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Development of Some Salinity Tolerant Tomato Mutants Using Gamma-Irradiation

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Abstract

Salinity stress is one abiotic stress that severely affects the crop yield. Tomato is one of the most important vegetable plants in the world which is also more sensitive to salinity stress. Therefore, this study's aim to create more salinity-tolerant tomato plants having desirable traits. Seeds of two commercial tomato cultivars (Super Strain B and Castle Rock) have been exposed to different doses of gamma rays (100, 200, 300 and 400 Gy), and the mutants were evaluated under salinity stress conditions during two successive generations (M0 and M1) in the field and one generation (M2) in greenhouse. Various abnormal phenotypic changes were observed in the M0 generation. Moreover, at both the M1 and M2 generations, all the evaluated traits significantly differed among the studied genotypes. Furthermore, some induced mutants, especially the C-10 mutant, had superiority over the origin cultivars in fruit yield production under saline conditions. Thus, these mutants could be used in breeding programs to generate more salinity-tolerant lines.

Keywords: gamma rays, genetic variation, *Solanum lycopersicum* L., mutation, tomatoes.

Introduction

Tomato (*Solanum lycopersicum* L. 2n = 2x = 24) is one of the most important crop species in the world. It belongs to the family of *Solanaceae* and its origin area is South America (Paran and Fallik, 2011). It is used as a fresh or processed product. Furthermore, it is one of the important sources of several minerals, carbohydrates, vitamin A, vitamin C, antioxidant and β-carotene (Campbell *et al*., 2004). In Egypt, the total production of tomato is about 6.81 million tons in 2020 (E.M.A.L.R, 2020). Salinity stress is one of the abiotic stresses that cause deleterious effects on the tomato yield (Tester and Davenport, 2003). To overcome these affects the plant breeders working on the production of more tolerant genotypes for salinity stress. Induction of genetic variations by mutation is one of the useful tools for plant improvement (Parry *et al.*, 2009). Mutation breeding has made a considerable contribution to the worldwide development of high-yielding agricultural genotypes. To create a desirable mutant population with a greater mutagenesis rate, various mutagenic agents, such as chemicals and radiations are used. Among many mutagenic agents, gamma radiation exposure is less harmful, and results point mutations or minor deletions (Gupta, 2019). Therefore, gamma radiation has commonly been used as a mutagenesis agent to induce different genetic variations in tomato and many plants (Sikder *et al.,* 2013; Akhtar, 2014 and Sikder *et al.,* 2015). Many tomato mutants having superior traits have been obtained by γ-rays (Matsukura *et al.,* 2007 and Zafar *et al.*, 2022).

The aim of the current study is to produce new promising tomato genotypes that have a higher capacity for salinity stress.

Materials and methods

Experimental details

Two commercial tomato cultivars, Super Strain B and Castle Rock (were kindly provided by the Horticulture Research Institute, Agriculture Research Center, Giza, Egypt) were used in the current study. The dry seeds were exposed to different doses of gamma rays (100, 200, 300 and 400 Gy) at the National Center for Radiation Research and Technology (NCRRT), Cairo, Egypt. In the 2019/2020 season, the irradiated seeds (M0) were germinated in seedling trays for 25 days, then the seedlings (M0 generation) were transferred to grow in the field having soil containing salinity of 6.58 milimose/cm (private agricultural farm in Badary, Assuit). Analysis of the field soil and the irrigation water are shown in Table (1). The transplanted individual mutants of each genotype were screened based on morphological characterization. At the end of the growing season, the seeds of survival mutants (eleven and fifteen genotypes from the original Super Strain B and Castle Rock cultivar, respectively) were individually collected (M1 seeds).

Table (1): Analysis of the field soil and the irrigation water.

Soil analysis									
meq/100g soil						EC mmohs/cm	pH	ECe mmohs/cm	saturation capacity %
Hco_3	Cl	K	Na	Mg	Ca	(2.5:1)	(2.5:1)	(Mathematical)	
0.75	7.57	0.33	5.43	2.25	4.50	6.58	7.13	28.21	58.30
Water analysis									
pH			EC mmohs/cm			Total dissolved salts mg/kg soil (ppm)			
7			2.30			1472			

Evaluation of M1 generation

In the 2020/2021 season, the seeds of each selected mutant (M1) and their original cultivars were germinated in seedling trays for 25 days, then the seedlings (M1 generation) were transferred to grow in the same field as the M0 generation. Some agro-morphological traits were evaluated, i.e., plant height (cm), stem diameter (mm), number of branches per plant, number of leaves, number of leaflets per leaf, length of leaflet in leaf (cm) and diameter of leaflet in leaf (cm).

