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Influence of pre-sowing treatments by gamma rays on growth, yield and some chemical constituents of *Sesamum indicum* L.

O.S. Hussein[✉] and N. HamideldinNatural Products Department, National Center for Radiation Research and Technology,
Atomic Energy Authority, P.O. box 29, Nasr City, Cairo[✉]Corresponding author: Omyma.S.Hussein@eaea.org.eg

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SUMMARY: The present work aims to improve the quantity and quality of seeds and/or seed oil by using low doses of radiation. Sesame seeds were exposed to γ - rays at levels of 30, 60 and 90 Gy. The results show that 30, 60 and 90 Gy doses activated most of growth and yield parameters significantly (weight of plant, number of capsules, weight of capsules/plant and weight of seeds/plant), with 60 Gy being the best dose. With regard to the total oil percentage in the produced crops, few changes have been observed, which did not reach the level of significance. The amount of unsaturated fatty acid (18:1, omega 9) was increase by 10.5% at a 30 Gy dose followed by 60 Gy (1.1%). The total of amino acid content showed that 30 Gy dose recorded the highest value ($350.4 \text{ mg}\cdot\text{g}^{-1}$) followed by 60 Gy ($285.6 \text{ mg}\cdot\text{g}^{-1}$) as compared to the control value ($254.4 \text{ mg}\cdot\text{g}^{-1}$). The values of phosphorus, potassium magnesium and iron which represent the major minerals in sesame seeds were increased in the irradiated samples.

KEYWORDS: *Amino acids; Fatty acid; γ - rays; Minerals; Oil content; Sesame*

RESUMEN: *Influencia de tratamientos con rayos gamma en la presiembra sobre el crecimiento, rendimiento y algunos componentes químicos de Sesamum indicum L.* El presente trabajo tiene como objetivo mejorar la cantidad y la calidad de las semillas y/o aceite de semillas mediante el uso de dosis bajas de radiación. Las semillas de sésamo se expusieron a rayos γ - a niveles de 30, 60 y 90 Gy. Los resultados mostraron que las dosis de 30, 60 y 90 Gy activan significativamente la mayor parte de los parámetros de crecimiento y rendimiento (peso de la planta, número de cápsulas, peso de cápsulas/planta y el peso de semillas/planta), siendo 60 Gy la mejor dosis. Con respecto al porcentaje total de aceite producido en los cultivos, se han observado pequeños cambios, pero no se alcanzó el nivel de significación. La cantidad de ácido graso insaturado (18: 1, omega 9) fue 10,5% que aumentó con dosis de 30 Gy seguido de 60 Gy (1,1%). El contenido total de aminoácidos mostró que dosis de 30 Gy registró el valor más alto ($350,4 \text{ mg}\cdot\text{g}^{-1}$), seguido de 60 Gy ($285,6 \text{ mg}\cdot\text{g}^{-1}$), en comparación con el valor de control ($254,4 \text{ mg}\cdot\text{g}^{-1}$). Los valores de fósforo, magnesio, potasio y hierro, que son los principales minerales en las semillas de sésamo incrementaron en las muestras irradiadas.

PALABRAS CLAVE: *Ácidos grasos; Aminoácidos; Contenido de aceite; Minerales; Rayos γ ; Sésamo*

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1. INTRODUCTION

Sesamum indicum L. crop is grown as a source of oil; its seeds contain 50–52% oil, 17–19% protein and 16–18% carbohydrates (Ustimenko-Bakumovsky, 1980). It is considered a good source of oil which has very good stability due to the presence of natural antioxidants (Ashri, 2007). It belongs to the category of most nutritious seeds and is used as a culinary spice. Sesamum produces unique chemical constituents which do not exist in other edible oils. These chemical constituents enable sesame oil to resist oxidative rancidity and thus contribute to its reputation of high quality, earning the sesame label “Queen of Oil seed crops” (Al-Yemeni *et al.*, 2000; Bedigian, 2000). Sesame is used in the treatment of anemia, blurred vision and relaxation of the bowel. Seed irradiation during the pre-sowing processes is one of the most effective methods for improving plant production, yield components and chemical composition (Rahimi and Bahrani, 2011). Although gamma radiation is a technology with immense applications in agriculture, industry and medicine, its potential exploitation in agriculture is limited because of a lack of information on the optimal dose of irradiation, which differs from one crop to another and from one application to another. Radiation mediated morphological, structural and/or functional changes in a plant which are governed by the intensity and duration of exposure to gamma rays (Singh and Datta, 2010). Gamma rays have been reported to differentially affect the morphology; anatomy, biochemistry, and physiology of a plant, depending on the irradiation level (Kim *et al.*, 2004; Wi *et al.*, 2005). These effects include 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. This work was carried out to investigate the response of sesame seeds (*Sesamum indicum* L.) to low doses of gamma rays for improving plant growth, yield and oil quality.

