds were exposed to different doses of gamma radiation (0 Gy, 100 Gy, 200 Gy, 300 Gy, 400 Gy and 500 Gy) as treatments. Treating the sunflower seeds with gamma radiation has a significant ($p<0.05$) effect on the tested parameters except on germination percentage. Untreated plants with gamma radiation and plants treated with lower doses of gamma radiation (100 and 200 Gy) showed comparable values in percentage survival as 100%, 94.5% and 92.5%, respectively. LD50 value was recorded as 440 Gy. A reducing trend in values in the measured variables has been observed with the increase in gamma radiation doses. The lowest values in all observations were recorded by the seeds exposed to 500 Gy, which is the highest dosage used in this experiment. One way of creating genetic variation in sunflower is by inducing mutations through gamma radiation. In order to improve plant production and traits, mutation breeding, the most beneficial and crucial technology for sunflowers [31].

El-Demerdash (2007) studied the effect of γ- irradiation doses 100, 150 and 200 Gy on soybean plants. It was found that plant height and number of branches per plant were deceased by γ- irradiation. Minimum plant height was recorded in plants treated with 600 Gy dose of gamma radiation. In chrysanthemum [4] and African marigold [49] have also been reported comparable observations. However, Diaz *et al.* (2018) have reported that contrasting observations in sunflower. According to their study, although plant height had decreased at higher doses of gamma irradiation, the lower doses of 100 Gy and 200 Gy had a stimulating effect on plant height. El-Sharnouby *et al.* (1997) established that *Hibiscus sabdariffia* seed exposed to γ- irradiation at (0, 1, 2, 4, or 8 Kr) increased plant height and number of branches per plant. However, only seed exposed to 1 Kr showed higher fruit fresh weight/plant than control treatment. Irradiation treatments generally increased fixed oil, carbohydrate and flavones. Hassan *et al.* (2000) examined the effect of 20, 40, 60 and 80 Kr γ- irradiation doses on growth of cowpea cv.Cream 7 plants under the greenhouse conditions. Irradiation treatments caused decrease in shoot fresh weights of the parental population with the increase of γ- dose and *vice versa* with M1 and M2 generations. Vaijapurkar *et al.* (2001) found that dose between 0.5 and 20 Gy induced morphological and cytological changes in onions type. The effect of γ- irradiation and phosphorus on chamomile growth and oil production was studied

Moussa and Abdul Jaleel (2011) studied the effect of gamma radiation doses (0,25,50,100 and 150 Gy) on (*Trigonella foenumgraecum* L.). It was found that gamma irradiation increased dry weight values from plants treated with 150 Gy.

Wi *et al.* (2006) found that the plants exposed to relatively low dose of γ- rays developed normally, while, the growth of plants irradiated with a high dose of γ- rays (50Gy) was significantly inhibited. Said (2001) reported that exposing the peppermint to gamma rays at 10 and 30 Gray increased chl a, b and carotenoids content, while, the 70 Gray dose decreased them in comparison with control. Kim *et al.* (2004) also characterize stimulatory effects of low dose gamma radiation on early plant growth; they investigated alterations in the photosynthesis and antioxidant capacity of red pepper (*Capsicum annuum* L.) seedlings produced from gamma-irradiated seeds. For two cultivars (Yeomyung and Joheung), three irradiation groups (2, 4, and 8 Gy, but not 16 Gy) showed enhanced development. They revealed that irradiation altered the compositions of photosynthetic pigments (chlorophylls and carotenoids) as well as the activities of antioxidant enzymes. Farid *et al* (1999) found that gamma irradiation treatments (10, 20 and 40 Gray) increased the content of Chl a and b in sweet marjoram herb. Concerning, fresh and dry weights of non-irradiated stressed damsisa plants grown under different salinity levels in soil. It was found that fresh and dry weights decreased, during the three stages of growth as compared to non-irradiated (control) which grown in control soil through both seasons. Similar effects were obtained on Chamomila rectutita with [1, 39].

Moreover, Colom and Vazzana (2002) showed that plant dry weight was negatively related to water stress in *Eragrotis curvvla*. Also, the reduction in dry weight under salinity stress was observed by [38]. In this respect, Reddy *et al.* (1997) reported that chlorophyll content of *chlorella* grown in saline medium increased with salinity, the increase was more in Chl (b) than Chl (a). Al-Sobhi *et al.* (2006) postulated that the increase in synthesis of Chl (b) under salinity is postulated to the cellular adaptation, to meet increasing demand of energy for NaCl toxicity on *Calotropis procera* seedling. The ratio of Chl a/b showed mostly a reduction with increasing salinity concentration, especially at flowering and fruiting stage. It was generally agreed that low doses of gamma rays could stimulate cell division, growth and development in plants. This effect of low dose of gamma-irradiation improves the stress-tolerance in plants subjected to the salt stress. Gamma rays have been reported to affect differentially the morphology, anatomy, biochemistry, and physiology or plant depending on the irradiation level. These effects included changes in plant cellular structure and metabolism, e.g. dilution of thylakoid membranes, alteration in photosynthesis, modulation of antioxidant system, and accumulation of phenolic compounds [29, 30, 55].

Other authors reported that chloroplasts were extremely sensitive to gamma irradiation compared to other cell organelles; low doses induced changes in thylakoid, and chlorophyll content, whereas higher doses inhibited chloroplast development and caused changes in synthesis of nucleic acid in plastids [54]. Zabalza *et al.* (2006) attributed the stimulating effect of irradiation on chlorophyll to stabilizing the enzyme active site and photosynthetic reactions. There is a cycle of interconnversion between Chl a and b that is particularly significant under stress [34]. In this context, Jaleel *et al.* (2007) found that stress enhances the activity of chlorophyllase and interferase with the de-nouo synthesis of protein, such as those that bind chlorophyll. The noticed increase incarotenoids due to stress conditions caused by either salinity and /or gamma rays was expected. Foyer and Harbinson (1994) reported that, carotenoids are involved protein of the photosynthetic apparatus against photo-inhibitory damage by singlet oxygen (O2-) that is produced by the excited triplet state of chlorophyll.

