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RESEARCH

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Effect of low gamma irradiation doses on growth, productivity and chemical constituents of Jerusalem artichoke (*Helianthus tuberosus*) tubers

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Abstract

Background: This field experiment was carried out during the two successive seasons of 2019 and 2020 at the experimental farm of the National Center for Radiation Research and Technology, Nasr City, Cairo, Egypt, to evaluate the effect of low gamma irradiation doses (0, 2.5, 5 and10 Gray) on growth, yield and chemical constituents of Jerusalem artichoke tubers as one of the non-traditional vegetable crops which had a high nutritional and medicinal value.

Results: The obtained results show that gamma irradiation at dose rate 5 Gy gave the best results of plant height, number of branches, shoot fresh and dry weight compared with treatments exposed to gamma irradiation at dose rate 2.5 and 10 Gy and also higher photosynthetic pigments such as chlorophyll a, b, a + b and carotenoids than un-irradiated tubers. Same stimulative dose (5 Gy) yielded the highest total yield per feddan, plant yield, tuber fresh weight and dry matter percentage of tubers. Regarding chemical constituents of tubers, it was observed that gamma irradiation at dose 5 Gy scored higher percentage of nitrogen, phosphorus, potassium, total carbohydrates and inulin than other doses. From another point, the highest concentration of total soluble phenols and flavonoids was correlated with 5 and 10 Gy of gamma irradiation.

Conclusions: The moderate dose of gamma irradiation 5 Gy has a stimulative effect on growth of Jerusalem artichoke which reflects on tubers yield and their chemical constituents.

Keywords: Jerusalem artichoke, Gamma irradiation, Productivity, Yield, Inulin

Background

Jerusalem artichoke (*Helianthus tuberosus* L.) or sunchoke is a member of family compositae, its origin is North America, the economic importance of Jerusalem artichoke referred to its tubers that contain about 75–85% of total sugars (Wang et al. 2013), and it has several characters such as high growth rate, high biomass, low cost of production and high capacity in the transformation of energy which gave it the opportunity to be cultivated in marginal, arid and semiarid lands.

Jerusalem artichoke is one of the most important crops that contain high amount of inulin, which is considered as an oligofructose composed of D-fructose units related to β (2–1) linkages with terminal glucose levels. Inulin is characterized by its beneficial effect as a probiotic agent that cannot be analyzed in human body as a result of its β-linkage arrangement and has the ability to diminish dietary energy intake. It has also an important role in regulating blood glucose levels, relieving hyperlipidemia, elevating the total count of

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bifidobacteria in the intestines and participating as an functional food/dietary fiber (Wang et al. 2016).

Gamma irradiation is a type of electromagnetic waves which has good penetration effect in molecules causing ionization of materials through the excitement of their electron (UNSC 2000). Particularly, the ionized cells could be characterized by the disturbance of host DNA which led to a notable changes in the inherited traits. The disturbance of DNA could be permanent which led to grave effects or might be temporary as a result of the ability of DNA in repairing itself after the damage following the mechanism of nucleotides in restoring themselves (Ali et al. 2016).

The physiological effect of low gamma irradiation doses on plant growth might be referred to the reaction between gamma rays and molecules in cells which produce free radicals. The resulted free radicals can change the main components of cells, and the appearance of the effect of low doses might be summarized in the acceleration of cell propagation, cell expansion, enzyme activity, tolerance against biotic or abiotic stress and the increase in plant yield (El-Beltagi et al. 2011). Also, there was a notable effect of gamma irradiation on increasing flavonoid, alkaloid, phenolic compound and antioxidant compound (Kim et al. 2006).

The doses below 1 KGy of gamma irradiation are considered low doses (Iglesias-Andreu et al. 2012). It was observed that low doses ameliorate the germination rate and development of okra and cucumber plants (Jaipo et al.2019), number of fruits and total yield of tomato (Wiendl et al. 2013), photosynthetic pigment concentration in lettuce (Marcu et al. 2013), and this stimulative effect of low doses of gamma irradiation was called hormesis, which is a scientific term that explains the promoting effect of low doses of gamma irradiation (Calabrese 2019).

Thus, the aim of this study was to evaluate the effect of gamma irradiation at different doses on Jerusalem artichoke as one of the non-traditional vegetable crops and study their effect on quantity and quality as well as chemical constituents of tubers.

