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Gamma radiation and its Influence on agronomic and genetic attributes of two Jerusalem artichoke genotypes

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ABSTRACT

Gamma radiation can be utilized as a mutagenic agent for inducing genetic variability in plant species. The present study was carried out to increase genetic variability and evaluate the effectiveness of different gamma rays doses (0, 10, 20, 30, and 40 Gy) on germination & survival percentage, plant height, number of branches/plant, tuber weight, total yield/plant, inulin, and dry matter percentage of two Jerusalem artichoke (*Helianthus tuberosus L.*) genotypes (Balady and Fuseau) during 2019 and 2020 seasons at the Experimental Farm of Kaha Research Farm, Kaluobia Governorate, Egypt. Results showed that a 10 Gy dose of gamma irradiation significantly increased plant height, tuber weight, yield per plant, dry matter, and inulin concentration. Increasing gamma-ray doses significantly reduced values for all of the studied traits, but the number of branches/plant increased with increased gamma-ray doses. According to the results of this study, gamma rays may cause mutations in Jerusalem artichoke through their three mutagenic treatments, and they can also improve several quantitative features. The high heritability and genetic advanced values suggest that future generations may see additional advancements.

KEYWORDS: *Helianthus tuberosus L.*, Gamma Irradiation, Genetic Parameters, Yield and Yield Components, Heritability.

1. INTRODUCTION

Helianthus tuberosus L., also called Jerusalem artichoke, earth apple, or sunchoke. It is regarded as a therapeutic plant. It is a perennial member of the Asteraceae family. The Jerusalem artichoke, which originated in North America, is now widely farmed all over the world for several purposes, including the food business, diabetes patients' diets, and the manufacturing of ethanol (Kiru and Nasenko, 2010). The Jerusalem artichoke plant looks similar to a sunflower (above ground) and a potato (underground), but it also produces a lot of tubers that are smaller, crispier, and sweeter than a potato and have a ginger-like appearance. It is a tuber crop containing large amounts of inulin which is considered a prebiotic substance with beneficial effects on human health (Puangbut *et al.*, 2017; Puttha *et al.*, 2012). Jerusalem artichoke is successfully grown in Middle Egypt about eight to ten years ago, and therefore, it can be grown widely in new lands in Egypt (Moustafa *et al*., 2018).

It could be genetically enhanced with little breeding efforts compared to several other crops. Genetic information about important Jerusalem artichoke traits is limited, so breeding programs are being carried out to improve genotypes with high inulin content and tuber yield. Mutation induction can be used to increase genetic variation to obtain plants with higher content of bioactive compounds (Volk and Richards, 2006; Kays and Nottingham, 2008).

Gamma irradiation may change the physiology and biochemistry structure of mutants because it contains a large amount of kinetic energy, causing structural changes in the chromosomes of plants (Datta et al., 2011; Puttha et al., 2012; 2013). Induced genetic variation for different plant characters in horticulture plants by gamma radiation, the success of mutation breeding by gamma rays depends on the irradiation doses and the plant genotypes (Aslam et al., 2016; Roslim et al., 2015). Irradiation mutations have been used in the improvement of tuber crops as potato, sweet potato, yam, and Jerusalem artichoke (Cheng et al., 2010; Shin et al., 2011; Yalindua et al., 2014& Songsri, 2019). Songsri (2019) pointed out that gamma rays may be useful for the improvement of important characteristics such as yield and inulin content in Jerusalem artichoke. Studies on the impact of ionising radiation on grown plants typically show that low doses have beneficial impacts on plant development characteristics whereas larger doses cause harm and mortality. (Majeed et al., 2017).

It is helpful to estimate genetic factors like heritability, genetic advance, and phenotypic and genotypic coefficients of variability to create successful breeding programs. The genotypic coefficient of variation (GCV) displayed by the plant attribute serves as a gauge for the extent of genetic variation. However, the GCV cannot be used to determine the percentage of variation that is solely inherited. Estimates of heritability alone do not provide an idea about the expected gain in the next generation but genetic advance must be taken into consideration in addition to estimates of heritability. Understanding heritability is essential because it shows how much a character may be passed on to future generations (Tabasum et al., 2010; Wani et al., 2014 and Kozgar, 2014).

