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IMPACT OF GAMMA IRRADIATION ON GROWTH PARAMETERS AND VARIABILITY IN MANDARIN ORANGE

Jyoti[1*], Ekta P. Ningot[2], D.M. Panchbhai[3] and R.P. Gajbhiye[4]
[1]Department of Fruit Science, Faculty of Horticulture, Dr. P.D.K.V., Akola, Maharashtra, India
[2]Department of Horticulture, College of Agriculture, Nagpur, Maharashtra, India
[3]Dean, Faculty of Horticulture, Dr. PDKV Akola, Maharashtra, India
[4]College of Agriculture, Mul, Chandrapur, Maharashtra, India
*Corresponding author E-mail: jkamble285@gmail.com
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ABSTRACT

An experiment titled "Impact of gamma irradiation on growth parameters and variability in Mandarin orange" was conducted during 2021-22 at the Centre of Excellence for Citrus, College of Agriculture, Nagpur, under Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The study aimed to investigate the effects of gamma irradiation on the budding success and growth performance of mandarin orange budgraft varieties, specifically Nagpur mandarin and Nagpur seedless, and to explore the potential for inducing variability through irradiation. Budsticks from both varieties were subjected to five different gamma ray doses (10 Gy, 20 Gy, 30 Gy, 40 Gy, and 50 Gy) along with a control, and then used for shield budding on rough lemon seedlings. The growth and performance of 500 budgrafts per treatment were monitored at 60, 120, and 180 days after sprouting. Results indicated that higher doses of gamma rays led to delayed sprouting, decreased sprouting percentages, and reduced shoot length and plant height, survival and mortality percentage. Additionally, leaves became narrower, and significant variations in branch number and leaf width were observed at doses of 30 Gy, 40 Gy, and 50 Gy, with 50 Gy resulting in no sprouting for Nagpur mandarin. High doses also caused a reduction in leaf length. These findings suggest that while gamma irradiation can induce variability, excessively high doses have severe negative effects, highlighting the need for determining optimal dose levels in future research. Higher doses also produced more foliar abnormalities (shape, size, margin, apex, colour changes, deformities), indicating effective mutagenesis. Elevated mortality at upper dose levels suggests that future mutation breeding should balance dose intensity against plant survival, while the observed leaf variants highlight material worth pursuing in subsequent selection work.
***Keywords* :** Mandarin orange, Mutation breeding, Gamma irradiation, Growth parameters, Mutation.

Introduction

The genus Citrus is of significant economic importance, recognized globally for its juice and pulp. Citrus is the leading fruit crop worldwide and ranks third in India after mango and banana. The mandarin group makes up 43% of the total production of cultivated citrus species, followed by sweet oranges (25%), acid lime and lemons (25%), and other citrus species (Kamatyanatt *et al.,* 2021). In India, citrus is grown on approximately 1064 thousand hectares, producing around 14071 thousand metric tons (Anon, 2022). Among all citrus species, mandarin occupies the largest area with 461 thousand hectares, yielding 6063 thousand metric tons (Anon, 2021). Mandarin orange, commonly known as 'easy peelers', is the most prevalent citrus fruit in India. Known as 'Tangerine' in the USA and 'Santra' or orange in India, mandarins are a polyembryonic species of Chinese origin. The fruits are medium-sized, globose, sweet, and easily separable into segments. They have a loose skin that can be peeled effortlessly (Ghosh, 2001).

Mandarins are highly consumed and demanded due to their smaller size, thinner skins, easy peeling, and export potential. Despite this, citrus breeders are continuously working to improve the quality of mandarin fruits, aiming to provide consumers with new, tasty, healthy, and easy-to-eat seedless fruits. The Nagpur mandarin, also known as Nagpur Santra, is considered the finest mandarin variety in India. Globally, citrus improvement programs focus on high fruit qualities (e.g., seedless, easy peeling, and mandarin types) and disease resistance. These programs utilize conventional breeding (hybridization), mutation breeding, and biotechnological techniques. However, citrus breeding faces challenges such as high heterozygosity, polygenic traits, and a long juvenile period, regardless of the techniques used (Sutarto *et al.,* 2009).