2. MATERIAL AND METHODS

Sesamum indicum L. shandweel-3 cultivar seeds were obtained from the Agricultural Research Center, Giza, Egypt. The sesame seeds were irradiated at levels of 30, 60 and 90 Gy in gamma cells using Co⁶⁰ as a source for radiation, in the National Center for Radiation Research and Technology (NCRRT), Cairo, Egypt. The dose rate was 0.48 Gy min⁻¹.

2.1. Experimental design

The sesame seeds exposed to gamma rays before sowing were sown together with control seeds in sandy-loam soils in completely randomized blocks with three replicates under a screened house. The soil

was fertilized according to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation (150 kg calcium super phosphate, 100 kg potassium sulphate and 100 kg ammonium sulphate) at the beginning of the experiment. At harvest time, the plants were collected and cleaned for recording growth, yield and other physiological parameters.

2.2. Growth and Yield Parameters

Ten plants were chosen and length of shoot (cm), stem diameter (cm), number of capsule (unit/plant) and length of capsule (cm), weight of capsule per plant (g), and weight of seeds per plant (g) were recorded. Also, the changes in physicochemical properties were estimated.

2.3. Physicochemical parameters

2.3.1. Moisture content

Moisture content was determined according to the AACC (1993).

2.3.2. Oil viscosity

Viscosity measurements were carried out using a Brookfield Rheology RV model DV-III, Viscometer which is computerized and programmable as controlled by Rheocalc (1.3 versions). An oil samples (8–16 mL) from sesame obtained from irradiated or unirradiated seeds was placed in sample adaptor cup and maintained at 25 °C using the Brookfield TC500 unit. The spindle used was a SC4-21 and applied within the up and down program (from 25 up to 250 rpm) and then reduced to 25 rpm with a 30 second interval between each speed rotation. The other speeds used were 50, 75 and 100 rpm; the viscosity cP was automatically calculated by the Rheocalc program software.

2.3.3. Total oil percentages

The total oil content of each treatment was extracted by weighing 10–15 g of sesame seed powder placed in soxhlet apparatus with hexane for about 16 hours. An empty, clean, dry, round flask was weighed before and after extraction. Solvents were evaporated and oil percentage was calculated (AOAC, 1984).

2.3.4. Estimation of fatty acids

The separation of fatty acid methyl esters from oil samples was prepared according to protocol 31 of the extraction of lipids and derivative formation (Hamilton *et al.*, 1992). Five mL of the sulphuric acid:methanol:toluene reagent were added to 50 mg

of lipids in a screw cap vial and heated in a water bath for 60 min. Five mL of water and 5 mL of diethyl ether were added and the mixture was shaken before removing the lower layer. The upper layer was decanted onto anhydrous sodium sulphate. The samples were analyzed at NCRRT with a Hewlett Packard gas chromatograph with a flame ionization detector. The gas chromatograph instrument was equipped with an hp 6890 innowax-cross linked polyethylene glycol column 30 m; i.d. 0.32 mm; 0.5 m film thickness. The oven temperature was programmed from 150 °C to 450 °C for five minutes; the injector and detector were kept at 260 °C and 275 °C, respectively. Nitrogen was used as carrier gas at a flow rate of 1.5 min⁻¹.

2.3.5. Mineral Content

Minerals were measured in sesame powder at NCRRT on an Energy Dispersive X-Ray-Analysis Model: (Oxford) attached to a scanning electron microscope (JEOL-JSM 5400). The analysis depends on the X-ray radiation emitted from each element, where the specimen was bombarded with high energetic electrons used to determine the kind of the elements that exist in the specimen surface and their percentages. The elements estimated were calcium, chlorine, iron, potassium, magnesium, sodium and phosphorus.