The objectives of this study were to determine the genetic variability and other genetic parameters of Jerusalem artichoke and measure the effects of gamma rays on growth and tuber yield as well as the bioactive component of inulin content.

2. MATERIALS AND METHODS

2.1. Plant materials

Tubers of two Jerusalem artichoke (*Helianthus tuberoses L*) genotypes, i.e. Balady and Fuseau (obtained from Hort. Res. Institute, Agri. Res. Center, Giza) were used. Both genotypes are well adapted to agro-climatic conditions of Kaha Research Farm, Kaluobia Governorate, Egypt.

2.2. Experimental procedures

The current study was conducted at Kaha Research Farm, Kaluobia Governorate during seasons of 2019 and 2020. Tubers of the two genotypes were subjected to gamma radiation at the rates of 10, 20, 30, and 40 Gray (Gy) at the National Center for Radiation Research and Technology, Nasr City, Cairo, Egypt. Gamma rays were emitted from Cobalt-60 source by the use of Co^{60} unite model Noratom – Nor, and dose rate of 44 r/sec.

The experimental design was set up using a randomized complete block design in a factorial (RBCD) with three replications with Jerusalem artichoke genotypes as factor A and the four gamma radiation doses as well as control as factor B. This experiment included 10 treatments (2 cultivars and 4 ray doses and control). In April 2019, the treated and untreated tubers were planted the next day after treatments at the experimental farm. Normal agricultural practices were adopted as recommended. The harvest process started after the appearance of maturity signs. Tubers were harvested from each plot in November 2019 (M_1 generation) and stored until the next season of a plantation. Tubers from the stored tubers of the 2019 season were planted in April 2020. Statistical design and plantation system along with cultural practices in this experiment were the same as in the first season. At harvest time, an accurate selection was carried out on plants resulting from the treatments (M_2 generation).

2.3. Data enrollment

When plants were fully vegetative developed (210 days after planting), germination percentage, plant height (cm), and number of branches /plant data were obtained. The values recorded for germination percentages at different times were also considered for calculating the survived plants' percentages. The plants were pulled out (290 days from planting) and separated into shoots and tubers. Tubers were washed in tap water to remove soil particles and then tuber weight (g) and yield/plant (kg) were determined. Inulin concentration and dry matter of tubers were determined according to Winton and Winton (1958).

2.4. Statistical analysis

Statistical analysis using the technique of variance analysis (ANOVA) by multiple range tests is used to analyze the recorded data. Duncan's multiple range test (1955) was used for the comparison between treatment means using a GenStat software program.

Phenotypic and Genotypic Coefficient of Variation (PCV and GCV)

According to **Singh and Choudhary (1985),** the PCV and GCV estimations were computed

$$\mathbf{PCV} = \frac{\sqrt{\sigma 2p}}{\bar{x}} \times 100$$

$$\mathbf{GCV} = \frac{\sqrt{\sigma 2g}}{\bar{x}} \times 100$$

The phenotypic variance is denoted by σ2p, the genotypic variance by σ2g and the trait mean by $\bar{X}$. As per Sivasubramanian and MadhavaMenon (1973), GCV and PCV levels were divided into low (0–10%), intermediate (10–20%), and high (20% and beyond.)

Estimate of broad sense heritability (H^2b %)

$$H^2b\% = \frac{\sigma 2g}{\sigma 2p} \times 100$$

As per **Robinson *et al*. (1949),** the heritability percentage was divided into low (0-30%), moderate (30-60%), and high (≥60%).