Methods

A field experiment was carried out during the two successive seasons of 2019 and 2020 under open field conditions at the sandy clay loamy soil of the experimental farm of the National Center for Radiation Research and Technology, Nasr City, Cairo, Egypt. The chemical and physical analyses of the experimental soil are presented in Table 1.

Table 1 Chemical and physical analyses of the experimental soil of Nasr City, Cairo governorate, during 2019 and 2020 seasons

Soil properties	Experimental year 2019	Experimental year 2020
pH (1:1)	7,32	7.31
EC (1:1) dS/m	2.2	1.8
Soluble anions (meq/l)		
CO_3^-	1.5	1.2
HCO_3^-	4.5	4.55
Cl^-	8.0	7.5
SO_4^-	11.7	9.6
Soluble cations (meq/l)		
Ca^{++}	10.5	10.1
Mg^{++}	3.5	3
K^+	0.50	0.41
Na^+	11.2	9.34
Sand (%)	57.3	58.4
Silt (%)	21.2	18.2
Clay (%)	21.5	23.4
Texture class	Sandy clay loam	Sandy clay loam

Irradiation process

Tubers of Jerusalem artichoke cv. Fuseau were obtained from Faculty of Agriculture Ain Shams University. Similar tubers in shape and size without damage or defects were subjected to different low doses of gamma irradiation through Cesium 137 source (0, 2.5, 5 and 10 Gy of gamma rays) at the dose rate of (0.65692 and 0.64188 Rad/second) at National Center for Radiation Research and Technology, Nasr City, Cairo, Egypt, during the two successive seasons.

Soil preparation

Calcium super-phosphate (15% P_2O_5) at 300 kg/fed was added during soil preparation, and 150 kg of ammonium nitrate (33% N) and 150 potassium sulfate (50% K_2O) were added after one month of cultivation and the second one after one month of the first addition. The irrigation was carried out through flood irrigation.

Each experimental plot consists of 3 rows (3 m of length and 0.3 m of width), and then, un-irradiated and irradiated tubers were sown, and the distance was 30 cm apart on the top of row at February 15 during the two successive seasons. The different treatments were arranged in a complete randomized block design.

Agricultural management, disease and pest control programs were done according to the recommendations of the Egyptian Ministry of Agriculture and Land reclamation. Harvesting was carried out at December 31 in both seasons when tubers reached the optimum stage of harvest.

Vegetative characteristics

Five plants were chosen randomly from three replicates (from the inner rows) at 210 days after sowing for estimating: plant height (cm), number of branches per plant, shoot fresh and dry weight (g), as well as leaf area per plant (cm^2).

Tuber yield and its components

Total yield was determined for each experimental plot at harvest time (290 days from planting), and tubers were harvested from each plot and then weighted and converted to determine total yield per feddan (ton), plant yield (kg), tuber fresh weight (g) and tuber dry matter percentage = (dry weight of tuber/fresh weight of tuber) × 100.

Chemical constituents

Chlorophyll a, b, a + b and carotenoids (mg/g fresh weight) in leaves were measured at 210 days from planting date according to Wettestein (1957). As for chemical constituents of tubers, total nitrogen percentage was estimated according to Plummer (1971), phosphorus percentage was determined according to Jackson (1958), potassium percentage was determined according to Piper (1950), total carbohydrates percentage was determined calorimetrically in dry matter of tubers according to Dubois et al. (1956), inulin percentage was estimated according to (Winton and Winton 1958), and total phenols and flavonoids were estimated according to Chang et al. (2002).

Statistical analysis

Data recorded were subjected to the statistical analysis of variance according to Snedecor and Cochran (1980), and means of separation were LSD at 0.05 level.

Results

Vegetative characteristics

Data presented in Table 2 show the effect of different low doses of gamma irradiation on growth characters of Jerusalem artichoke plants, and from the obtained results, it could be concluded that there was significant difference among different doses and 5 Gy of gamma irradiation scored the tallest plant, the highest number of branches, shoot fresh and dry weight as well as leaf area per plant compared to others doses during the two successive seasons, followed insignificantly by both irradiation doses 2.5 and 10 Gy. It was shown that all irradiation doses caused a remarkable amelioration of plant vegetative growth parameters compared to un-irradiated tubers.

Photosynthetic pigments of leaves

Concerning photosynthetic pigments of Jerusalem artichoke leaves, data tabulated in Table 3 show that there was a notable effect of low doses on chlorophyll a, b, a + b and carotenoids, whereas 5 Gy led to higher concentration of chlorophyll a, b, a + b and carotenoid than other doses in the first and the second season, respectively, followed insignificantly by 2.5 and 10 Gy, while control treatment (un-irradiated tubers) scored the lowest values as introduced in Table 3.