Mutations are sudden heritable changes in an organism's genetic material, leading to new traits not derived from genetic segregation or recombination (Van Harten, 1998). Russo et al. (1981) used gamma rays to induce mutations in 'Monreal' Clementine mandarin, resulting in mutants with fewer seeds per fruit. Neville *et al.* (1998) developed a precise method to determine radiation dose, replacing the unit kilo rad (kR) with gray (Gy). Mutation breeding, the intentional induction of mutations for crop improvement, has significantly advanced desirable traits in various crops (Lammo *et al.,* 2017). Historical natural mutations have improved crops like grapes and citrus. For instance, a sparse-seeded kinnow mutant was developed using a 20 Gy gamma radiation dose, with bud scions grafted onto rough lemon rootstock (Khalil *et al.,* 2011). Gamma irradiation is widely used by citrus breeders to produce seedless clones from commercial varieties of citrus fruits, achieving higher mutation frequencies and new variants (Rattanpal *et al.,* 2019). Bermejo *et al.* (2011) found budwood irradiation effective for cultivar improvement and producing seedless variants. In India, mutagenesis has been applied to acid lime, sweet orange, and mandarins, with plants currently in early evaluation stages. As demand for high-quality fruit increases, induced mutagenesis will play a crucial role in future crop improvement.

The present study aims to examine the effect of gamma irradiation on the budding success and growth parameters of mandarin orange bud grafts and to study the effect of gamma irradiation for induction of variability in mandarin orange through gamma irradiation. This research will help identify variations in growth, quality parameters, and the survival rate of mandarin orange bud grafts induced by gamma irradiation. Inducing mutations in the Nagpur mandarin variety through gamma irradiation may lead to desirable changes in traits such as fruit yield, thin skin, total soluble solids (TSS) content, extended shelf life, and uniform color development. This approach holds significant potential for creating variability in clonally propagated fruit crops like mandarin.

Materials and Methods

The experiment titled "Impact of gamma irradiation on growth parameters and variability in Mandarin orange" was conducted at the Centre of Excellence for Citrus, College of Agriculture, Nagpur, during 2021-2022. In this study, 500 budsticks each of Nagpur mandarin and Nagpur seedless oranges were irradiated at Bhabha Atomic Research Centre (BARC) in Trombay with doses of 10, 20, 30, 40, and 50 Gy using a gamma chamber with 60Co. The irradiated budsticks were then budded onto rough lemon rootstock using the T budding technique, and the experiment was designed using the T test methodology. The treatments included: T_1 - Nagpur mandarin with no irradiation (Control), T_2 - Nagpur mandarin with 10 Gy Gamma rays, T_3 - Nagpur mandarin with 20 Gy Gamma rays, T_4 - Nagpur mandarin with 30 Gy Gamma rays, T_5 - Nagpur mandarin with 40 Gy Gamma rays, T_6 - Nagpur mandarin with 50 Gy Gamma rays, T_7 - Nagpur seedless with no irradiation (Control), T_8 - Nagpur seedless with 10 Gy Gamma rays, T_9 - Nagpur seedless with 20 Gy Gamma rays, T_{10} - Nagpur seedless with 30 Gy Gamma rays, T_{11} - Nagpur seedless with 40 Gy Gamma rays, and T_{12} - Nagpur seedless with 50 Gy Gamma rays.

Observations on growth parameters were recorded at various intervals after budding. The number of days required for sprouting of buds was noted following successful budding, with the time taken for the first sprouting recorded for each selected budded plant, and the mean value calculated. The percentage of sprouting was recorded at 30-day intervals, reflecting the number of budded plants that sprouted after budding. The number of sprouted bud grafts was calculated to determine the percentage of sprouting using the following formula:

$$\text{Percent sprouting} = \frac{\text{Number of sprouted plants}}{\text{Total number of budded plants}} \times 100$$

For shoot length (cm), the growth of new bud sprouts was recorded for each selected plant up to 30 days, and the mean shoot length was measured using a measuring scale. The average number of leaves per shoot of bud grafts, length of leaves (cm), width of leaves (cm), length of internode (cm), plant height (cm) were measured using a measuring scale. Number of branches per plant, colour of leaves observed visually. Leaf abnormalities percentage (%) recorded on changes in leaf shape, size and colour. Mortality percentage (%), survival percentage (%) at 60-day intervals for up to 180 days were calculated using following formula.