Expected and Estimate Genetic Advance (GA)

$$\mathbf{GA} = K\sqrt{\sigma 2p}\, H^2b$$

According to **Addissu (2012**) where K, a constant that symbolizes the selection strength, the value is 2.06 when K is 5%.$\sqrt{\sigma 2P}$ is the phenotypic standard deviation, H^2b is the heritability. To determine genetic advance as a percentage of the mean (GA%), the following equation was used:

$$\mathbf{GA\ \% = \frac{GA}{\bar{x}} \times 100}$$

It was classified as low (0–10%), moderate (10–20%), and high (20% or higher) as given by (Johnson et al., 1955).

3. RESULTS AND DISCUSSION

3.1. Survival percentage

The survival percentage of Jerusalem artichoke under different gamma irradiation doses during two seasons is illustrated in Fig.1. The survival rate decreased with the increase of irradiation doses. The control and 10 Gy dose showed the best survival probability while the 30 Gy dose showed the lowest value for both genotypes. An irradiation dose of 40 Gy caused complete mortality for both genotypes. This may be because exposure to large doses of gamma rays causes DNA damage in cells, which slows down plant growth and development.

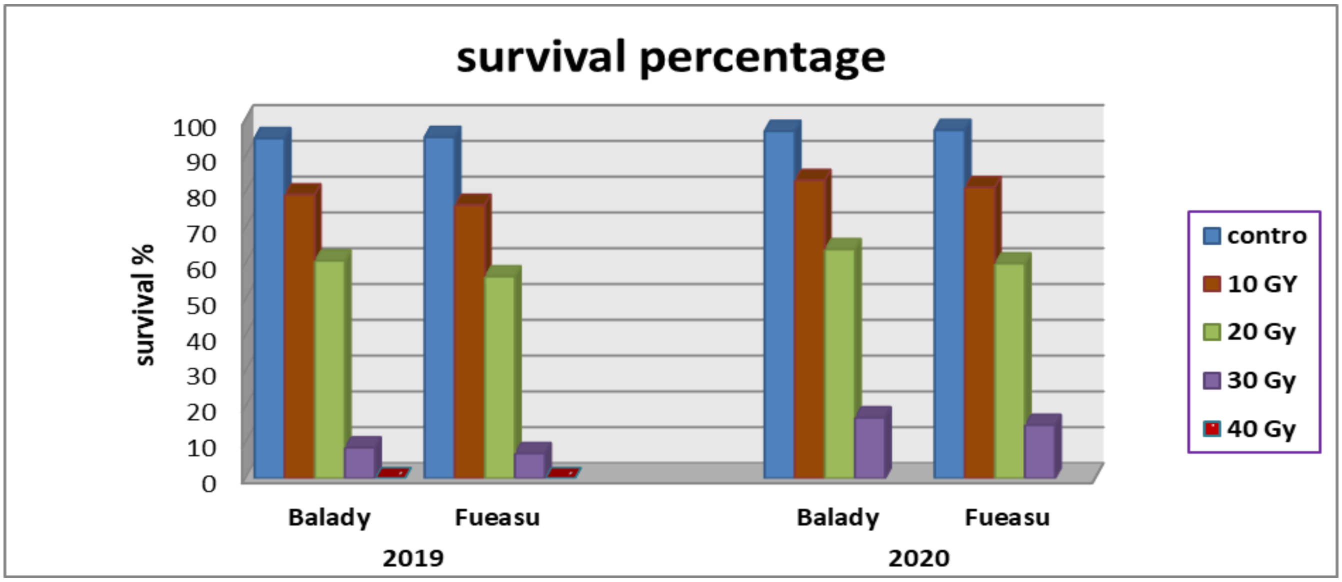

Fig. 1 Survival percentage as affected by various doses of gamma irradiation and Jerusalem artichoke cultivars during the two seasons

For genotypes, the Balady genotype survival rate is the superior survival rate of the Fuseau genotype during the two seasons. This may be a result of the Fuseau genotype having larger tubers than the Balady genotype. The study revealed that Jerusalem artichoke survival rates vary depending on variety and tuber size. This supports previous findings that the survival rate was different between varieties of the same species (Songsri et al., 2019; Aslam et al., 2016; Roslim et al., 2015). Additionally, compared to genotypes with larger tubers, the genotype with smaller tubers was more radiation-resistant. The percentage of the irradiated area is a crucial factor since more radiation exposure causes more damage to plant tissue. Likewise, Bado et al. (2016) illustrated that micro-tuber sprouting ability was most resistant to gamma irradiation in potato.