2.3.6. Amino Acids

The amino acids analysis was done in an amino acids laboratory, NCRRT after sample preparation by weighing (100 mg) dried sesame seed powder in screw-capped glass tubes containing 10 mL of 6.0 N HCl, kept in an oven at 110 °C for 24 hours for complete digestion (AOAC, 1990). The sample was filtered and the volume was completed to 100 mL with distilled water. Five mL of the solution were evaporated to dryness. A suitable volume of sodium citrate buffer (pH 2.2) was added to the dried film of each hydrolyzed sample. After all materials had completely dissolved, the samples were filtered through a 0.4 µm membrane filter and made ready for injection (Baxter, 1996). The system used for analysis was the high performance amino acid analyzer, Biochroma 20 Pharmacia Biotech at NCRRT. Data analysis of the chromatogram was done by Chromatography Data System Tutorial and user's Guide, version 6.7.

2.4. Statistical analysis

The data obtained were analyzed statistically using the Costat statistical program software, 1990 and Duncan's multiple range according to Duncan (1955).

3. RESULTS

3.1. Growth and yield characteristics

The data in Table 1 show a significant increase in the growth and yield parameters of sesame plants resulting from seeds exposed to γ - rays at levels of 30, 60 and 90 Gy before sowing. It was noticed that dose 60 Gy was more effective for weight of plant, number of capsules, weight of capsules/plant and weight of seeds/plant to register the greatest improvement. Gamma rays may cause changes in shoot morphological characteristics at the level of 30, 60 or 90 and Gy affected the stem diameter. Stem diameter increased significantly by 46.9% in the 30 Gy treatment and increased by 71.9% in both the 60 and 90 Gy treatments.

3.2. Oil Percentage and oil characteristics

The data showed that moisture content and oil contents were increased in the 30 Gy dose of gamma rays irradiated population followed by 60 and 90 Gy (Table 2). Moisture and oil contents increased in the seeds produced from 30 Gy samples followed by 60 Gy. The amount of unsaturated fatty acids (Oleic 18:1, omega 9) was increased by 10.5% at 30 Gy followed by the 60 Gy dose which increased by 1.1%, while a slight increase (0.45%) in fatty acids (linoleic 18:2, omega 6) at dose 90 Gy was observed. Omega 6 and omega 9 are antioxidant components. Furthermore, doses of γ - rays 30 or 60 Gy caused a great drop in oil viscosity, although dose 90 Gy increased it significantly.

3.3. Mineral content

It is evident from Table 3 that K and P are the main constituents in the ash of sesame seeds. The contents of K were especially high in comparison to Na which is considered to be an advantage from the nutritional point of view. However, a large variation in the Ca content has been reported. It was noticed that the control value of 27.2 g·kg⁻¹ decreased to 24.4 g·kg⁻¹ in the 60 Gy treatment and 17.7 g·kg⁻¹ in the 30 Gy treatment. Magnesium represents the fourth major element found in sesame seeds after P, K and Ca. Magnesium was significantly improved in the irradiated sample. Iron was present in a low amount in the untreated sample (0.96%), while it was increased by 202%, 56.3% and 35.4% in 30, 60 and 90 Gy treatments, respectively.

3.4. Amino acids

All values of amino acids were separated in the profiles of the samples treated with 30, and 60 Gy and all amino acids, except proline, were increased above the control value. The results (Table 4) revealed that

TABLE 1. Effect of pre-sowing irradiation treatments on sesame growth and yield parameters

Dose (Gy)	Plant height (cm)	Stem diameter (cm)	Plant weight (g)	Capsule length (cm)	Capsule number/plant	Capsules weight/plant (g)	Seeds weight/plant (g)
0.0	146.2 ^a	0.64 ^c	26.2 ^b	3.7 ^a	39.4 ^c	18.5 ^b	13.0 ^c
30	147.4 ^a	0.94 ^b	48.6 ^a	4.0 ^a	80.8 ^{ab}	34.8 ^a	18.0 ^b
60	154.0 ^a	1.1 ^a	58.7 ^a	4.2 ^a	101.8 ^a	39.5 ^a	27.0 ^a
90	162.4 ^a	1.1 ^a	59.6 ^a	4.1 ^a	64.2 ^b	39.4 ^a	19.0 ^b

The control (0.0) represents untreated plants. The other groups of plants were irradiated with different doses of γ - rays. Each value is the mean of ten replicates. Different letters indicate significant variation.