Evaluation of M2 generation

Seeds of each M1 mutant and their original cultivars were germinated in seedling trays for 25 days, then the seedlings (M2 generation) were transferred to grow in pots in a greenhouse under ideal conditions at the Faculty of Agriculture, New Valley University, New Valley, Egypt, and the irrigation water was the tap water. After 7 days all the pots were divided into 2 groups each of them contained three pots for each genotype. One group was irrigated with tap water as a control, but the other one was tap water supplemented with a series of concentrations of NaCl. It started with 50 mM, then the concentration was increased gradually (100, 150, or 200 mM) for one week for each concentration.

Statistical analysis

An analysis of variance (ANOVA) according to Gomez and Gomez (1984) was conducted. Least significant differences (L.S.D) were used in mean comparisons or Duncan's Multiple Range Test (DMRT) (Duncan, 1955) at a 0.05 level of probability as described by Gomez and Gomez (1984). The recorded data were analyzed by using CoSTAT statistical software program.

Results and discussion

Screening for salinity tolerance

To develop new more salt-tolerant tomato genotypes, the two cultivars, Super Strain B and Castle Rock, were treated with different doses (100, 200, 300 and 400 GY) of gamma rays. The treated seeds (M0) were germinated in seedling trays. At the seedling stage, several different mutant phenotypes were detected, including seedlings with enlarged cotyledons, three-cotyledonous plants and dwarf seedlings (Fig. 1A-C). After 25 days of seed germination, the seedlings were transferred to grow in soil that contained a salinity value of 6.58 melmose/cm. A lot of them died, but the most survival plants produced fruits that either had or did not have seeds. Moreover, several different abnormal fruit phenotypes were observed, including the size and shape of the fruit and the number of chambers, in addition to the seedless fruits (Fig. 1D-M).

Figure (1): Different mutant abnormal phenotypes were induced by gamma rays. (A-C) germinated M0 seedling in trays seedling: (A) enlarged cotyledons, (B) 3 cotyledons in the mutants, (C) dwarfed seedlings. (D-F) growing mutants in soil under salinity conditions: (D) more tolerant mutant, (E) less tolerant mutant, (F) more sensitive mutant. (G-j) the fruit morphology of Super Stain B and its mutants: (G) changes in the shape and fruit size, (H) 4 chambers in the control, (I) 5 and 6 chambers in mutants, (J) seedless mutant. (K-M) the fruit morphology of Castle Rock cultivar and its mutants: (K) changes in the shape and fruit size, (I) 3 chambers in the control, (M) 2 and 4 chambers in the mutants.

In tomato former studies, several gamma rays induced mutants have been isolated and characterized (Sikder *et al*., 2013; Akhtar, 2014 and Sikder *et al*., 2015). Mutation causes many different biological alterations on germination and all the plant developmental stages because of alteration in genetic makeup. Several studies revealed that the germination rate was negatively correlated with the gamma radiation intensity (Zafar *et al.*, 2022 and reviewed by Ulukapi and Nasircilar, 2015). Also, our results are like their finding, where the germination is highly affected at higher doses (data not shown). These affects could be a result of biochemical alterations that took place in the genes responsible for seed germination. Moreover, Kiong *et al.* (2008) reported that the degree of chromosomal aberrations which are caused by irradiation dose determined the rate of germination and the survival rate. Furthermore, we found many phenotypic changes consistent with the findings of

several researchers (Matsukura *et al*., 2007 and Chun *et al*., 2020).

Evaluation of M1 population under salinity stress conditions

Measuring of some vegetative traits

The M1 seeds (seeds collected from of the M0 plants) were grown in seedling trays for 25 days, then were transferred to the soil with 6.58 melmose/cm salt. Among them, eleven and fifteen different genotypes survived and were evaluated and comparing with their original cultivars Super Strain B and Castle Rock, respectively. The results in Table (2) show highly significant differences among the mutants as well as original cultivars in seed germination rate, plant height, stem diameter, roots length, number of branches per plant, number of leaves per plant, number of leaflets per leaf, length of leaflet in leaf and diameter of leaflet in leaf.