$$\text{Mortality percentage} = \frac{\text{Number of plants failed to survive}}{\text{Total number of budded plants}} \times 100$$

$$\text{Leaf abnormalities percentage} = \frac{\text{Total number of abnormal plants}}{\text{Number of sprouted plants}} \times 100$$

$$\text{Survival percentage} = \frac{\text{Number of survived plants}}{\text{Number of sprouted plants}} \times 100$$

The induced variations in polygenic traits were estimated using statistical parameters including mean, standard error (S.E.), standard deviation (S.D.), and coefficient of variation (C.V.) for each character. The significance of different treatments was evaluated using the Z-test or small t-test, as recommended by Panse and Sukhatme (1954).

By employing these methods, the study aimed to elucidate the effects of gamma irradiation on various growth parameters and induce potential mutations in Nagpur mandarin and Nagpur seedless oranges.

Result and Discussion

The results of the experiment are presented, with data analyzed using a non-replicated t-test design. The findings, which cover growth, quality, and survival percentages, are detailed with tabular representations.

The data on average number of days for bud sprouting increased with gamma irradiation compared to the control (25.23 days for T_1 and 26.10 days for T_7) (Table 1 & Fig.1) . The shortest sprouting time among irradiated treatments was in T_2 (10 Gy), averaging 29.60 days. The coefficient of variation ranged from 6.12% to 9.70%, higher than in the control groups T_1 (4.74%) and T_7 (7.14%). No sprouting occurred in T_6 (50 Gy). These results suggest that lower doses of gamma irradiation result in fewer days for sprouting compared to higher doses, likely due to the mutagenic effects of gamma rays causing chromosomal aberrations that delay sprouting. The results are in agreement with the findings of Brar and Bal (2003) in guava and Krasinah *et al*. (2012) in mango.

The control treatments had the highest sprouting percentages 77% for T_1 and 73.6% for T_7. Among the irradiated treatments, T_2 (10 Gy) had the highest sprouting percentage at 57.2%, while T_{12} (50 Gy) had the lowest at 5.67% (Table 2 & Fig.1). These results indicate that higher doses of gamma irradiation reduce sprouting percentages, likely due to the lethal effects of radiation causing tissue death. The present findings are consistent with those reported by Karsinah *et al.* (2012) in mango.

The data on shoot length suggest that at 60 days, the control group (T_1) had the longest shoot length (14.57 cm), while T_{12} (50 Gy) had the shortest (6.31 cm). Variability was lower in the control groups (2.75% for T_1, 3.98% for T_7), with the highest variation in T_2 (11.53%) and the lowest in T_{12} (8.39%). At 120 days, T_1 still had the longest shoots (23.09 cm) and T_{12} the shortest (11.43 cm), with variation ranging from 9.54% in T_{12} to 11.62% in T_2. By 180 days, T_1 maintained the longest shoot length (33.38 cm), while T_{12} remained the shortest (16.85 cm). T_2 had the highest variation (12.99%) and T12 the lowest (9.73%), compared to the control groups (T_1 at 5.42% and T_7 at 3.40%) (Table3). The results indicated that higher doses of gamma irradiation decreased shoot length and plant height, with significant variance observed. These findings align with studies by Mahure *et al.* (2010) on chrysanthemum, Sharafi *et al.* (2013) on almond, and Kumari *et al.* (2015) on chrysanthemum.

The data presented in Table 4 revealed that at 60 days, T_4 (30 Gy) had the highest leaf count (16.37), while T_{12} (50 Gy) had the lowest (6.10). T_4 also showed the highest variation (12.96%) and T_8 the lowest (11.78%), with control T_7 at 4.73%. By 120 days, T_4 still had the most leaves (30.60), while T_5 (40 Gy) had the fewest (16.86), with maximum variation in T_4 (13.96%) and minimum in T_3 (12.33%), compared to control T_7 (4.51%). At 180 days, T_4 had the highest leaf count (36.57) and T_{11} (40 Gy) the lowest (25.78). T_4 also had the highest variation (15.09%) and T_8 the lowest (13.66%), compared to T_7 (3.84%). These results suggest that higher doses of gamma irradiation tend to increase the number of leaves per shoot, though no clear mutation trend was observed, consistent with findings by Sparrow and Gunckel (1965) and Brar and Bal (2003) in guava.