TABLE 2. Effect of pre-sowing irradiation treatments on moisture content, oil content, oil viscosity and major fatty acids

Dose Gy	Moisture %	Oil %	Oil Viscosity cP				Fatty acids			
			25	50	75	100	16:0	18:0	18:1	18:2
0.0	3.1 ^a	49.7 ^a	36 ^b	33.3 ^a	33.0 ^a	33.0 ^a	10.9	3.9	44.9	44.3
30	3.8 ^a	62.4 ^a	30 ^c	17.0 ^b	16.0 ^b	15.0 ^b	11.0	3.9	49.6	35.5
60	3.2 ^a	58.6 ^a	22 ^d	19.0 ^b	18.8 ^b	18.5 ^b	8.4	2.8	45.4	43.4
90	3.2 ^a	55.7 ^a	40 ^a	35.0 ^a	34.0 ^a	33.5 ^a	8.5	2.8	44.2	44.5

The control (0.0) represents untreated plants. The other groups of plants were irradiated with different doses of γ - rays. Each value is the mean of three replicates. Different letters indicate significant variation.

TABLE 3. Effect of pre-sowing irradiation treatments on mineral contents of sesame crops

Treatment Gy	Ca	Cl	Fe	K	Mg	Na	P
0.0	27.2 ^a	0.9 ^c	0.96 ^d	24.0 ^c	14.8 ^c	1.9 ^b	30.4 ^d
30	17.7 ^d	1.7 ^a	2.9 ^a	27.5 ^b	14.9 ^{bc}	1.6 ^{bc}	33.9 ^b
60	24.4 ^b	0.91 ^c	1.5 ^b	24.1 ^c	15.3 ^a	2.6 ^a	31.2 ^c
90	18.6 ^c	1.4 ^b	1.3 ^c	28.0 ^a	15.1 ^b	1.4 ^c	34.4 ^a

The control (0.0) represents untreated plants. The other groups of plants were irradiated with different doses of γ - rays. Each value is the mean of three replicates. Different letters indicate significant variation.

Leucine ($67.2 \text{ mg}\cdot\text{g}^{-1}$) was the prominent amino acid in sesame followed by arginine ($37.2 \text{ mg}\cdot\text{g}^{-1}$), glutamic acid ($24 \text{ mg}\cdot\text{g}^{-1}$) and aspartic ($18.0 \text{ mg}\cdot\text{g}^{-1}$) in 30 Gy sesame plants. The constant value of proline in all irradiated treatments ($2.4 \text{ mg}\cdot\text{g}^{-1}$) was less than the control value ($3.6 \text{ mg}\cdot\text{g}^{-1}$) and considered as a reference for mild doses used for sesame because proline increases under stress with high doses. But, nine amino acids remained constant in the higher dose used (90 Gy) while the rest decreased except for cystine, which increased by 2.04% (from $8.4 \text{ mg}\cdot\text{g}^{-1}$ in the control to $9.6 \text{ mg}\cdot\text{g}^{-1}$). The total of amino acids revealed that 30 Gy had the highest value (350.4) followed by 60 Gy (285.6).