As shown in Table (3), the germination percentage of M1 seeds show wide range of variability, among all the studied genotypes, the Super Strain B cultivar was the highest genotype (99.5 %), while the C-5 mutant was the lowest genotype (50.75%). Concerning the plant height, the C-10 and **C-5** were the tallest (119.25 cm) and the shortest (41 cm) genotypes, respectively. On the other hand, the stem diameter ranged from 1.2 to 3.85 cm for the **C-5** mutant and the C-10 mutant, respectively. As for the number of branches per plant, the C-10 mutant had the highest value (13.25) over all the evaluated genotypes, while the lowest value (4.5) was for both the C-4 and the C-5 mutants. Regarding the number of leaves per plant, the C-10 mutant had the highest value (411.75), while the lowest value (54.25) was for the original cultivar (Castle Rock)**.** The number of leaflets per leaf varied significantly among all the genotypes, both the S-2 and S-3 mutants recorded the highest value (8), while the lowest value (5) was for the S-1, S-5, C-2, C-3, C-4, C-9 and C-15 mutants. On the other hand, the leaflet length varied from 3.55 cm for the C-15 mutant to 7.475 cm for the S-8 mutant. Furthermore, the diameter of the leaflets ranged from 2.55 cm for both S-1 and C-4 mutants to 4.45 cm for the C-10 and C-3 mutants (Table 3).

Measuring of some yield components and fruit physical traits

The yield components and fruit physical properties of the studied 26 mutants and their 2 original cultivars were evaluated under salt conditions. The results in Table (4) show highly significant differences among all the 28 tested genotypes for all the tested 7 characters.

For the percentage of fruit set, the C-10 mutant recorded the highest ratio (91.525%), but the C-4 had the lowest ratio (47.75%, Table 5). Regarding the number of fruits in a cluster, both C-1 and C-10 mutants had the highest value (4), while the lowest value (2) was for the C-2, C-3, C-4 and C-5 mutants. On the other hand, the C-10 mutant was the highest (13674.5g) mutant in the total yield, while the lowest value (440 g) was for the C-4 mutant. Regarding the mean of fruit weight, the C-9 mutant recorded the highest value (129.75g), but the Castle Rock cultivar had the lowest value (25.25g). For the fruit length, the C-9 mutant had the highest value (6.0775cm) of fruit length, while the lowest value (3.725cm) was for the C-4 mutant. Concerning the fruit diameter, the C-9 recorded the highest value (5.882cm), but the Castle Rock cultivar had the lowest value (3cm). For the number of fruits per plant, the C-10 mutant had the highest number (236.75), while the lowest number (4.5) was for the C-4 mutant (Table 5).

Table (2): Mean square (MS) for 8 vegetative characteristics of the studied 26 M1 mutants and their original cultivars.

Trait	Source of variance	df	MS
Seeds germination%	Blocks	3	0.6309524^{ns}
	Genotypes	27	882.0172***
	Error	81	2.9087302<-
Plant height	Blocks	3	17.869048^{ns}
	Genotypes	27	1205.5807***
	Error	81	12.140653<-
Stem diameter	Blocks	3	0.0324702^{ns}
	Genotypes	27	1.1489517***
	Error	81	0.0159888<-
Number of branches/ plants	Blocks	3	0.8809524^{ns}
	Genotypes	27	15.137566***
	Error	81	0.4488536<-
Number of leaves/ plants	Blocks	3	338.32143^{ns}
	Genotypes	27	30718.507***
	Error	81	283.51896<-
Number of leaflet/ leaf	Blocks	3	0.0357143^{ns}
	Genotypes	27	3.6547619***
	Error	81	0.085097<-
Length of leaflet in leaf	Blocks	3	0.054881^{ns}
	Genotypes	27	3.9833201***
	Error	81	0.1000661<-
Diameter of leaflet in leaf	Blocks	3	0.0474702^{ns}
	Genotypes	27	1.2056713***
	Error	81	0.0311739<-

*** and ^{ns} highly significant and non-significant at 0.05 and 0.01 levels of probability, respectively.

Evaluation of M2 mutants under salinity stress conditions

To evaluate the M_2 induced mutants for their ability to tolerate salinity stress, offspring of the selected mutants from M1 and their original cultivars were subjected to a series of concentrations of NaCl starting with 50 mM, the concentration was increased gradually up to (100, 150, or 200 mM) for one week for each concentration (Fig. 2). The evaluation included, shoots length, number of leaves, wet weight of shoots and leaves, wet weight of roots, dry weight of shoots and leaves and dry weight of roots (Tables 6, 7).