It was evident from the data presented in Table 5 that at 60 days, the control group (T_1) had the longest leaf length (4.81 cm), while T_{12} (50 Gy) had the shortest (2.50 cm). The coefficient of variation ranged from 6.57% to 11.23%, with T_3 having the highest variability and T_5 the lowest (7.60%). At 120 days, T_1 still had the longest leaves (5.36 cm), and T_{12} the shortest (3.53 cm), with T_3 showing the highest variation (11.76%) and T_5 the lowest (8.33%). By 180 days, T_1 maintained the longest leaf length (6.01 cm), while T_5 had the shortest (4.38 cm). T_3 showed the highest variation (12.00%) and T_5 the lowest (8.84%). Higher doses of gamma irradiation reduced leaf length and increased variability. Higher doses of gamma irradiation led to a decrease in leaf length and increased variability. These findings align with studies by Sharafi *et al.* (2013) in almonds, Kapadiya *et al.* (2014) in chrysanthemums, and Rattanpal *et al.* (2019) in mandarins.

The data in Table 6 highlights that at 60 days, T_4 (30 Gy) had the widest leaves (2.41 cm), while T_{12} (50 Gy) had the narrowest (1.36 cm). Controls T_1 and T_7 measured 1.79 cm and 1.76 cm, respectively. T_4 had the highest variation (10.74%), while T_8 (10 Gy) had the lowest (8.00%), compared to controls T_1 (5.59%) and T_7 (5.68%). At 120 days, T_4 continued to have the widest leaves (2.74 cm), and T_{11} (40 Gy) the narrowest (1.51 cm). T_4 showed the highest variation (11.25%), while T8 had the lowest (8.51%). By 180 days, T_4 still had the widest leaves (3.65 cm) and T_{11} the narrowest (1.87 cm), with T_4 showing the highest variation (11.66%) and T_8 the lowest (9.00%), compared to controls T_1 (3.11%) and T7 (4.61%). Overall, higher gamma doses generally increased leaf width, though results varied by dose, consistent with findings from Sharafi *et al.* (2013), Kapadiya *et al.* (2014), Batra and Dwivedi (2015), and Rattanpal *et al.* (2019).

The findings in Table 7 demonstrate that T_1 had the longest internodal length at 60 days (1.74 cm), while T_{12} (50 Gy) had the shortest (1.47 cm). The coefficient of variation ranged from 5.75% in T_1 to 13.55% in T_2 (10 Gy), with T_2 having the highest variation and T12 the lowest (10.76%). At 120 days, T_1 remained the longest (2.44 cm) and T_{12} the shortest (1.90 cm), with T_2 showing the highest variation (15.02%) and T_{12} the lowest (11.16%). By 180 days, T_1 had the longest internodal length (2.76 cm) and T_{12} the shortest (1.96 cm), with T_2 again showing the highest variation (15.97%) and T_{12} the lowest (12.07%). These findings indicate that higher gamma doses reduce internodal length, consistent with previous studies by Ravikin (1975), Hearn (1984), Sukhjinder *et al.* (2018), and Rattanpal *et al.* (2019).

According to the data presented in Table 8, it is clear that the control group (T_1) consistently had the tallest plants, measuring 20.7 cm at 60 days, 31.37 cm at 120 days, and 43.26 cm at 180 days. T_{12} (50 Gy) had the shortest plants, with heights of 15.25 cm, 23.16 cm, and 33.93 cm at the same intervals. The coefficient of variation increased with higher gamma irradiation doses. T_2 (10 Gy) exhibited the highest variation, while T12 had the lowest. The variation ranged from 11.91% to 15.92%, with T_2 having the highest (15.92%) and T_{12} the lowest (13.31%), compared to control T_1 (3.26%) and T_7 (3.64%). These results suggest that higher doses of gamma irradiation reduce plant height, aligning with findings from studies Waqar *et al.* (1992) on kinnow, Brar and Bal (2003) on guava, Kaur and Rattanpal (2008) on rough lemon, Sharafi *et al.* (2013) on almond, and Kapadiya *et al.* (2014) on chrysanthemum.