Objective of this study, identifying the effects of gamma radiation on the morphology and vegetative growth of sunflower. Also, studying different gamma radiation doses were applied to sunflower seeds to determine their effects on some plant characteristics.

Materials and Methods

This experiment was carried out during the two successive seasons of 2024/2025.

Plant Material: Sunflower seeds, were obtained from the Agriculture Research Center, Ministry of Agriculture, Dokky, Giza, Egypt. Seeds were used for the radiation treatments, then cultivated and after harvesting, the seed transfer to laboratory in order to carry out lab analysis for quality evaluation of sunflower seeds.

Radiation treatments Seeds were irradiated with different doses of gamma rays (0, 5, 10, 15, 20, 25 and 30 Gy). The irradiation facility was carried out at the National Center for Radiation Research and Technology (NCRRT) using Cesium 137 as source of gamma rays. The dose rate was 0.89 rad /sec and 0.87 rad/ sec respectively. Gamma treatments shown in Table 1.

Table 1: Effects of different doses of gamma radiation on number of leaves per plant.

No.	Treatments	Gamma doses of cesium (Cs137)
1	T1	0 Gy (Control)
2	T2	5 Gy
3	T3	10 Gy
4	T4	15 Gy
5	T5	20 Gy
6	T6	25 Gy
7	T7	30 Gy

Table 2: Averages of some physico-chemical and mechanical analysis of experimental soil during two successive seasons of 2024/2025.

Properties	values	Properties	values
pH	7.4	Ca+2(meq/l)	8.4
Ec ds/m	2.1	Mg+2(meq/l)	2.7
HCO_3 -(meq/1)	1.65	O.M %	1.1
Cl-(meq/l)	12	Clay %	12.8
SO— 4(meq/1)	8.45	Sand %	60
Na+(meq/l)	10.35	Silt %	27.2
K+(meq/l)			0.36

O.M = organic matter **Ec** = Electrical conductivity

Soil analysis The chemical, physical and mechanical analysis of soil was presented in Table 2. The chemical analysis was determined according to Jackson (1973). The organic matter content was determined according to Black (1982).

5kg soil obtained from the experimental farm of NCRRT. The ratios of sand loamy soils were 3:2 mixed with recommended fertilizers. For salinity groups, the proper concentration for each group were mixed well with soil before sowing.

Agricultural practices

Fertilization Plants were fertilized according to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation (150kg calcium super phosphate/fed, 100kg potassium sulphate/fed and 100kg ammonium sulphate/fed).fartilization rate at the time pot added 0.5g/kg potassium sulphate and ammonium sulphate, 0.75g/kg calcium super phosphate at the beginning of the experiment during the two seasons.

Planting

In the first of May, during the two successive seasons, seven plots were planted, six of them were planted with irradiated seeds by gamma radiation of Cesium (Cs137), those exposed to γ-rays at doses of (5, 10, 15, 20, 25, 39 Gy) and last plot was sown with seeds of untreated control. Four replications for each dose were carried out.

Irrigatation

All plots were irrigated with water till 66% of field capacity, every (10 – 15 gays) till the end of experiment.

Sampling

In both seasons, samples were collected from each treatment for representing the vegetative growth sample. Ten plants were taken as samples for measuring growth Parameters such as chlorophyll a (mg/g), chlorophyll b (mg/g), total Chlorophyll (mg/g), plant height (cm), stem diameter (cm), disc diameter (cm), number of leaves/ plant, leaf area (cm^2), full leaf weight (g), disk weight (g), and (disk, stem, leaf, full plant of fresh weights (g)).

Growth parameters measurements

The height and diameter measurements: Plant height was measured after planting of the seedlings and height was measured in cm from the soil surface to the apex of the top most leaf. Also, stem and disc diameters were in cm.

The weight measurements: Full leaf weight, disk hole of leaves weight, and (disk, stem, leaf, full plant of fresh weights were measured in (g) by digital balance with accuracy two decimal.

Chl a, Chl b, and Total Chlorophyll

Fresh leaves were extracted with dimethyl formamide solution [HCON (CH3)2] and placed overnight at cool temperature (5°C). Chl a, b and carotenoids were measured by Shimadzu UV-120- 02 spectrophotometer at wavelengths 663, 647 and 470 nm, respectively. Chlorophyll and carotenoids were calculated according to the equation described by, Nornai (1982).

Chlorophyll a = 12.70 A663 – 2.79 A647

Chlorophyll b = 20.76 A647 – 4.62 A663

Total Chlorophyll = 17.90 A647 + 8.08 A663

Total Carotenoids = [1000 A470 – (3.72 Chl(a) -104 Chl(b))] /229

Statistical analysis

The experiment layout was designed in randomized complete block design with factor was seven gamma ray doses (0, 5, 10, 15, 20, 25 and 30) Gy. Data of growth characters were statistically analyzed. Means were compared using the least significant difference test (LSD) at 5% level (Snedecor and Cochran, 1980).

Figure 1: Sunflower plant stages from irradiated seeds by gamma Cesium (Cs137) from germination to harvesting stage. **a)** Irradiated sunflower plant (Germination stage) **b)** Sunflower plant vegetation (Growing stage) **c)** Sunflower full growing (Flowering stage) **d)** Sunflower closed harvesting (Harvesting stage).

Results and Discussions

Morphological effects

1-Chlorophyll pigments:

1-1-Chl (a), Chl (b) and total chlorophyll concentrations of plant leaf: Effect of gamma rays' cesium (Ce 137) on photosynthetic plant pigments concentration were showed in Figure 2 shows the relationship between gamma radiation doses of cesium (Cs137) and Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant. It shows that increasing the dose from 5 to 25 Gy led to increases of the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant from (1.26 to 2.12), (0.56 to 1.10), and (1.86 to2.74 mg/g) respectively, then the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant were decreases to (1.61, 0.85, and 2.12 mg/g) respectively at a dose of 30 Gy in the first season. In the second season, the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant were increased from (1.04 to 1.78), (0.48 to 0.96), and (1.58 to 2.69 mg/g) respectively, then the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant were decreases to (1.26, 0.65, and 2.09 mg/g) respectively at a dose of 30 Gy., compared to untreated sample (control) of the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant which were (1.09, .054, and 1.79 mg/g) and (0.64, 0.37, and 1.20 mg/g) for first and second seasons, respectively. These results indicate that the leaf area of plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy. It is clear from the dats in Tables (7,8, and 9) that salinity treatments induced significant increases in Chl a, Chl b, and consequently of the total Chl as well as carotenoid concentrations in leaves of damsisa plants at different stages of growth during the two seasons of experiment. In accordance with these results Reddy *et al.* (1992), Singh and Dubey (1995) found that chlorophyll content increase in salt tolerant *Salicornia brachiata* and in salt tolerant *Oryza sativa* plants respectively.