4. DISCUSSION

Gamma radiation is a potent group of mutagens widely used to create additional variability for crop improvement. Low doses of γ - irradiation may increase the enzymatic activity and stimulate the embryo which in turn causes an increase in the

rate of cell division and affects vegetative growth and causes thickening of the stem and increases plant dry weight, number and weight of capsules. Similar findings were cited by other researchers. Sjodin (1962) and Moussa and Abdul Jaleel (2010) studied the effect of radiation doses (0.0–150 Gy) on *Trigonella foenum-graecum* L. and noticed that 150 Gy gamma irradiation dose increased dry weight values. Radiation causes oxidative injury by acceleration of free radical generation in living systems. The primary damage induced by ionizing radiation is modified in the enzymatic repair processes (Alikamanoglu *et al.*, 2007). Lower doses of γ - irradiation (0–200 Gy) might facilitate better germination, growth and development when all the barriers are overcome, including dormancy in *Terminalia arjuna* (Roxb), Akshatha *et al.* (2013). Gamma irradiation at the levels of 30 or 60 Gy affected the stem diameter. Similar findings were reported by El-Khateeb *et al.* (2007), who stated that lower doses of gamma irradiation affected and changed shoot chemical and anatomical structure in *Melissa* plantlets. The increase in

TABLE 4. Effect of pre-sowing irradiation treatment on amino acid contents of sesame crop

Amino acids (mg·g ⁻¹)	γ-ray Gy			
	Control	30	60	90
Aspartic	13.2	18.0	16.8	13.2
Threonine	10.8	16.8	13.2	10.8
Serine	12.0	16.8	14.4	10.8
Glutamic	18.0	24.0	21.6	18.0
Proline	3.6	2.4	2.4	2.4
Glycine	9.6	12.0	10.8	8.4
Alanine	7.2	10.8	8.4	7.2
Cystine	8.4	13.2	10.8	9.6
Valine	12.0	18.0	14.4	10.8
Methionine	13.2	18.0	14.4	10.8
Isoleucine	12.0	18.0	13.2	12.0
Leucine	50.4	67.2	51.6	40.8
Tyrosine	10.8	16.8	12.0	9.6
Phenylalanine	15.6	21.6	18.0	15.6
Histidine	15.6	21.6	16.8	15.6
Lysine	13.2	18.0	15.6	13.2
Arginine	28.8	37.2	31.2	28.8
Total (mg·g ⁻¹)	254.4	350.4	285.6	237.6

oil percentages may be attributed to the difference in moisture content in sesame seeds. Many researchers noticed significant differences in the percentages of oil in two Nigerian sesame cultivars irradiated with 4, 8, 12 and 16 μSv doses of fast neutron irradiation (Falusi *et al.*, 2013) and in *Capsicum annum* (Falusi *et al.*, 2012a; Falusi *et al.*, 2012b). Sesame seeds contain up to 55% oil which is rich in linoleic and oleic acids; it has a cholesterol-lowering effect (Martinchik, 2011). The same trends were seen concerning the shortage in oil viscosity upon using gamma irradiation 5, 10, 15 k Gy (Swailam and Hammad, 2012; Swailam, 2009).

For optimal growth and development, 17 essential elements are required by crop plants. If any element is lacking in the soil or not adequately balanced with other nutrients, growth suppression or even complete inhibition may result (Mengel *et al.*, 2001). The minerals investigated in sesame plants are shown in Table 3. Phosphorus, calcium and potassium represent the major minerals in the control plants. From the nutritional point of view, the available nutrient status was significantly improved (Fe, K, Mg, P) in irradiated samples. Magnesium contents were generally in accordance with previous publications. Beside the familiar function of Mg²⁺ as the central ion in the chlorophyll molecule, it is essential because it combines with ATP (thereby allowing ATP to function in many reactions) and because it activates many enzymes needed in

photosynthesis, respiration and formation of DNA and RNA (Salisbury and Ross, 1992).

Except for proline, the increase in amino acid values in irradiated samples above the control ones was similar to those reported for black Cumin (Al-Jassir, 1992), sesame (Swailam, 2009) and mung bean (Hussein, 2010). Pathirana and Subasinghe, (1993) added that the seeds are highly resistant to irradiation.

5. CONCLUSIONS

Gamma rays (30 and 60 Gy) increased sesame yield, oil fractions, mineral contents and amino acids. While unsaturated fatty acids were increased, the saturated ones decreased. The amount of unsaturated fatty acid (18:1, omega 9) was increased by 10.5% at 30 Gy dose followed by 60 Gy (1.1%). The high levels of unsaturated fatty acids increase the quality of the oil for human consumption. Therefore, further investigation on a broad scale is required of radiation doses and intensities to determine the best dose for oil quantity and quality.

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