The variation in the number of branches per plant showed that T_{12} (50 Gy) consistently had the highest branch numbers: 2.67 at 60 days, 5.50 at 120 days, and 4.67 at 180 days. The lowest branch counts were in T_1, T_2, T_3, T_7, T_8, and T_9 at 60 days, T_2 at 120 days, and T_8 at 180 days (Table 9). The coefficient of variation was highest in T_{12} across all intervals, indicating significant variability. Overall, gamma irradiation increased branch numbers compared to controls, aligning with findings from studies on Sparrow Gunkel (1965), Brar and Bal (2003) in guava and Kapadiya *et al.* (2014) in chrysanthemum & guava.

It was evident from the data presented in Table 10 & Fig.2, the highest mortality (40%) occurred in T_{12} (Nagpur seedless, 50 Gy), while T_3 (Nagpur mandarin, 20 Gy) showed the lowest among irradiated treatments (11.6%). Controls (T_1, T_7) recorded 4.96% and 10.69%, respectively. No sprouting was observed in T_6 (Nagpur mandarin, 50 Gy), resulting in 100% mortality. Overall, mortality increased with dose, except in T3 and T9 (20 Gy) at 60 days after sprouting. At 120 days after sprouting, mortality remained highest in T_{12} (33.3%) and lowest in T_2 (Nagpur mandarin, 10 Gy; 1.53%). Controls had no mortality. T_6 again showed no sprouting (100% mortality). At 180 days after sprouting T_{12} still had the highest mortality (33%), while T_9 (Nagpur seedless, 20 Gy) had the lowest (2.58%). No mortality occurred in T_1, T_2, T_3, T_4, T_7, and $_{T8}$. T6 continued with no sprouting (100% mortality). Overall, mortality rose with increasing gamma dose, confirming a dose-dependent effect, while low doses (10–20 Gy) had minimal impact.

These findings agree with earlier reports that higher radiation exposures can reduce viability in vegetative propagules (Dhatt *et al.,* 2000).

Table 10 & Fig.3 shows that, at 120 days after sprouting no leaf abnormalities were seen in T_1, T_7, T_2, T_3, T_8, or T_9. T_6 (Nagpur Mandarin, 50 Gy) failed to sprout. The highest abnormality (50%) occurred in T_{12} (Nagpur Seedless, 50 Gy), while the lowest among sprouted irradiated treatments was in T_5 (Nagpur Mandarin, 40 Gy; 8.3%). Again, T_1, T_7, T_2, T_3, T_8, and T_9 remained free of abnormalities. T_6 (Nagpur Mandarin, 50 Gy) did not sprout. T_{12} showed 100% leaf abnormality (Nagpur Seedless, 50 Gy), whereas T_4 (Nagpur Mandarin, 30 Gy) had the lowest abnormality among sprouted irradiated treatments (11.6%) at180 days after sprouting. Controls and lower irradiation doses exhibited little to no foliar abnormality, while high doses especially 50 Gy-produced pronounced effects. Observed abnormalities included altered leaf shape, size, margin, apex form, colour changes, and leaf fusion.

These trends are consistent with reports of radiation-induced foliar variation in other ornamentals and crops (Dwivedi & Banerji 2008, Dahlia; Kumari *et al.* 2013, Chrysanthemum; Taberi *et al.* 2016, Turmeric).

Table 11 summarizes the leaf color varied with treatment: controls (T_1, T_7) showed pale green leaves, while T_2, T_3, T_8, T_9, and T_{10} exhibited light green foliage. Dark green leaves were observed in T_4, T_5, T_{11}, and T_{12}. No sprouting occurred in T_6 (Nagpur mandarin, 50 Gy).

Similar results were reported in the 'F12/1' cherry cultivar, where mutants exhibited darker leaves (Theater and Hedtrich, 1990).