1-2-Total carotenoids concentrations of plant leaf: Figure 3 illustrates the relationship between gamma radiation doses of cesium (Cs137) and Total carotenoids concentrations of plant leaf. It shows that increasing the dose from 5 to 25 Gy increases the Total carotenoids concentrations of plant leaf from 6.25 to 8.77 mg/g. The Total carotenoids concentrations of plant leaf then decrease to 7.14 mg/g at a dose of 30 Gy in the first season. In the second season, the Total carotenoids concentrations of plant leaf increase from 6.21 to 8.48 mg/g, then decreases to 7.02 mg/g at a dose of 30 Gy., compared to untreated sample (control) which was 5.95 and 5.88 g for first and second season, respectively. These results indicate that the Total carotenoids concentrations of plant leaf in both seasons are similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy. Also, the photosynthetic pigments were increased in damsisa plants arise from irradiated seeds at different

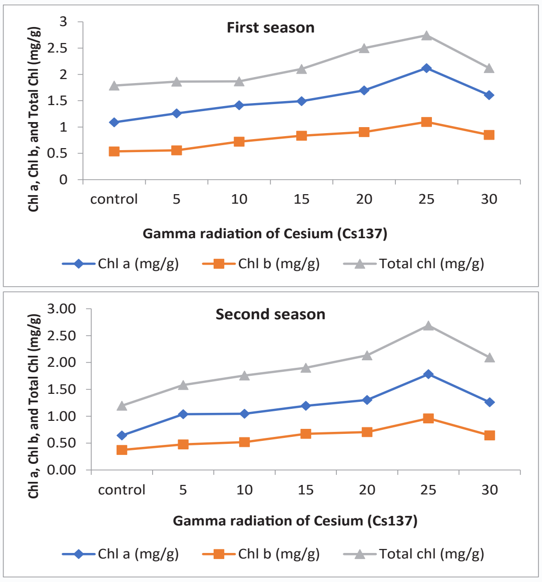

Figure 2: Effect of gamma ray of cesium 137 on Chl a, Chl b, and total Chl of sunflower plant.

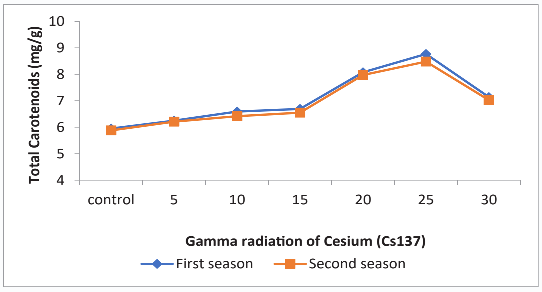

Figure 3: Effect of gamma ray of cesium 137 on total Carotenoids of sunflower plant.

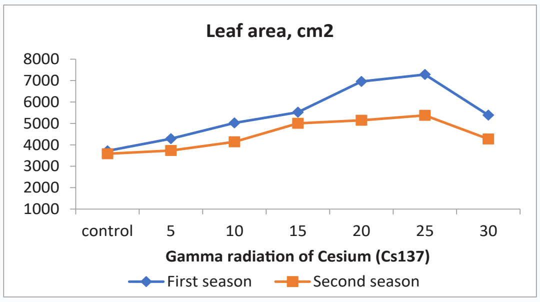

Figure 4: Effect of gamma ray of cesium 137 on leaf area of sunflower plant.

stages during two seasons of growth, Table (7) the same results were obtained by Orabi (1998) on cowpea plants. The author indicates that the doses of 10 and 20 Gy gamma irradiation significantly increased, Chl a, b and (a+b) as well as carotenoid contents of leaves, compared with the un-irradiated control. Similar results were obtained by Farid *et al* (1999) on sweet marjoram exposed to (10, 20 and 40 Gy) of radiation; Said (2001) who exposing the peppermint to (10, 30 Gy) and Hamideldine and Hussein (2009) on Egyptian clover. It is also clear from Table (9,10 and11) that Chl (a) predominated over chlorophyll (b).

2-Leaf area calculation factors:

2-1-Leaf area of plant: Figure 4 shows the relationship between gamma radiation doses of Cesium (Cs137) and leaf area of plant. It shows that increasing the dose from 5 to 25 Gy led to increases the leaf area of plant from 4287.1 to 7284.2 cm^2, then the leaf area of plant decreases to 5387.1 cm^2 at a dose of 30 Gy in the first season. In the second season, the leaf area of plant increases from 3735.4 to 5377.4 cm2, then decreases to 4274.1 cm^2 at a dose of 30 Gy., compared to untreated sample (control) which was 3720.1 and 3584.2 cm for first and second seasons, respectively. These results indicate that the leaf area of plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

2-2-Full leaf weight: Figure 5 shows the relationship between gamma radiation doses of cesium (Cs137) and full leaf weight. It shows that increasing the dose from 5 to 25 Gy led to increases the full leaf weight from 24.8 to 38.3 g, then the full leaf weight decreases to 32.0 g at a dose of 30 Gy in the first season. In the second season, the full leaf weight increases from 19.5 to 28.6 g, then decreases to 25.4 g at a dose of 30 Gy., compared to untreated sample (control) which was 20.9 and 17.6 g for first and second seasons, respectively. These results indicate that the full leaf weight in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

2-3-Disc hole weight of fifteen plants leaves: Also, Figure 5 shows the relationship between gamma radiation doses of cesium (Cs137) and disc hole weight of fifteen plant leaves. It shows that increasing the dose from 5 to 25 Gy led to increases the disc hole weight of fifteen plant leaves from 236.2 to 277.2 g. The d disc hole weight of fifteen plant leaves, then decreases to 247.4 g at a dose of 30 Gy in the first season. In the second season, the disc hole weight of fifteen plant leaves increases from 230.4 to 271.9 g, then decreases to 227.5 g at a dose of 30 Gy., compared to untreated sample (control) which was 230.4 and 1222.6 g for first and second season, respectively.