Tuber yield

Regarding total yield of tubers and its component, the outlined data in Table 4 show that there was a

Table 2 Effect of gamma irradiation doses on plant height, number of branches, fresh and dry weight of shoots as well as leaf area per plant of Jerusalem artichoke plants during the two successive seasons of 2019 and 2020

Treatments	Plant height (cm)	No. branches/plant	F.W. shoots/plant (g)	D.W. shoots/plant (g)	Leaf area / plant (m^2)
Frist season					
0 (un-irradiated)	140.33	3.00	491.87	159.43	2.64
2.5 Gy	187.33	3.00	1198.57	377.27	3.14
5 Gy	192.33	5.33	1602.30	475.77	4.25
10 Gy	187.33	2.67	1186.27	322.73	3.65
$LSD_{0.05}$	**2.64**	**1.67**	**245.35**	**76.52**	**0.78**
Second season					
0 (un-irradiated)	143.53	5.67	1055.23	297.30	2.55
2.5 Gy	185.28	6.67	1895.70	253.80	3.52
5 Gy	195.36	7.67	1719.63	391.50	4.44
10 Gy	185.33	6.33	1432.30	303.30	3.76
$LSD_{0.05}$	**3.22**	**1.07**	**289.30**	**55.13**	**0.51**

Bold indicates L.S.D. at 0.05 least significant differences

Table 3 Effect of gamma irradiation doses on chlorophyll a, chlorophyll b, chlorophyll a+b and carotenoids of Jerusalem artichoke plants during 2019 and 2020 seasons

Treatments	Chl a mg/g F.W	Chl b mg/g F.W	Chl a+b mg/g F.W	Carotenoids mg/g F.W
Frist season				
0 (un-irradiated)	2.24	1.58	2.24	1.44
2.5 Gy	2.66	1.78	2.66	1.53
5 Gy	3.25	1.98	3.25	1.95
10 Gy	2.85	1.80	2.85	1.68
$LSD_{0.05}$	**0.31**	**0.06**	**0.24**	**0.02**
Second season				
0 (un-irradiated)	2.08	1.46	2.08	1.43
2.5 Gy	2.55	1.57	2.55	1.58
5 Gy	3.55	1.88	3.55	1.94
10 Gy	2.88	1.68	2.88	1.72
$LSD_{0.05}$	**0.22**	**0.04**	**0.21**	**0.02**

Bold indicates L.S.D. at 0.05 least significant differences

Table 4 Effect of gamma irradiation doses on total yield per feddan, plant yield, tuber fresh weight and tuber dry matter percentage of Jerusalem artichoke plants during the two successive seasons of 2019 and 2020

Treatments	Total yield (Ton/fed)	Plant yield (kg)	Tuber fresh weight (g)	Tuber dry matter%
Frist season				
0 (un-irradiated)	16.58	1.58	29.66	22.31
2.5 Gy	19.65	1.96	33.85	23.30
5 Gy	22.35	2.73	46.55	24.25
10 Gy	20.35	2.03	35.35	23.20
$LSD_{0.05}$	**1.05**	**0.23**	**3.56**	**0.12**
Second season				
0 (un-irradiated)	17.20	1.66	29.85	22.22
2.5 Gy	19.87	1.98	33.77	23.37
5 Gy	22.87	2.86	47.32	24.85
10 Gy	20.74	2.31	36.55	23.33
$LSD_{0.05}$	**1.22**	**0.33**	**4.23**	**0.14**

Bold indicates L.S.D. at 0.05 least significant differences

significant difference among different doses, whereas tubers irradiated with 5 Gy followed by 2.5 Gy and 10 Gy gave plants yielded higher total yield per feddan, plant yield and tuber fresh weight as well as tubers dry matter percentage than un-irradiated tubers in both seasons.

It is shown from vegetative growth characters presented in Table 2 that these vegetative growth characters were highly reflected on tuber fresh weight and plant yield as well as tuber dry matter as shown in Table 4 which ultimately led to an increase in total yield per feddan. In this concern, total yield ton/fed was increased in both first and second seasons.

In another mean, the increment of total yield per plant of Jerusalem artichoke plant was mainly attributed to the increase in average weight of tubers accompanied by tubers irradiated with 5 Gy.