The results of the analysis of variance in Table (6) show highly significant differences among all the evaluated genotypes, as well as between the control and salinity treatment for all the 6 studied characters. The shoots length of all the genotypes under normal conditions ranged from 16.67 to 53 cm for S-6 and C-10 mutants, respectively, with an average of 32.3cm (Table 7). On the other hand, under salinity stress, the C-10 mutant had the highest value (44 cm), but the lowest value (14 cm) was recorded by the super strain B cultivar, with an average of 23.25 cm. Moreover, the percentage of the shoot reduction varied from 5.49% for the S-5 mutant to 49.19% for the S-9 mutant with an average of 30.1%. For the number of leaves per plant, the highest value under normal conditions was 24.67 and the lowest value was 9.33 with a range of 13.2. Under salinity stress, the C-10 mutant recorded the highest value (15.7), but the Super Strain B variety had the lowest value (5), with an average of 8.9. However, the percentage of reduction ranged from 14.29% for the S-7 mutant to 57.56% for the S-9 mutant with an average of 32.28%. For the wet weight of the shoots and leaves trait, the average under normal conditions was 13.77 g, and it ranged from 8 to 26.67 g. Under salinity stress, the C-10 mutant had the highest value (19.33g), while the S-8 mutant recorded the lowest value (3g). The percentage of reduction in the wet weight of shoots and leaves was ranged from

24.99% for the S-6 mutant to 70.00% for the S-8 mutant with an average of 43.1(Table 7).

Table (3): Mean performance of the studied 8 vegetative traits for the 11 and 15 mutants and their 2 original cultivars, Super Strain Band (S) and Castle Rock (C) cultivar, respectively, under salt stress environment at M1 generation.