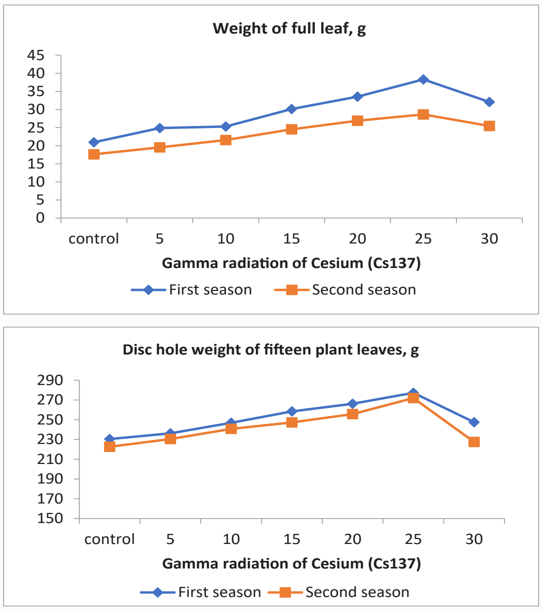

Figure 5: Effect of gamma ray of cesium 137 on full leaf and disc hole weight of fifteen plant leaves.

The plants treated with the dosages higher than 25 Gy exhibited sunflower leaves compared to the control. The plant seeds exposed to all radiation doses from 20 - 25 Gy showed abnormalities in leaves. The changes in these developing leaves may be due to the physiological changes caused within the cells by radiation stress. They might have developed green pigments to mitigate the radiation effects with their maturity. A mutagenesis study on *Calendula officinalis* belonging to the family Asteraceae by Tiwari and Kumar (2011) indicated that exposing the seeds of *C. officinalis* to gamma radiation dose ranging from 2.5 Krad – 7.5 Krad showed morphological abnormalities in leaf and plants. Further increase in radiation dose increased the abnormal leaves. Similar results were observed by Kapoor *et al.* (2014) in *Glebionis segetum*. They mentioned that the percentage of abnormal leaves significantly increased with the increase in gamma radiation dose. Further, maximum deformed plants were recorded in plants treated with 100 Gy. This significant development of abnormalities may be due to radiation damage of the irradiated plants, specifically chromosomal breakage (Gaul, 1970), which generally causes physiological, morphological and cytological disturbance by gamma radiation. Same The same trend was recorded in Chrysanthemum by Misra *et al.* (2009) that, per cent abnormal leaves significantly increased with the increase in gamma rays' dose over the control. The different types of leaf abnormalities included change in leaf shape and size, margins, apex, fission and fusion were recorded after irradiation.

3-Morphological changes:

3-1-Plant length: Figure 6 shows the relationship between gamma radiation doses of cesium (Cs137) and length of plant. It shows that increasing the dose from 5 to 25 Gy led to increases the length of plant from 213.3 to 237 cm., then the length of plant decreases to 217 cm at a dose of 30 Gy in the first season. In the second season, the length of plant increases from 192 to 225.6 cm, then decreases to 215 cm at a dose of 30 Gy., compared to untreated sample (control) which was 193.3 and 187.6 cm for first and second season, respectively. These results indicate that the length of plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy. Latha and Dharmatti (2018) reported similar results in marigold were exposing the marigold plants to higher doses of gamma radiation caused a reduction in plant height significantly.

3-2-Disc diameter: Figure 6 shows the relationship between gamma radiation doses of cesium (Cs137) and disc diameter. It shows that increasing the dose from 5 to 25 Gy led to increases the disc diameter from 10.8 to 15.3 cm., then the disc diameter decreases to 13.3 cm at a dose of 30 Gy in the first season. In the second season, the disc diameter increases from 10.7 to 13.3 cm, then decreases to 12.2 cm at a dose of 30 Gy., compared to untreated sample (control) which was 10.4 and 10.1 cm for first and second seasons, respectively. These results indicate that the disc diameter in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

3-3-Stem diameter: Figure 6 shows the relationship between gamma radiation doses of cesium (Cs137) and stem diameter. It shows that increasing the dose from 5 to 25 Gy led to increases the stem diameter from 1.7 to 2.2 cm., then the stem diameter decreases to 2.0 cm at a dose of 30 Gy in the first season. In the second season, the stem diameter increases from 1.6 to 2.0 cm, then decreases to 1.8 cm at a dose of 30 Gy., compared to untreated sample (control) which was 1.6 and 1.5 cm for first and second seasons, respectively.

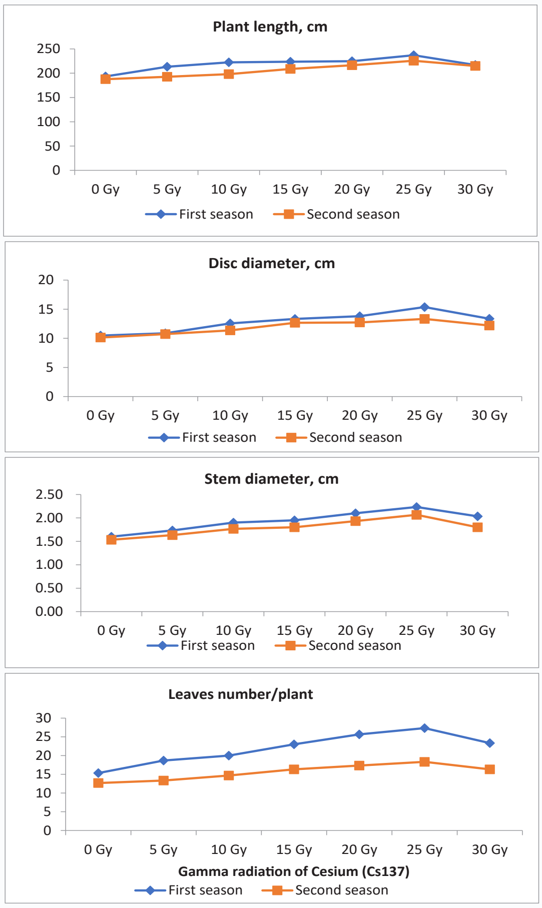

Figure 6: Effect of gamma ray of cesium 137 on plant length, disc diameter, stem diameter and leaf number of sunflower plant.