3.2. Effect of irradiation on vegetative and reproductive characters

Table 1 displays the variance in the examined variables as influenced by various gamma irradiation dosages and Jerusalem artichoke genotypes. Fuseau genotype significantly exceeded Balady genotype in all studied traits except the germination percentage.

Concerning the doses of gamma rays, results in Tables 1 show significant differences among gamma radiation doses for all the studied traits. The highest values were found in the low doses, in other words, the higher doses gave the lower values for all traits except the number of branches/plant. The number of branches/plant increased with increased gamma rays doses.

Table 1. performance of Jerusalem artichoke as affected by genotypes and gamma-ray doses.

treatments		Germination %	Plant height (cm)	N0. of branches /plant	Tuber weight (g)	Yield/plant (kg)	Inulin %	Dry matter %
2019								
Gamma ray doses	**control**	97.17a	165.30a	3.36d	52.00b	3.32b	4.30b	23.90b
	10 Gy	80.17b	166.70a	3.82c	56.30a	3.70a	5.54a	26.79a
	20 Gy	61.83c	100.70b	4.78b	29.20b	1.03c	3.94c	21.55c
	30 Gy	9.50d	80.80c	5.46a	14.90c	0.50d	3.42d	20.35d
	40 Gy	0.00e	0.00d	0.00e	0.00e	0.00e	0.00e	0.00e
Genotypes	**Balady**	50.33a	100.20b	3.10b	29.40b	1.63b	3.17b	17.74b
	Fuseau	48.93b	105.15a	3.90a	31.60a	1.79a	3.71a	19.30a
2020								
Gamma ray doses	**control**	98.5a	166.17 b	3.50d	56.50b	3.41b	4.76b	24.36b
	10 Gy	86.00b	172.20a	4.40c	58.30a	3.90a	5.82a	27.28a
	20 Gy	63.85c	101.00c	4.9b	33.50c	1.18c	4.13c	22.88c
	30 Gy	19.00d	79.00d	5.85a	18.00d	0.62d	3.64d	21.42d
Genotypes	**Balady**	67.93a	124.67b	4.03b	39.75b	2.16b	4.03b	22.90b
	Fuseau	65.75b	134.58a	5.3a	41.92a	2.39a	5.14a	25.10a

Means designed by the same letter at each column are not significantly different at the 5% level according to Duncan's multiple range test.

The germination percentage of Jerusalem artichoke decreased with increased irradiation dose (Table 1). The highest germinations were recorded for the control (97.17, 98.50%) followed by 10 Gy (80.17, 86.00%) in the 2019 and 2020 seasons, respectively. However, the 40 Gy dose completely inhibited the Jerusalem artichoke germination. Regardless of genotypes, Balady exhibited higher germination (50.33 and 67.93) than Fuseau (48.93 and 65.75) in the two seasons, respectively. This could be due to chromosome aberrations, physiological damage, and cell damage (Cheng et al., 2010). Marcu et al. (2013); Songsri et al. (2019) also reported that the high gamma rays doses (>30 Gy) inhibited the emergence ability of lettuce and Jerusalem artichoke. Also, high gamma irradiation may damage the proteins along with the failure of RNA and lead to the inhibition of tissue culture growth (Kiong et al., 2008).