Genotypes	Seeds germination rate	Plant height	Stem diameter	Number of branches/plant	Number of leaves/plant	Number of leaflet/leaf	Length of leaflet in leaf	Diameter of leaflet in leaf
S	99.5^{a}	89.25^{ef}	2.7^{c}	6^{hij}	136.75^{def}	7^{b}	7.25^{ab}	3.775^{bc}
S-1	92.5^{efgh}	95.75^{bc}	1.925f^{ghij}	6.25^{ghi}	135.75^{def}	5^{e}	4.55^{j}	2.55^{i}
S-2	85.5^{l}	68.75^{kl}	2.05^{efg}	5.5^{ijk}	97.5^{hij}	8^{a}	6.55^{def}	3.25ef^{gh}
S-3	94.5^{cdef}	75.75^{hij}	1.825^{hij}	6.5^{gh}	87.5^{ijk}	8^{a}	6.55^{def}	3.55^{cd}
S-4	89.75^{ij}	98.75^{b}	1.75^{jkl}	6.25^{ghi}	95.5^{hij}	7^{b}	6.25^{fg}	4.25^{a}
S-5	94.75^{cde}	94^{bcde}	2.3^{d}	6.5^{gh}	296^{c}	5^{e}	4.1^{k}	3.4^{def}
S-6	87^{kl}	87.5^{f}	2.225^{de}	8d^{e}	141.5^{de}	7^{b}	6.05^{gh}	3.35^{defg}
S-7	91.75^{hi}	94.5^{bcd}	2.625^{c}	8.25^{de}	277.5^{c}	7^{b}	6.55^{def}	3.25^{efgh}
S-8	92.5^{efgh}	90.75^{def}	1.95^{fghi}	5.5^{ijk}	91.5^{hijk}	7^{b}	7.475^{a}	4^{b}
S-9	95.25^{cd}	87.5^{f}	1.975^{fgh}	5.5^{ijk}	97.75^{hij}	7^{b}	6.15^{fg}	3.45^{de}
S-10	96.75^{bc}	77.75^{ghi}	2.725^{bc}	7.5^{ef}	104.75^{hij}	6.5^{c}	6.375^{efg}	3.1^{h}
S-11	92.75^{efgh}	81^{g}	1.75^{jkl}	6^{hij}	110^{ghi}	6^{d}	6.225^{fg}	3.2^{fgh}
C	98^{b}	56.25^{no}	1.4^{m}	5^{kl}	54.25^{m}	7^{b}	6^{gh}	3.25^{efgh}
C-1	92^{ghi}	56.5^{n}	1.875^{ghij}	7.5^{ef}	82.5^{jkl}	7^{b}	5.1^{i}	3.25^{efgh}
C-2	81^{m}	73.75^{ij}	2.075^{ef}	6.5^{gh}	136.5^{def}	5^{e}	5.05^{i}	3.05^{h}
C-3	69.5^{n}	88^{f}	2.05^{efg}	6.25^{ghi}	133.5^{defg}	5^{e}	6.7^{cde}	4.45^{a}
C-4	53.75^{o}	73.75^{ij}	1.575^{lm}	4.5^{l}	70.25^{klm}	5^{e}	7.05^{abc}	2.55^{i}
C-5	50.75^{p}	41^{p}	1.2^{n}	4.5^{l}	62.75^{lm}	6^{d}	4.35^{jk}	2.65^{i}
C-6	51.5^{op}	55.5^{no}	1.4^{m}	6.5^{gh}	86^{jkl}	7^{b}	5.625^{h}	2.65^{i}
C-7	53.5^{o}	95^{bcd}	1.8^{hij}	5.75^{hijk}	93.25^{hijk}	7^{b}	5.625^{h}	3.1^{h}
C-8	82.5^{m}	78.75^{gh}	1.9^{fghij}	6.5^{gh}	153de	7^{b}	6.55^{def}	4.25^{a}
C-9	94.25^{defg}	93.5^{cde}	2.9^{b}	11.5^{b}	351.25^{b}	5^{e}	6.075g	3.2^{fgh}
C-10	89.75^{ij}	119.25^{a}	3.85^{a}	13.25^{a}	411.75^{a}	6^{d}	6.875^{bcd}	4.45^{a}
C-11	92^{ghi}	62.5^{m}	1.925^{fghij}	6.5^{fh}	156^{d}	7^{b}	6.55^{def}	3.825^{b}
C-12	91.25^{hij}	72.5^{jk}	1.95^{fghi}	7^{fg}	133.75^{def}	7^{b}	6^{gh}	3.35^{defg}
C-13	92.25^{fgh}	51.5^{o}	1.6^{kl}	5.25^{jk}l	70^{klm}	7^{b}	6.725^{cde}	3.125^{gh}
C-14	92.75^{efgh}	79^{gh}	1.9^{fghij}	9.25^{c}	131^{efg}	7^{b}	7.45^{a}	3.475^{de}
C-15	89.25^{jk}	65.5^{lm}	1.775^{ijk}	8.5^{cd}	113.75^{fgh}	5^{e}	3.55	2.575^{i}
LSD $_{0.05}$	2.399503	4.902196	0.177990	0.942588	23.689760	0.410418	0.4450545	0.248408

The different letters represent statistically significant differences between genotypes ($p < 0.05$)

Table (4): Mean square (MS) for 7 yield components and fruit physical properties of the studied 26 M1 mutants and their 2 original cultivars.

Trait	Source of variance	df	MS
Fruit set	Blocks	3	4.5157318^{ns}
	Genotypes	27	794.38641***
	Error	81	3.3041868<-
Number of fruits in cluster	Blocks	3	0.0238095^{ns}
	Genotypes	27	1.0714286***
	Error	81	0.0546737<-
Yield	Blocks	3	48413.56^{ns}
	Genotypes	27	43572064***
	Error	81	119714.26<-
Mean of fruits weight	Blocks	3	3.6489286^{ns}
	Genotypes	27	2447.6031***
	Error	81	5.8805952<-
Fruit length	Blocks	3	0.0148104^{ns}
	Genotypes	27	1.2291543***
	Error	81	0.0162234<-
Fruit diameter	Blocks	3	0.0240318^{ns}
	Genotypes	27	1.8380112***
	Error	81	0.0172701<-
Number of fruits/plant	Blocks	3	5.6279762^{ns}
	Genotypes	27	8904.7312***
	Error	81	20.183532<-