These results indicate that the stem diameter in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy. Hegazi and Hamideldin (2010) studied the effect of different doses of gamma irradiation (300,400 and 500Gray) on growth of two okra varieties. Results showed that 400 Gy gave the highest number of branches per plant, leaf area and fresh and dry weight per plant followed by 300, then 500Gy.

3-4-Leaves number of plant: Figure 6 shows the relationship between gamma radiation doses of cesium (Cs137) and leaves number of plant. It shows that increasing the dose from 5 to 25 Gy led to increases the leaves number of plant from 19 to 27, then the leaves number of plant decreases to 23 at a dose of 30 Gy in the first season. In the second season, the leaves number of plant increases from 14 to 18, then decreases to 17 at a dose of 30 Gy., compared to untreated sample (control) which was 15 and 13 for first and second season, respectively. These results indicate that the leaves number of plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy. Generally, gamma radiation enhanced plant growth and in teturn, number of leaves since all used doses gave number of leaves higher than control. Many investigators mentioned that, gamma radiation had stimulatory effect on plant height and number of leaves, Hussien (1996) concluded that soybean plants of 90 days old carried the highest number of leaves when they grew from seeds irradiated with 200 Gy.

4-Fresh weights of different parts of plants:

4-1-Fresh discs weight per plant: Figure 7 shows the relationship between gamma radiation doses of cesium (Cs137) and fresh discs weight/plant. It shows that increasing the dose from 5 to 25 Gy led to increases the fresh discs weight per plant from 233.7 to 299.9 g, then the fresh discs weight per decreases to 256.8 g at a dose of 30 Gy in the first season. In the second season, the fresh discs weight per plant increases from 149.0 to 266.6 g, then decreases to 214.4 g at a dose of 30 Gy., compared to untreated sample (control) which was 129.0 and 120.7 g for first and second seasons, respectively. These results indicate that the fresh discs weight per plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy). As for gamma irradiation, the results indicated that the low doses (20, 30 and 40 Gy dose) stimulated the plant growth parameters, i.e. height, number of leaves, fresh and dry weight of plants, Baek (2005).

4-2-Fresh leaves weight per plant: Figure 7 shows the relationship between gamma radiation doses of cesium (Cs137) and fresh leaves weight per plant. It shows that increasing the dose from 5 to 25 Gy led to increases the fresh leaves weight per plant from 261.0 to 398.8 g, then the fresh leaves per plant weight decreases to 344.0 g at a dose of 30 Gy in the first season. In the second season, the fresh leaves weight per plant increases from 176.8 to 364.6 g, then decreases to 303.2 g at a dose of 30 Gy., compared to untreated sample (control) which was 165.7 and 164.3 g for first and second seasons, respectively. These results indicate that the fresh leaves weight per plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

4-3-Fresh stem weight: Figure 7 shows the relationship between gamma radiation doses of cesium (Cs137) and fresh stem weight. It shows that increasing the dose from 5 to 25 Gy led to increases the fresh stem weight from 116.6 to 170.9 g, then the fresh stem weight decreases to 149.7 g at a dose of 30 Gy in the first season. In the second season, the fresh stem weight increases from 90.5 to 120.9 g, then decreases to 100.7 g at a dose of 30 Gy., compared to untreated sample (control) which was 108.8 and 88.0 g for first and second seasons, respectively. These results indicate that the fresh stem weight in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

4-4-Fresh full plant weight: Figure 7 shows the relationship between gamma radiation doses of cesium (Cs137) and fresh full plant weight. It shows that increasing the dose from 5 to 25 Gy led to increases the fresh full plant weight from 475.6 to 861.6 g, then the fresh full plant weight decreases to 669.6 g at a dose of 30 Gy in the first season. In the second season, the fresh full plant weight increases from 354.6 to 744.2 g, then decreases to 549.1 g at a dose of 30 Gy., compared to untreated sample (control) which was 347.2 and 302.8 g for first and second seasons, respectively. These results indicate that the fresh full plant weight in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy. Moreover, the results obtained showed that gamma radiation caused an increase in fresh and dry weights of plants. Also, 40 or 80 Gy produced plants heaviest in weight (fresh or dry weight) at flowering or fruiting stage during both seasons. Similar results were obtained Kawther *et al.* (1996), El-Mogy (1999) and Nassar *et al.* (2004).

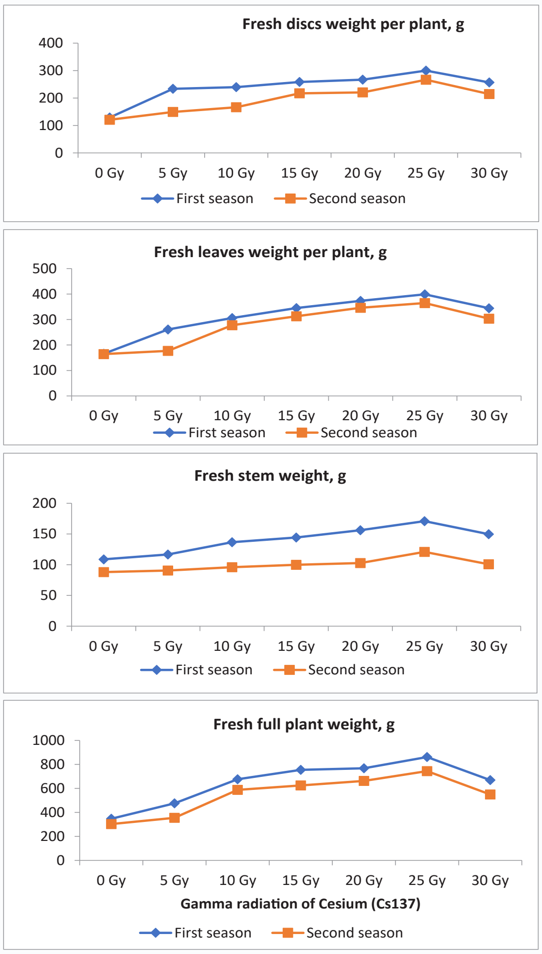

Figure 7: Effect of gamma ray of cesium 137 on discs, leaves, stem and full plant fresh weights of sunflower plant.