Chemical constituents of tubers

The phytochemical compounds, i.e., total carbohydrates percentage, nitrogen, phosphorus, potassium percentage, total soluble phenols, flavonoids concentrations and inulin percentage in tubers, were affected by different low doses of gamma irradiation, whereas data presented in Table 5 show that 5 Gy of gamma irradiation gave higher percentage of nitrogen phosphorus and potassium than control treatment.

Regarding total carbohydrates and inulin percentage, data illustrated that the highest percentages of both previous characters were obtained from tubers obtained from 5 Gy of gamma irradiation. From another point, it was noticed that tubers irradiated with 5 and 10 Gy of gamma irradiation yielded higher concentration of total soluble phenols and flavonoids than un-irradiated and 2.5 Gy of gamma irradiation in both seasons.

Discussion

Gamma radiation has been widely used for the improvement of various traits of many plant species (Roslim et al. 2015; Songsri et al. 2019).

The simulative effects of gamma irradiation on vegetative growth characters of Jerusalem artichoke are in agreement with the results obtained by Songsri et al. (2019) who found that low doses of gamma rays had positive effect on plant height of Jerusalem artichoke plants and also Hegazi and Hamideldin (2013) who observed that low doses of gamma irradiation were accompanied by an increase in number of branches per plant, leaf area per plant, fresh and dry weight per plant of okra. From another point, Abd El-Rahman et al. (2016) suggested that low doses of gamma rays scored the tallest plant and highest number of branches per plant of mung bean plants. Hamideldin and Hussien (2013) stated that low dose 10 Gy of gamma rays led to the tallest plant, leaf area and number of branches of potato plants.

Gamma rays are a type of electromagnetic spectrum which participates to ionizing radiation with charged particles like electrons or photons (Kim et al. 2004). The biological effect of gamma irradiation referred to the interaction between rays and water in different cells which produce free radicals, and these free radicals have either positive or negative effect on ameliorating

Table 5 Effect of gamma irradiation doses on nitrogen, phosphorus, potassium, total carbohydrates, inulin, phenols and flavonoids of Jerusalem artichoke tubers during the two successive seasons of 2019 and 2020

Treatments	%					mg/g D.W	
	N	P	K	Total carbohydrates	Inulin	Total soluble phenols	Flavonoids
Frist season							
0(un-irradiated)	1.33	0.45	2.88	16.35	9.55	36.55	11.55
2.5 Gy	1.60	0.54	2.95	17.33	10.33	37.36	12.32
5 Gy	1.88	0.66	3.25	18.68	11.43	38.33	12.36
10 Gy	1.58	0.52	3.05	17.86	10.87	38.98	12.96
$LSD_{0.05}$	**0.02**	**0.02**	**0.10**	**1.02**	**0.42**	**1.02**	**1.03**
Second season							
0(un-irradiated)	1.30	0.48	2.58	16.58	9.67	35.33	9.32
2.5 Gy	1.68	0.50	2.98	17.44	10.43	36.58	12.33
5 Gy	1.85	0.65	3.64	19.2	11.52	37.65	12.65
10 Gy	1.70	0.51	3.08	17.76	10.75	37.88	13.01
$LSD_{0.05}$	**0.03**	**0.01**	**0.20**	**9.4**	**0.32**	**1.03**	**1.04**

Bold indicates L.S.D. at 0.05 least significant differences

or damaging important component of plant cell which reflect on morphological, anatomical characters and biochemical as well as physiological process as a result of radiation dose, the expansion of thylakoid membranes, modification of photosynthesis process, amendment of photosynthesis process, modification of antioxidative system (Wi et al. 2005).

There are two factors affect the effect of gamma rays on plant growth characters: The first is related to plant characteristics such as species, genus and growth stage, and the second one is related to irradiation process like source of irradiation, dose level and dose rate (Jan et al. 2012).

High doses of gamma rays have a negative effect on different vital processes and growth characters of different plants, whereas seeds irradiated with high doses showed negative influence on protein synthesis, balance of endogenous hormones, gas exchange and enzyme activity (Hameed et al. 2008). Low doses or simulative doses have a tonic effect on germination, plant growth and different vegetative characters (Hong et al. 2017). The animating effect of low doses on growth characters might be referred to the positive mutant effect such as the fast repair of DNA, the activation of endogenous hormones and enzymes related to germination and plant development (Majeed et al. 2018). From another point, low doses accelerate cell division in meristematic tissues which reflect on enhancing and stimulating vegetative characters (Dhakshanamoorthy et al. 2011). The correlation between the increase in plant height and low doses of gamma irradiation might be related to its effect on stimulating cell division and different vital processes that enhance nucleic acid synthesis (Asare et al. 2017). Also, low doses of gamma irradiation might be the main reason that enhances the potentials of antioxidant and led to a good relation among endogenous hormones in irradiated cells which reflect on growth characters (Wi et al. 2007).