The survival data recorded at 180 days after sprouting are summarized in (Table 11 & Fig.4). The survival was highest in the non-irradiated controls (T_1: 89.61%; T_7: 68.83%). Among irradiated treatments, T_2 (Nagpur mandarin, 10 Gy) maintained the greatest survival (67.48%), whereas T_{12} (Nagpur seedless, 50 Gy) dropped to 7.14%, and T_6 (Nagpur mandarin, 50 Gy) showed no survivors (0%). Survival generally declined with increasing gamma dose; low doses (e.g., 10 Gy in T_2, T_8) supported markedly better survival than high doses (50 Gy in T_6, T_{12}). These trends align with reports of improved survival at lower irradiation levels in guava (Zamir *et al.,* 2003) and Citrus (Sutarto *et al.,* 2009).

Conclusion

This study examined the effects of gamma irradiation on the budding success and growth performance of Nagpur mandarin and Nagpur seedless orange varieties. Higher doses of gamma rays led to delayed sprouting, reduced sprouting percentages, shorter shoot lengths, decreased plant heights, and increased abnormalities such as deformed leaves. While doses of 30-50 Gy induced significant variability, they also resulted in severe negative effects, with 50 Gy causing no sprouting in Nagpur mandarin. These findings suggest the potential of gamma irradiation for inducing variability in citrus breeding, but highlight the need for optimizing dose levels to balance mutation benefits with growth viability.

Table 1: Days required for sprouting of buds

Days required for sprouting of buds					
Treatment	**Range**	**Mean**	**Variance**	**S.D.**	**CV (%)**
T_1 (Control)	0	25.23	3.43	1.85	4.74
T_2 (10 Gy)	7	29.60	8.25	2.87	9.70
T_3 (20 Gy)	12	36.47	11.57	3.40	9.33
T_4 (30 Gy)	8	44.07	10.27	3.20	7.27
T_5 (40 Gy)	7	45.60	10.73	3.28	7.18
T_6 (50 Gy)	0	0	0	0	0
T_7 (Control)	0	26.10	3.47	1.86	7.14
T_8 (10 Gy)	8	29.63	7.83	2.80	9.44
T_9 (20 Gy)	11	36.57	12.25	3.50	9.57
T_{10} (30 Gy)	9	44.67	14.71	3.84	8.59
T_{11} (40 Gy)	9	48.87	15.98	4.00	8.18
T_{12} (50 Gy)	6	51.17	9.80	3.13	6.12

Table 2: Effect of different doses of gamma irradiation on per cent sprouting (%)

Treatment	**Per cent Sprouting %**
T_1 (Control)	77
T_2 (10 Gy)	57.2
T_3 (20 Gy)	47.8
T_4 (30 Gy)	36.8
T_5 (40 Gy)	15.2
T_6 (50 Gy)	0
T_7 (Control)	73.6
T_8 (10 Gy)	52.8

T_9 (20 Gy)	47.8
T_{10} (30 Gy)	36.6
T_{11} (40 Gy)	13.8
T_{12} (50 Gy)	5.67

Table 3: Effect of different doses of gamma irradiation on shoot length (cm)

Treatment	Range			Mean			Variance			S.D.			CV (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1(Control)	0	0	0	14.57	23.09	33.38	0.16	1.21	3.27	0.4	1.1	1.81	2.75	4.76	5.42
T_2(10Gy)	4.5	5.1	8.8	12.57	22.1	30.02	2.1	6.6	15.2	1.45	2.57	3.90	11.53	11.62	12.99
T_3(20 Gy)	4.4	5.3	8.4	10.9	20.98	27.28	1.3	5.7	10.8	1.14	2.39	3.29	10.46	11.38	12.05
T_4(30Gy)	4.8	3.8	6.5	9.65	16.95	23.5	0.98	3.2	7.1	0.99	1.79	2.66	10.26	10.55	11.34
T_5(40Gy)	3.8	1.9	3.8	9.14	14.12	22.41	0.72	2	5.19	0.85	1.41	2.28	9.28	10.02	10.17
T_6(50Gy)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7(Control)	0	0	0	13.77	22.32	31.81	0.3	1.63	1.17	0.55	1.28	1.08	3.98	5.72	3.40
T_8(10Gy)	4.3	6	9.6	11.23	21.99	29.72	1.3	5.61	10.88	1.14	2.37	3.30	10.15	10.77	11.10
T_9(20Gy)	1.7	4.2	6.4	10.88	20.84	24.1	1.19	4.65	6.78	1.09	2.16	2.60	10.03	10.35	10.80
T_{10}(30Gy)	4.5	4	5.8	9.41	16.7	23.32	0.84	2.98	6.43	0.92	1.73	2.54	9.74	10.34	10.87
T_{11}(40Gy)	1.7	1.1	1	8.27	12.99	21.17	0.64	1.91	5.42	0.80	1.38	2.33	9.67	10.64	11.00
T_{12}(50Gy)	2.3	4.5	1.9	6.31	11.43	16.85	0.28	1.19	2.69	0.529	1.09	1.64	8.39	9.54	9.73