Conclusions

For Chl a, Chl b, and total Chlorophyll: It shows that increasing the dose from 5 to 25 Gy led to increases of the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant from (1.26 to 2.12), (0.56 to 1.10), and (1.86 to2.74 mg/g) respectively, then the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant were decreases to (1.61, 0.85, and 2.12 mg/g) respectively at a dose of 30 Gy in the first season. In the second season, the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant were increased from (1.04 to 1.78), (0.48 to 0.96), and (1.58 to 2.69 mg/g) respectively, then the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant were decreases to (1.26, 0.65, and 2.09 mg/g) respectively at a dose of 30 Gy., compared to untreated sample (control) of the Chl (a), Chl (b) and total chlorophyll concentrations in leaf of plant which were (1.09, .054, and 1.79 mg/g) and (0.64, 0.37, and 1.20 mg/g) for first and second seasons, respectively. These results indicate that the leaf area of plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

Leaf area of plant and plant length: It shows that increasing the dose from 5 to 25 Gy led to increases the leaf area of plant and plant length from (4287.1 to 7284.2 cm^2), and (213.3 to 237 cm), then the leaf area and length of plant decrease to (5387.1 cm^2), and (217 cm) at a dose of 30 Gy in the first season. In the second season, the leaf area and length of plant ere increased from (3735.4 to 5377.4 cm2), and (192 to 225.6 cm), then decreases to (4274.1 cm^2), and (215 cm) at a dose of 30 Gy., compared to untreated sample (control) which was (3720.1 and 3584.2 cm^2) and (193.3 and 187.6 cm) for first and second seasons, respectively. These results indicate that the leaf area and length of plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

Fresh full plant weight and fresh discs weight/plant: It shows that increasing the dose from 5 to 25 Gy led to increases the fresh full plant weight and fresh discs weight/plant from (475.6 to 861.6 g), and (233.7 to 299.9 g) then the fresh full plant weight and fresh discs weight/plant decreases to (669.6 g), and (256.8 g) at a dose of 30 Gy in the first season. In the second season, the fresh full plant weight and fresh discs weight/plant increases from (354.6 to 744.2 g), and (149.0 to 266.6 g) then decreases to (549.1 g), and (214.4 g) at a dose of 30 Gy., compared to untreated sample (control) which was (347.2 and 302.8 g), and (129.0 and 120.7 g) for first and second seasons, respectively. These results indicate that the fresh full plant weight and fresh discs weight/plant in both seasons is nearly similar. Furthermore, the optimal gamma radiation dose of cesium (Cs137) ranges between 20 and 25 Gy.

Acknowledgements

All authors extend their gratitude to Natural products Research department, National Center for Radiation Research and Technology, Egyptian Atomic Energy Authority; Agricultural Engineering Research Institute, Agriculture Research Center, Cairo, Egypt., and Rural Sociology and Agricultural Extension Department, Agricultural Faculty, Ain Shams University, Egypt for supporting carryout this research work.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