Increasing gamma irradiation doses significantly decreased plant height, tuber weight, total yield per plant, inulin, and dry matter accumulation during two seasons. The highest values were reported for tubers treated with a 10 Gy dose (166.70, 172.17; 56.30, 58.3; 3,70, 3.9; 5.54, 5.82; 26.79, 27.28) for the previous traits in the two seasons, respectively. As well as the lowest values were recorded for tubers treated with a 30 Gy dose (80.8, 79.0; 14.9, 18.0; 0.5, 0.62; 3.42, 3.64; 20.35, 21.42) for the same traits in the two seasons, respectively. Tubers treated with a 10 Gy dose surpassed control for prior traits in the two seasons (Table 1).

These observations were consistent with Cheng et al. (2010); Sianipar et al. (2013), and Songsri et al. (2019) who found that greater gamma radiation doses harm the morphological traits of potato; rodent and Jerusalem artichoke tubers. The balance of hormones and enzyme activity is affected by high doses of gamma rays, which inhibit the rate of cell elongation and result in a reduction in plant growth (Stoeva, 2002; Kiong et al., 2008). Low doses of irradiation had increased enzyme activation, which stimulates the rate of cell division and results in an increase in plant growth. Similar results regarding reductions in plant height were also visible in various plant species such as rice (Efendi et al., 2017), mungbean (Roslim et al., 2015), potato (Cheng et al., 2010), and Jerusalem artichoke (Songsri et al., 2019). Whilst higher doses induced a greater number of branches. Plant mutants from the 30 Gy dose had a higher number of branches than the other gamma-ray doses in the two seasons. These findings were similar in Jerusalem artichoke and other tuber crops such as potato and sweet potato (Songsri et al., 2019; Cheng et al., 2010 Wang et al., 2007). In contrast, Sianipar et al.

(2013) found that the higher irradiation doses had decreased the number of shoots in rodent tuber; these diversities could be due to the difference in plant species. The Jerusalem artichoke's flower color could not be changed by gamma rays. The yellow color in Jerusalem artichoke is distinctly very stable; these outcomes are confirmed by the observation of Songsri et al. (2019).

3.3. Effect of interaction between irradiation and genotypes on vegetative and reproductive characters

Data in Tables 2 and 3 show the effect of the interaction between gamma radiation doses and Jerusalem artichoke genotypes on genotypes traits.

Results revealed that Balady and Fuseau genotypes reacted differently due to various gamma radiation doses concerning the studied traits. The interaction between Jerusalem artichoke genotypes and gamma rays was significant for all the studied characters during the two seasons.

For germination percentage, Balady had the highest values (81.67, 87.17) when its tubers were treated with a 10 Gy dose compared with the other doses. The lowest values (9.0, 18.0) were detected by Fuseau when it was subjected to a 30 Gy dose during tow seasons, respectively. Under the 10 Gy dose, the Fuseau genotype recorded the tallest plants (168.33,176.0), while the shortest plants were detected by the Balady genotype (74.33, 70.0) when it was subjected to a 30 Gy dose in the two seasons, respectively. Plant height significantly increased under 10 Gy dose in the two genotypes.

Balady genotype produced the highest tuber (59.0, 61.3) and yield weight (4.1, 4.23) when the tubers were exposed to the lowest dose (10 Gy) in both seasons respectively. Tuber weight and total yield/plant significantly increased under low doses of gamma radiation and surpassed the other irradiation doses, but it was statistically equal to the control in the case of the Fuseau genotype (56.67, 55.0, 3.56, and 3.56) in the 2020 season, respectively (table 3). On the other hand, tubers irradiated with the lowest dose (10 Gy) exhibited the highest values of inulin for Balady (5.17, 5.06) and Fuseau (5.92, 6.56) in both seasons respectively. As well as dry matter percentage (26.41, 26.70 and 27.17, 27.90) for Balady and Fuseau in both seasons respectively.