*** and ^{ns} highly significant and non-significant at 0.01 levels of probability, respectively.

For dry weight of shoots and leaves, the highest value under non-stress conditions was 3.36g for the C-10 mutant and the lowest value was 0.80g for the S-6 mutant with an average of 1.72g. Under salinity stress, the C-10 mutant had the highest value (3.03g), while the S-8 mutant had the lowest value (0.21g), with an average of 1.03g. On the other hand, the wet weight of roots under normal conditions ranged from 4.67 to 16 g for the S-4 mutant and the C-10 mutant, respectively, with an average of 8.3g. Under salinity stress, the highest value (12.33g) was shown by the C-10 mutant, while the lowest value (2.33g) was obtained by both the Super Strain B and the S-2 mutant, with an average of 4.7g. Regarding the dry weight of roots, the values under normal conditions varied from 1.51g for the C-11 mutant to 0.39g for the S-4 mutant, with an average of 0.93g. Under the salinity stress, the C-10 mutant had the highest value (1.47g) and the S-9 mutant had the lowest value (0.20g, Table 7).

According to our results, some of the evaluated mutants were more superior than their original cultivars, while some of them were lower in some tested characters. These significant fluctuations in their performance in comparison to their origin cultivars are also observed by Zafar *et al.*, 2022 and Rafiq *et al.*, 2017 who confirmed that the growth, plant height, reproductive and yield parameters are indicators for biological impairments triggered by mutagenic agents. However, superiority in growth is due to stimulation with a low level of radiation that causes an increasing in hormonal signaling rate in plant cells (Wi *et al*., 2007). As our results, Chun *et al*. (2020) found an increase in growth because of a low dose of mutagenic agent. In contrast, a high dose of radiation limits growth because it causes biological damage to the cell cycle and the entire genome. Furthermore, the mean value of yield component and fruit physical traits in the induced mutant differed from the untreated (control) cultivars. Similar findings were noted by Chun *et al*. (2020). Thus, genetic variability that is induced by mutations can be used to develop new promising tomato lines having desirable and novel attributes. However, those induced mutants need more evaluation trials.

Table (5): Mean performance of 7 yield components and fruit physical properties for the evaluated 26 mutants and their 2 original cultivars (Super Strain B and (S) Castle Rock (C) cultivar) under salt stress environment at M1 generation.