Table 4: Effect of different doses of gamma irradiation on leaves shoot^{-1}

Treatment	Range			Mean			Variance			S.D.			CV (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	DAS 60	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1(Control)	0	0	0	12.63	25.40	34.67	0.35	0.99	1.4	0.59	0.99	1.18	4.68	3.92	3.41
T_2(10Gy)	1	3	2	12.43	24.37	32.67	2.45	11.12	20.84	1.57	3.33	4.57	12.59	13.68	13.97
T_3(20 Gy)	1	3	2	14.40	27.60	34.33	3.34	11.59	22.3	1.83	3.40	4.72	12.69	12.33	13.76
T_4(30Gy)	1	1	3	16.37	30.60	36.57	4.5	18.25	30.46	2.12	4.27	5.52	12.96	13.96	15.09
T_5(40Gy)	4	2	4	7.47	16.86	27.08	0.85	5.12	15.5	0.92	2.26	3.94	12.34	13.42	14.54
T_6(50Gy)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7(Control)	0	0	0	12.50	24.27	31.87	0.35	1.2	1.5	0.59	1.10	1.22	4.73	4.51	3.84
T_8(10Gy)	1	3	2	12.30	24.13	31.53	2.1	8.97	18.54	1.45	2.99	4.31	11.78	12.41	13.66
T_9(20Gy)	1	3	4	14.27	27.37	33.90	3.4	12.42	24.06	1.84	3.52	4.91	12.92	12.88	14.47
T_{10}(30Gy)	1	1	1	16.30	30.57	36.33	4	15.25	26.65	2.00	3.91	5.16	12.27	12.77	14.21
T_{11}(40Gy)	5	3	4	9.18	18.22	25.78	1.2	5.5	12.75	1.10	2.35	3.57	11.93	12.87	13.85
T_{12}(50Gy)	3	3	4	6.10	25.00	34.00	0.6	10.65	22	0.77	3.26	4.69	12.70	13.05	13.80

Table 5: Effect of different doses of gamma irradiation on length of leaf (cm)

Treatment	Range			Mean			Variance			S.D.			CV (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1(Control)	0	0	0	4.81	5.36	6.01	0.1	0.02	0.08	0.32	0.14	0.28	6.57	2.64	4.71
T_2(10Gy)	1.5	0.5	0.8	4.45	4.98	5.75	0.12	0.18	0.27	0.35	0.42	0.52	7.78	8.52	9.04
T_3(20 Gy)	1.8	0.5	0.9	3.67	4.58	5.07	0.17	0.29	0.37	0.41	0.54	0.61	11.23	11.76	12.00
T_4(30Gy)	2.1	0.6	0.9	3.55	4.11	4.89	0.13	0.2	0.3	0.36	0.45	0.55	10.16	10.88	11.20
T_5(40Gy)	0.5	0.5	0.4	3.48	3.98	4.38	0.07	0.11	0.15	0.26	0.33	0.39	7.60	8.33	8.84
T_6(50Gy)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7(Control)	0	0	0	4.57	5.22	5.81	0.13	0.05	0.04	0.36	0.22	0.20	7.89	4.28	3.44
T_8(10Gy)	2.3	0.6	0.6	4.44	5.02	5.74	0.14	0.21	0.3	0.37	0.46	0.55	8.43	9.13	9.54
T_9(20Gy)	3.4	0.7	0.9	3.78	4.54	5.58	0.15	0.25	0.4	0.39	0.50	0.63	10.25	11.01	11.33
T_{10}(30Gy)	2.8	0.8	0.8	3.66	3.92	4.83	0.12	0.15	0.26	0.35	0.39	0.51	9.46	9.88	10.56
T_{11}(40Gy)	1.4	0.4	0.5	3.11	3.91	5.07	0.07	0.12	0.23	0.26	0.35	0.48	8.51	8.86	9.46
T_{12}(50Gy)	1	0.2	0.6	2.50	3.53	4.50	0.05	0.11	0.2	0.22	0.33	0.45	8.94	9.40	9.94