Table 2. Effect of interaction between gamma radiation doses and Jerusalem artichoke genotypes on Jerusalem artichoke traits in 2019 season

Variable	germination %	Plant height(cm)	No. of branches/plant	Tuber weight (g)	Yield/plant (kg)	Inulin %	Dry matter %
Balady control	97.00a	163.70b	3.00d	50.30c	3.10d	3.87de	22.90c
10 Gy	81.67b	165.00ab	3.70c	59.00a	4.10a	5.17b	26.41a
20 Gy	64.00d	98.00d	3.80c	27.00e	0.72f	3.77e	20.42e
30 Gy	10.00f	74.33f	4.80b	10.50g	0.23g	3.07f	18.97f
40 Gy	0.00g	0.00g	0.00e	0.00h	0.00h	0.00g	0.00g
Fuseau control	97.33a	167.00ab	3.70c	53.70b	3.53b	4.74c	24.90b
10 Gy	78.67c	168.33a	4.00c	53.70b	3.32c	5.92a	27.17a
20 Gy	59.67e	103.33c	5.70a	31.50d	1.33e	4.11d	22.67c
30 Gy	9.00f	87.33e	6.20a	19.30f	0.76f	3.76e	21.72d
40 Gy	0.00g	0.00g	0.00e	0.00h	0.00h	0.00g	0.00g

Means designed by the same letter at each column are not significantly different at the 5% level according to Duncan's multiple range test.

Table 3. Effect of interaction between gamma radiation doses and Jerusalem artichoke genotypes Jerusalem artichoke traits in 2020 season

Variable	Germination %	Plant height (cm)	No. of branches/plant	Tuber weight (g)	Yield/plant (kg)	Inulin %	Dry matter %
Balady control	98.33a	161.70c	3.20e	50.30c	3.26c	3.93e	23.00e
10 Gy	87.17b	168.30b	3.90d	61.30a	4.23a	5.06 c	26.70b
20 Gy	66.20d	98.00e	4.10d	31.30e	0.86e	3.83e	21.70f
30 Gy	20.00f	70.00g	4. 90c	16.00g	0.28f	3.3f	20.30g
Fuseau control	98.67a	170.67b	3.80de	56.67b	3.56b	5.60b	25.70c
10 Gy	84.83c	176.00a	4.80c	55.60b	3.56b	6.56a	27.90a
20 Gy	61.50e	104.00d	5.80b	35.70d	1.49d	4.42d	24.10d
30 Gy	18.00g	87.00f	6.80a	19.67f	0.95e	3.98 e	22.60e

Means designed by the same letter at each column are not significantly different at the 5% level according to Duncan's multiple range test.

3.4. Genetic parameters

For the successful breeding of any plant species, it is necessary to know their genetic potential, the structure of the genotypic and phenotypic variance, heritability, and interdependence of functionally related traits. Estimates of genetic parameters in M2 are presented in Table 4. In general, the phenotypic coefficient of variability was higher than the genotypic coefficient of variability. The highest PCV values were the number of branches/plant and inulin concentration (38.40% and 34.55%, respectively). However, the moderate (10-20) estimates were plant height (10.96%), yield per plant (15.40%), and dry matter (12.84%). Nevertheless, the smallest PCV values (0-10) were for germination, survival percentage, and tuber weight (4.74, 4.44%, and 8.18respectively).

The highest estimates of GCV (>20%) were recorded for the number of branches/plant and inulin concentration (37.56% and 34.19%, respectively), while the moderate estimates were those of plant height (10.75%), yield per plant (14.20%), and dry matter (12.72%). Meanwhile, the smallest GCV were those of germination, survival percentage, and tuber weight (5.09, 4.87 %, and 7.14 respectively). Even while the genotypic coefficient of variation showed how much genetic diversity was present in the genotypes for different phenotypes, it did not provide us enough scope to determine how much of the variance was heritable. In light of this, heritability information is necessary for crop enhancement. According to the results, all traits showed high heritability values. It was discovered that features with heritability in the broad sense ranged from 76.25 percent (tuber weight) to 98.2 percent (dry matter %).