genotypes	Fruit set	Number of fruits in cluster	Yield (g)	Mean of fruits weight (g)	Fruit length (cm)	Fruit diameter (cm)	Number of fruits/plant
S	87.065^{def}	3^{bc}	4221.5^{i}	54.25^{m}	4.4375^{p}	4.1^{k}	77.5^{ef}
S-1	87.675^{bcde}	3^{bc}	6739.5^{e}	83.25^{fg}	5.025^{jkl}	4.775^{efg}	81^{e}
S-2	87.2075^{cdef}	3^{bc}	5785.25^{g}	74^{h}	4.8^{mno}	4.4^{j}	78.5^{ef}
S-3	89.075^{abcd}	2.25^{d}	6486.75^{ef}	70.25^{i}	4.775^{mno}	4.45^{hij}	92.75^{d}
S-4	84.975^{fg}	2.75^{c}	5060^{h}	73.25^{hi}	4.7^{no}	4.375^{j}	69^{g}
S-5	91.475^{a}	3.25^{b}	10150^{b}	86^{ef}	5.15^{hij}	4.7^{efg}	118.8^{b}
S-6	83.1625^{gh}	3^{bc}	4516.75^{i}	75.5^{h}	5.1^{ijk}	4.8^{ef}	59.75^{h}
S-7	90.15^{ab}	3.75^{a}	9689.75^{bc}	94.5^{d}	5.4^{def}	5.175^{d}	102^{c}
S-8	56.35^{l}	3^{bc}	1455^{lmn}	87^{e}	4.925^{klm}	4.5^{hij}	16.75^{op}
S-9	60.3875^{k}	2.75^{c}	1434^{lmn}	80.75^{g}	5.225^{fghi}	4.625^{fgh}	17.75^{op}
S-10	89.75^{abc}	3.25^{b}	7645.5^{d}	65^{j}	4.9^{lm}	4.4^{j}	117.5^{b}
S-11	86.925^{def}	3^{bc}	6199.75^{fg}	80.25^{g}	5.325^{efgh}	4.775^{efg}	77^{ef}
C	81.075^{h}	3^{bc}	1352.25^{mn}	25.25^{p}	3.775^{q}	3^{n}	53^{i}
C-1	70.1125^{j}	4^{a}	1852.25^{l}	55^{lm}	5.25^{efghi}	4.425^{ij}	33.5^{k}
C-2	68.725^{j}	2^{d}	3633.75^{j}	114^{b}	5.325^{defg}	5.7^{ab}	32^{klm}
C-3	82^{h}	2^{d}	4567.5^{i}	82.75^{fg}	5.425^{de}	5.075^{d}	55.25^{hi}
C-4	47.75^{n}	2^{d}	440^{o}	38.5^{o}	3.725^{q}	3.8l	4.5^{p}
C-5	76.175^{i}	2^{d}	2532.5^{k}	60.25^{k}	4.625^{o}	4.6^{ghi}	42^{j}
C-6	61.475^{k}	3^{bc}	2789.25^{k}	107.5^{c}	5.675^{bc}	5.575^{b}	26^{mn}
C-7	77.375^{i}	3^{bc}	3627^{j}	41^{o}	3.9^{q}	3.525^{m}	88.5^{d}
C-8	61.85^{k}	3^{bc}	1834^{lm}	70.25^{i}	5.03^{jkl}	4.825^{e}	26.25^{lmn}
C-9	86.15^{ef}	3^{bc}	9373.25^{c}	129.75^{a}	6.0775^{a}	5.8825^{a}	72.25^{fg}
C-10	91.525^{a}	4^{a}	13674.5^{a}	57.825^{kl}	5.15^{hij}	4.1^{k}	236.75^{a}
C-11	77.3725^{i}	3^{bc}	5059^{h}	114.75^{b}	5.525^{cd}	5.725^{ab}	44.25^{j}
C-12	51.9^{m}	3^{bc}	1139.75^{n}	91.5^{g}	5.25^{efghi}	5.375^{c}	12.5^{p}
C-13	63.2275^{m}	3^{bc}	1646^{lm}	109.25^{c}	5.725^{b}	5.675^{b}	15^{p}
C-14	69.1925^{j}	3^{bc}	2370.25^{k}	73.25^{hi}	5.2^{ghij}	4.825^{e}	32.5^{kl}
C-15	54.45^{lm}	3^{bc}	1069^{n}	48.625^{n}	4.8175^{mn}	4.405^{j}	22no
LSD $_{0.05}$	2.557419	0.328972	486.791028	3.411774	0.179201	0.184892	6.320744

The different letters represent statistically significant differences between genotypes ($p < 0.05$)

Conclusion

Gamma rays were used to induce different mutants from two commercial tomato cultivars (Super Strain B and Castle Rock). The induced mutants were evaluated at M0, M1, and M2 generations for their performance under salinity stress conditions. Many phenotypic changes were detected, and the evaluated traits significantly varied among the induced mutants. Some induced mutants, particularly the C-10 mutant produced more productivity than the origin cultivars under saline conditions. Therefore, gamma radiation is a beneficial tool to induce useful genetic variability that can be utilized for improving tomato crop productivity.

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Conflicts of Interest The authors declare that they have no conflict of interest.

Table (6): Analysis of variance of the studied 26 M2 mutants and their 2 original cultivars for the studied traits under salinity stress.

Trait	Blocks		Genotypes		Salinity		Genotypes x salinity		Error		
	df	MS	df	MS	df	MS	df	MS	df	MS	
Shoots length	2	30.377^{ns}	27	322.523***	1	3584.222***	27	3584.222^{ns}	106	10.043<-	
Number of leaves/plants	2	5.043^{ns}	27	54.459***	1	747.556***	27	4.876 ^{ns}	106	3.427<-	
Wet weight of shoots and leaves	2	8.228^{ns}	27	89.637***	1	1261.136 ***	27	5.418 ^{ns}	106	5.235<-	
Wet weight of roots	2	6.006^{ns}	27	38.750***	1	519.136***	27	5.687*	106	3.415<-	
Dry weight of shoots and leaves	2	0.084^{ns}	27	2.4852***	1	18.988***	27	0.233*	106	0.121<-	
Dry weight of roots	2	0.027^{ns}	27	0.6964***	1	6.205***	27	0.087***	106	0.035<-	

*, *** and ^{ns} significant, highly significant and non-significant at 0.05 and 0.01 levels of probability, respectively.