Regarding the influence of low doses on photosynthetic pigments, Aly et al. (2021) found that low doses of gamma rays scored the highest concentration of chlorophyll a, b and carotenoids of red radish leaves. The effect of low doses of gamma ray on increasing the concentration of photosynthetic pigments might be related to its effect on inducing a beneficial mutation which led to a variation in cell structure and vital process like expansion of thylakoids membranes and amelioration of photosynthesis process which reflect on pigment bulk that adjust the color of plant leaves (Gaafar et al. 2016).

As for the influence of low doses of gamma rays on yield, similar finding was obtained by Wang et al. (2007) who stated that low doses increase total yield of sweet potato roots, Cheng et al. (2010) who found that potato tubers irradiated with 5 Gy yielded 70% increase in total yield than untreated tubers and Songsri et al. (2019) who observed that 5 Gy of gamma irradiation increased tubers fresh weight of Jerusalem artichoke.

The simulative effect of low doses 5 Gy of gamma ray on vegetative characters such as plant height, number of branches, shoot fresh and dry weight as well as leaf area as presented in Table 2 might be reflected on increasing photosynthesis process which leads to an accumulation of carbohydrates and then after produces higher tubers in weight which increases total yield. From another point, low doses of gamma rays have the ability to increase the enzyme activity which reflects on enhancing cell division that leads to an increase in plant development and leaf area which reflects on tuber yield (Ali et al. 2016).

Respecting the influence of gamma rays on chemical constituents of tubers, similar result was obtained by Afrin et al. (2019) who found that low dose of gamma ray scored the highest percentage of nitrogen and phosphorus in onion bulb, Hamideldin and Hussien (2013) who observed that low dose 10 Gy scored the highest percentage of phosphorus and potassium in potato tubers and also Aly et al. (2019) who observed that low dose of gamma ray increased both phenols and flavonoids of eggplant fruits. From another point, Kebeish et al. (2015) confirmed that low dose of gamma irradiation 10 Gy led to a higher percentage of carbohydrates than high doses in bulbs of garlic. The impact of gamma irradiation on increasing macronutrients in tubers such as nitrogen, phosphorus and potassium might be referred to the influence of low dose 5 Gy of gamma irradiation on enhancing the growth parameters of plants as presented in Table 2 and photosynthetic pigments as shown in Table 3 which reflect on vital process such as photosynthesis which ameliorates the absorption of minerals and increases their percentage in tubers (storage organs).

The reduction of carbohydrates percentage in tubes with the increase in gamma rays doses might be related to the enhancement of the metabolic activation of hydrolyzing enzymes (Maity et al. 2004).

The impact of gamma rays on phenolic compound depends on dose level, whereas low doses could stimulate the content of phenolic compound in different irradiated plant organs, which depend on antioxidant molecule structure or fraction of some chemical bonds (Pereira et al. 2015). The devastating of gamma ray and oxidation had the opportunity to break the bonds of polyphenols which are characterized by low molecular weight that increases antioxidant phenolic compounds (Adamo et al. 2004).

Conclusions

Gamma radiation has been widely used for the amelioration of various traits of many plant species, one of them is Jerusalem artichoke, and this study proved that low dose 5 Gy of gamma irradiation which can be created before cultivation through the irradiation of tubers by Cesium 137 gamma source has a simulative impact on vegetative characters of Jerusalem artichoke which reflects on increasing total yield and chemical constituents of tubers, which gave the chance to cultivate irradiated tubers of Jerusalem artichoke under marginal and unfertile soils and obtain high yield with high quality.

Abbreviations

Gy: Gray; N: Nitrogen; P: Phosphorus; K: Potassium; No.: Number; F.W.: Fresh weight; D.W.: Dry weight; fed.: Feddan.

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Author contributions

A.M.M. performed the field experiment and was a major contributor in writing the manuscript. A.M.E.H. performed the field experiment and revised the paper. S.H. performed the chemical analysis of the samples, and A.M.M.E.T. coordinated the data collection and statistical analysis. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are included in this published article.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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