1. **Abdul Qados A. M. S.** Effect of arginine on growth, yield and chemical constituents of wheat grown under salinity condition. Academic J Plant Sci, 2009; 2(4): 267-268.
2. **Abu-Tahon M, Isaac G and Mogazy A.** Protective role of Fat hen (Chenopodium album L.) extract and gamma irradiation treatments against Fusarium root rot disease in Sunflower plants. *Plant biology*. 2020. https://doi.org/10.1111/plb.13229.
3. **Al-Sobhi O. A, Al-Zahrani H. S and Al-Ahmadi S. B.** Effect of salinity on chlorophyll & carbohydrate contents of *Calotropis Procera* seedlings scientific. Journal of King Faisal University, 2006; 7: 105-115.
4. **Bajpay A and Dwivedi D. H.** Gamma ray induced foliage variegation and anatomical aberrations in Chrysanthemum (*Dendranthema grandiflora* T.) cv. Maghi. *Journal of Pharmacognosy and Phytochemistry*, 2019; 8(4), 871-874.
5. **Beak M. H, Kim J. H, Chung B. Y, Kim J. S and Lee I. S.** Alleviation of salt stress by low dose γ-irradiation in rice. Biologia plantarum, 2005; 49(2): 273-276.
6. **Black E. D.** Methods of Soil Analysis, Agron. No.9, Part 1: Physical and mineralogical properties, Amer.Soc. Agron., Madison, WI, USA. 1982.
7. **Centorame L, Gasperini T, Ilari A, Del Gatto A and Foppa Pedretti E.** An overview of machine learning applications on plant phenotyping, with a focus on sunflower. *Agronomy*, 2024a; *14*(4), 719. https://doi.org/10.3390/AGRONOMY14040719.
8. **Chang X, Li X, Zhao H, Qian W, Liu J, Zhang Y and Wang X.** Profiling the aroma compounds of sunflower seed oils subjected to different roasting conditions based on GC–Orbitrap-MS and sensory molecular network. *Journal of Food Composition and Analysis*, 2025; *139*, 107124. https://doi.org/10.1016/j.jfca.2024.107124.
9. **Colom M. R and Vazzana C.** Water stress effects on three cultivars of *Eragrostis curvula*. Italy J. Agron, 2002; 6: 127-132.
10. **Díaz L. E, García S. A. L, Morales R. A, Báez R. I, Pérez V. E, Olivar H. A, Vargas R. E. J, Hernández H. P, De la Cruz T. E, García A. J. M** and **Loeza C. J. M**. Effect of gamma radiation of 60Co on sunflower plants (Helianthus annuus L.) (Asteraceae), from irradiated achiness. Scientia Agropecuaria, 2018; 9(3): 313 – 317.
11. **El-Beltagi M. S, Ismail M. A and Mohamed F. H**. Induced salt tolerance in common bean (*Phaseolus vulgaris* L.) by gamma irradiation. Pak. J of Biol. Sci, 2006; 9 (6): 1143-1148.
12. **El-Demerdash H. M.** Genetic studies on two soybean cultivars irradiated with gamma rays. Isotope & Rad. Res, 2007; 39(3): 719-730.
13. **El-Mogy A. M. E.** Physiological studies on growth and active ingredients of *Ambrosia maritime* L. Plants. Ph.D. Thesis, Fac. Agric, Zagazig Univ, Egypt. 168p. 1999.
14. **El-Sharnouby S. E, Naguib N. Y and Hussein M. S.** Effect of gamma irradiation and sulphur fertitizer on growth and chemical composition of *Hibiscus sabdarifa* L, J. Physiol. Sci, 1997; 21(1): 115-127.
15. **Farid M. R, Haba E. A, Mahmoud H. F and El-Sawy M. M. A.** Physiological and biochemical response of sweet marjoram (*Majorana hortensis* L.) to foliar kinetin application and gamma radiation. Memofiya J. Agric. Res, 1999; 24(1): 251-260.
16. **Foyer C. H and Harbinson J.** Oxygen metabolism and the regulation of photosynthetic electron transport. In:causes of photooxidative stress and amelioration of defense systems in plants, foyer C.H and P.M. mullineaux (Eds.). CRC Press, Boca raton. FL, 1994; 13: 1-42.
17. **Gaul H.** Plant injury and lethality. (In) Manual on Mutation Breeding. Vienna, FAO/IAEA, 1970; pp 85–90.
18. **Giannini V, Maucieri C, Vamerali T, Zanin G, Schiavon S, Pettenella D. M, and Borin M.** Sunflower: from Cortuso's description (1585) to current agronomy, uses and perspectives. *Agriculture*, 2022; *12*(12), 1978. https://doi.org/10.3390/agriculture12121978
19. **Graña S. Á, Abarquero D, Claro J, Combarros-Fuertes P, Fresno J. M and Tornadijo M. E.** Behaviour of sunflower (Helianthus annuus L.) oil and high oleic sunflower oil during the frying of churros. *Food Chemistry Advances*, 2025; *6*, 100899. https://doi. org/10.1016/j.focha.2025.100899.
20. **Hassan H. M, Ali M. A and Darwish I. M.** Effect of gamma irradiation on the susceptibility of cowpea to root knot nematode (*Meloidogyneincognita*). Minia. J. Agric.Res. & Develop, 2000; 20 (1): 47-56.
21. **Hegazi A. Z and Hamideldin N.** The effect of gamma irradiation on enhancement of growth and seed yield of okra (*Abelmoschus esculentus*L. Monech) and associated molecular changes. Journal of Horticulture and Forestery, 2010; 2(3): 38-51.
22. **Hossam S. EL-BELTAGI, Ghada A. TAWFIC, Said A. SHEHATA, Shaimaa R. ALI, Osama A. ABDEL HAMID, Abd El-Rahman A. AHMED and Mohamed M. EL-MOGY.** The effect of seed priming with UV and gamma rays on the growth, production, and storage ability of cauliflower heads. Not Bot Horti Agrobo, 2023; 51(3): 13264. DOI:10.15835/nbha51313264
23. **Hussein O. S**. Effect of some treatments on vitality of stored saybean seeds. M.Sc. Thesis, Fac.of Sci., AI-Azhar University for Cairo, Egypt,1996; 184p.
24. **Iglesias-Andreu L, Sánchez-Velásquez L, Tivo-Fernández Y, Luna-Rodríguez M, Flores-Estévez N, Noa-Carrazana J, Ruiz-Bello C and**

Moreno-Martínez J. Effect of gamma radiation on Abies religiosa (Kunth) Schltd. et Cham. Chapingo Magazine. Forest and environmental science series, 2010; 16(1), 5-12. DOI: 10.5154/r.rchscfa.2009.06.021.

25. **Jackson M. l.** Soil chemical analysis. Prentice-Hall, Inc. Limited New York. 1973; pp125-179.

26. **Jaleel C. A, Manivannan P, Lakshmanan G. M. A, Sridharan R and Panneerselvam R.** NaCl as a physiological modulator of proline metabolism and antioxidant *Phyllanthus amarus*.Comptes rendus Biol, 2007; 330: 806-813**.**

27. **Kapoor M, Kumar P and Lal S**. Gamma radiation induced variations in corn marigold (*Glebionis segetum*) and their RAPD-based genetic relationship. Indian *Journal of Agricultural Sciences*, 2014; 84(7), pp.796-801.

28. **Khatkar D and Kuhad M. S.** Short-term salinity induced changes in two wheat cultivars at different growth stages. Biol. Plant, 2000; 43(4): 629-632.

29. **Kim J. H, Beak M. H, Chnug B. Y, Wi S. G and Kim J. S.** Alternation in the photosynthic pigments and antioxidant machineries of red pepper (*Capsicum annuum* L.) seedlings from gamma –irradiated seeds. J. Plant Biol, 2004; 47: 314-321.

30. **Kovacs E and Keresztes A.** Effect of gamma and UV-B/C radiation on plant cell. Micron, 2002; 33: 199-210.

31. **Kumar P. R. R and Ratnam S. V.** Mutagenic effectiveness and efficiency in varieties of sunflower (*Helianthus annuus* L.) by separate and combined treatment with gamma-rays and sodium azide. *African Journal of Biotechnology*, 2010; 9(39), 6517-6521. DOI: 10.5897/AJB10.2017.