Table 4. Estimates of genetic parameters for all the studied traits in the M_2 generation of Jerusalem artichoke

Variable	Mean($\bar{x}$)	Coefficient of Variation (%)		H^2b (%)	GA	GA%
		PCV	GCV			
Germination%	66.84	4.74	4.53	91.55	5.97	8.93
Survival%	64.36	4.44	4.17	88.62	5.21	8.10
Plant height (cm)	129.63	10.96	10.75	96.00	28.16	21.70
Number of branches/plant	4.86	38.40	37.56	95.70	3.67	75.60
Tuber weight (g)	40.80	8.18	7.14	76.25	5.25	12.85
Yield/plant (kg)	2.28	15.40	14.20	83.70	0.62	26.60
Inulin%	4.59	34.55	34.19	97.90	3.20	69.60
Dry matter %	23.99	12.84	12.72	98.20	6.230	25.90

Phenotypic and genotypic Coefficient of Variation (PCV and GCV) broad sense heritability (H^2b), expected genetic advance (GA %)

For plant height, the number of branches/plant, yield per plant, inulin and dry matter concentration, and higher genetic advance (>20%) were noted (21.70, 75.60% and 26.60%, 69.6%, and 25.90%, respectively), followed by the moderate value of genetic advance (10-20%) that were recorded for tuber weight (12.85%). The lowest values for the genetic advance were for germination and survival percentage (8.93 & 8.10 %, respectively).

For yield traits, many studies revealed that heritability in the broad sense was moderate to high estimates (Hasanuzzaman et al., 2012; Devi, 2014; Adday, 2016; Rohini et al., 2017, and Amer, 2018). High H2b coupled with high GA were observed in plant height, the number of branches/plant, yield/plant, inulin, and dry matter concentration.

4. CONCOLUTION

Gamma radiation has been widely used for the amelioration of various traits of many plant species, one of them is Jerusalem artichoke. This study found that 10 Gy dose of gamma irradiation has impacted on vegetative characteristics of Jerusalem artichoke which reflects on increasing total yield and bioactive component of inulin content of Balady and Fuseau genotypes. The high heritability and genetic advance values suggest that future generations may see additional advancements.

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الملخص العربي

إشعاع جاما وتأثيره على الصفات الزراعية والوراثية فى صنفين من الطرطوفة

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قسم بحوث البطاطس والخضر خضرية التكاثر –معهد بحوث البساتين– مركز البحوث الزراعية

يمكن استخدام إشعاع جاما كعامل مطفر لإحداث التباين الوراثى في الأنواع النباتية. أجريت الدراسة الحالية لزيادة التباين الوراثي وتقييم فعالية الجرعات المختلفة من أشعة جاما (٠،١٠، ، ٢٠ ، ٣٠ ، ٤٠ جراي) على نسبة الإنبات والبقاء ، ارتفاع النبات ، عدد الفروع / نبات ووزن الدرنة ، المحصول الكلى / نبات ، نسبه الإنولين وكذلك النسبة المئوية للمادة الجافة فى صنفين من الطرطوفة (بلدي وفيوزا) خلال موسمي ٢٠١٩ و ٢٠٢٠ في مزرعة أبحاث قها بمحافظة القليوبية ، مصر. أظهرت النتائج أن الجرعة ١٠ جراي أدت إلى زيادة معنوية في طول النبات ووزن الدرنات والمحصول الكلى / نبات وتركيزكل من الأنيولين والمادة الجافة. أدت زيادة الجرعه من أشعة جاما إلى انخفاض معنوي في قيم جميع الصفات المدروسة ، ولكن زاد عدد الفروع / النبات مع زيادة جرعات أشعة جاما. وفقًا لنتائج هذه الدراسة ، قد تسبب أشعة جاما طفرات في صنفين الطرطوفه من خلال استخدام الجرعات الثلاثه المطفرة ، ويمكنها أيضًا تحسين العديد من الصفات الكمية. تشير القيم العالية لدرجه التوريث بالمعنى الواسع (% H2b) وكذلك التقدم الوراثى (GA%) إلى أنه يمكن إجراء مزيد من التحسين الوراثى في الأجيال القادمة.