Table (7): Mean performance of the evaluated 26 mutants and their 2 original cultivars (Super Strain B and (S) Castle Rock (C) cultivars) for 6 traits under normal (N) and salinity stress (SS) conditions at M2 generation.

genotypes	Shoots length (cm)		Number of leaves/plant		Wet Weight of shoots and leaves (g)		Dry weight of shoots and leaves (g)		Wet weight of roots (g)		Dry weight of roots (g)	
	N	SS	N	SS	N	SS	N	SS	N	SS	N	SS
S	22.67	14	10.33	5	9.33	3.67	1.79	0.36	5.667	2.33	0.44	0.26
S-1	28.67	21	10.67	8	12	5	1.92	0.56	5.667	3.67	0.63	0.30
S-2	28.67	17.67	10	7.67	11.33	5.67	0.80	0.33	5.667	2.33	0.44	0.23
S-3	29.33	19.33	11	8.33	12.33	5	1.64	0.50	6.667	4.33	0.79	0.31
S-4	25.33	16.67	9.33	6.67	8	4.67	0.80	0.34	4.667	3.67	0.39	0.23
S-5	36.33	34.33	16.33	13.3 3	14.67	11	2.09	1.37	7.667	6	1.48	1.28
S-6	16.67	15	9.33	6	9.33	7	0.80	0.37	5.33	2.67	0.45	0.25
S-7	34.67	31.33	11.67	10	14	10	1.55	1.27	7.33	5.67	1.29	0.58
S-8	20.67	10.67	9.33	4.67	10	3	0.84	0.213	5.67	3.33	0.46	0.19
S-9	20.33	10.33	11	4.67	12	4.33	1.25	0.37	6.33	3.33	0.77	0.20
S-10	30.33	28.67	11.33	9.67	12.33	8.67	1.73	1.38	6	4.67	0.75	0.32
S-11	26.67	18.33	10	8	12	4.67	1.43	0.40	6.667	4	0.63	0.38
C	32.33	21	13.33	8.33	12.33	7	1.33	0.92	7.33	3.67	0.71	0.46
C-1	37.33	23	12.67	9	14.33	7.67	2.593	1.03	8.33	4.33	1.18	0.61
C-2	38.67	28	14.67	10 10.3	17.67	12.33	2.6	1.97	12	5.67	1.47	0.69
C-3	41	28.33	14.67	3	17.67	12.33	2.13	1.84	11.33	6	1.02	0.66
C-4	36.67	25	14.33	9.33	15.67	9.33	2	1.31	9.33	5.67	1.1	0.6
C-5	34	24	13.33	9.67	14.67	9.67	1.28	0.89	6.33	4	0.79	0.61
C-6	32	23.67	14	9.33	12	6	1.4	0.55	6.67	4	0.9	0.38
C-7	33	24.67	15.33	9.67	13.33	8.67	1.4	1.07	7.33	5	1.21	0.67
C-8	34.67	21.67	12	7.67	12	7.33	1.94	1.01	7	3.67	0.61	0.49
C-9	46.33	36	20.33	14 15.6	21.67	15.67	2.87	2.53	14.67	9.33	1.33	1.03
C-10	53	44	24.67	7 11.3	26.67	19.33	3.36	3.03	16	12.33	1.6	1.47
C-11	39	29	19	3	18	12.33	2.03	1.68	14	7.33	1.51	0.92
C-12	32.67	20.67	13.33	8.33	13	6.33	1.33	1.07	8	3.67	0.75	0.44
C-13	32.67	21.33	11.33	8.33	10.67	7	1.2	0.87	7	4	0.62	0.47
C-14	34	24.67	14.67	9	17	7.67	2.17	1.04	13.33	4.33	1.43	0.62
C-15	32	20.33	12.67	7.67	13.33	5.67	2	1	11	3.67	1.4	0.38
average	32.33	23.25	13.33	8.33	13.77	8.06	1.72	1.03	8.28	4.70	0.93	0.54

Figure (2): Response of the mutants, and their original cultivars (Super Strain B and Castle Rock) to salinity stress, after the treatment with a series of concentrations of NaCl started with 50 mM, then the concentration was increased gradually (100, 150 or 200 mM) for one week for each concentration. (a) Super Strain B cultivar and its derived mutants watered by tap water as a control, (b) the NaCl treatment; (c) Castle Rock cultivar and its derived mutants watered by tap water as a control, (d) the NaCl treatment.

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