32. **Latha S and Dharmatti P.** Genetic variability studies in Marigold. *International Journal of Pure Applied Bioscience*, 2018; 6(3), 525-528. DOI:10.18782/2320-7051.5381.

33. **Li Z, Xiang F, Huang X, Liang M, Ma S, Gafurov K and Wang Q.** Properties and characterization of sunflower seeds from different varieties of edible and oil sunflower seeds. *Foods*, 2024; *13*(8), 1188. https://doi.org/10.3390/ foods13081188.

34. **Matile P, Hortensteiner S and Thomas H**. Chlorophyll degradation. Ann. Rev.Plant Physiol.Plant Mol Biol, 1999; 50: 67-95.

35. **Misra P, Banerji B. K and Kumari A.** Effect of gamma irradiation on Chrysanthemum cultivar 'Pooja' with particular reference to induction of somatic mutation in flower colour and form. *Jounal of Ornamental Horticulture*, 2009; 12: pp. 213–6.

36. **Moussa M and Abdul Jaleel A.** Physiological Effects of Glycinebetaine on Gamma-Irradiated Fenugreek Plants (*Trigonella foenum-graecum* L.). International Journal of Vegetable Science, 2011; 17: 60-74.

37. **Muller M. H, Latreille M and Tollon C.** The origin and evolution of a recent agricultural weed: population genetic diversity of weedy populations of sunflower (*Helianthus annuus* L.) in Spain and France. Evolutionary applications, 2011; 4(3), 499-514. DOI:10.1111/j.1752-4571.2010.00163.x

38. **Munns R.** Comparative physiology of salt and water stress. Plant Cell Environ, 2002; 25: 239–250.

39. **Nassar A, Hashim M. F, Hassan S. N and Abo-Zald H**. Effect of gamma rays and phosphorus on Chamomile. Int. J. Agri. Biol, 2004; 6(5)**:** 776-780.

40. **Nornai R.** Formula for determination of chlorophylls pigments extracted with N. N. dimethyl formamide. Plant Physiol, 1982; 69: 1371-1381.

41. **Orabi O. A. I.** Effect of seed irradiation and salinity on growth, chemical composition, and seed production and its quality of cowpea. Egypt J Appl Sci, 1998; 13 (1): 201-215.

42. **Reddy M. P, Sanish S and Lyengar E. R. R.** Photosynthetic studies and compartmentation of ions in different tissues of *Salicornia brachiata* Rob under saline conditions Photosynthetica, 1992; 26: 173- 179.

43. **Reddy M. P, Rao U. S and Lyengar E. R. R.** Carbon metabolism in plants under stress, 1997; p.159–190. In: P.K. Jaiwal, R.P. Singh, and Agulati (eds.). Strategies for improving salt tolerance in higher plants. Science Publ, Enfield, N. H.

44. **Rifnas L. M, N. P. Vidanapathirana, T. D. Silva, N. Dahanayake, S. Subasinghe, S. Weerasinghe, S. A. P. Nelka, H. Rohanadeera and W. G. C. Madushani.** Effect of gamma radiation on morphological changes and vegetative growth in sunflower (*Helianthus annuus* L.). AGRIEAST, 2022; 16(2): 25-34. http://doi.org/10.4038/agrieast.v16i2.114

45. **Rifnas L, Vidanapathirana N, Silva T, Dahanayake N, Subasinghe S, Weerasinghe S, Nelka S, Rohanadeera H and Madushani W.** Effect of gamma radiation on morphological changes and vegetative growth in sunflower (Helianthus annuus L.). *AGRIEAST: Journal of Agricultural Sciences*. 2022. https://doi.org/10.4038/agrieast.v16i2.114.

46. **Said H. A. I.** Biochemical studies on the major constituents of mint oil under the influence of some environmental conditions. M.Sc. Thesis, Fac. Agric., Ain Shams Univ, Cairo. Egypt, 2001; 142p.

47. **Sevil Yalcin and Gulruh Ulakoglu.** Determination of Proper Gamma Radiation Doses in Sunflower Varieties. Journal of IISTE (International Institute for Science, Technology and Education. Vol.5, No.9, 2019; 25 pages. **ISSN** 2422-8702 (Online), **DOI:** 10.7176/JSTR/5-9-04

48. **Singh A. K and Dubey R. S.** Changes in chlorophyll a and b contents and activities of photosystems 1 and 2 in rice seedlings induced by NaCI. Photosynthetica, 1995; 31(4): 489- 499.

49. **Singh V. N, Banerji B, Dwivedi A and Verma A.** Effect of gamma irradiation on African marigold (*Tagetes erecta* L.) cv. Pusa Narangi Gainda. *Journal of Horticultural Sciences*, 2009; 4(1), 36-40.

50. **Snedecore G. W and Cochran W. G.** Statistical methods. Seventh Edition, Iowa State Univ, Ames, Iowa, U.S.A. 1980.

51. **Tiwari A. K and Kumar V.** Gamma-rays induced morphological changes in pot marigold (*Calendula officinalis*). *Progressive Agriculture*, 2011; 11(1), pp. 99-102.

52. **Vaijapurkar S. G, Agarwal D, Chaudhuri S. K, Senwar K. R and Bharnagar P. K.** Gamma-irradiated onions as a biological indicator of radiation dose. Radiat Meas, 2001; 33: 833 –836.

53. **Wi S. G, Chung B. Y, Kim J. H, Baek M. H, Yang D. H, Lee J. W and Kim J. S.** Ultrastructural changes of cell orangelles in *Arabidopsis* stem after gamma irradiation. J. Plant Biol, 2005; 48 (2): 195-200.

54. **Wi S. G, Chung B. Y, Kim J. S, Baek M. H, Lee J. W and Kim Y. S**. Effect of gamma irradiation on morphological changes and biological responses in plants. Micron, 2006; 38(6): 553-564.

55. **Zabalza A. S, Gaston L. M, Sandalio L. A and Royuela M.** Oxidative stress is not related to the mode of action of herbicides that inhibit acetolactate synthase. Environ. Exp. Bot, 2006; 59: 150-159.