Table 6: Effect of different doses of gamma irradiation on width of leaves (cm)

Treatment	Range			Mean			Variance			S.D.			CV (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1(Control)	0	0	0	1.79	2.56	3.22	0.01	0.01	0.01	0.10	0.10	0.10	5.59	3.91	3.11
T_2(10Gy)	0.5	2.4	0.2	1.48	2.57	2.73	0.016	0.061	0.062	0.13	0.25	0.25	8.55	8.92	9.12
T_3(20 Gy)	1.5	0.4	0.1	1.83	2.37	2.86	0.023	0.041	0.061	0.15	0.20	0.25	8.29	8.54	8.64
T_4(30Gy)	0.6	0.5	0.3	2.41	2.74	3.65	0.067	0.095	0.181	0.26	0.31	0.43	10.74	11.25	11.66
T_5(40Gy)	0.5	0.3	0.6	1.49	1.77	1.88	0.024	0.035	0.042	0.15	0.19	0.20	10.40	10.57	10.90
T_6(50Gy)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7(Control)	0	0	0	1.76	2.51	3.07	0.01	0.02	0.02	0.10	0.14	0.14	5.68	5.63	4.61
T_8(10Gy)	0.4	2.3	0.4	1.37	2.23	2.70	0.012	0.036	0.059	0.11	0.19	0.24	8.00	8.51	9.00
T_9(20Gy)	1.3	0.4	0.4	1.81	2.34	2.83	0.024	0.041	0.073	0.15	0.20	0.27	8.56	8.65	9.55
T_{10}(30Gy)	0.5	0.5	0.4	2.37	2.70	3.63	0.049	0.072	0.134	0.22	0.27	0.37	9.34	9.94	10.08
T_{11}(40Gy)	0.6	0.5	0.5	1.47	1.51	1.87	0.023	0.026	0.043	0.15	0.16	0.21	10.32	10.68	11.09
T_{12}(50Gy)	0.4	0.2	0.6	1.36	1.60	2.12	0.02	0.031	0.059	0.14	0.18	0.24	10.40	11.00	11.46

Table 7: Effect of different doses of gamma irradiation on length of internode (cm)

Treatment	Range			Mean			Variance			S.D.			CV (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1(Control)	0	0	0	1.74	2.44	2.76	0.01	0.01	0.02	0.10	0.10	0.14	5.75	4.10	5.12
T_2(10Gy)	1.1	0.9	1.2	1.65	2.40	2.73	0.05	0.13	0.19	0.22	0.36	0.44	13.55	15.02	15.97
T_3(20 Gy)	1.2	0.8	0.9	1.60	2.37	2.71	0.039	0.095	0.132	0.20	0.31	0.36	12.34	13.01	13.41
T_4(30Gy)	1.3	0.6	0.6	1.56	1.97	2.67	0.036	0.061	0.119	0.19	0.25	0.34	12.16	12.54	12.92
T_5(40Gy)	1.3	0.3	0.7	1.48	1.94	2.39	0.027	0.053	0.085	0.16	0.23	0.29	11.10	11.87	12.20
T_6(50Gy)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7(Control)	0	0	0	1.71	2.38	2.59	0.005	0.01	0.02	0.07	0.1	0.14	4.14	4.20	5.46
T_8(10Gy)	1.3	1.2	1	1.64	2.38	2.57	0.043	0.09	0.06	0.21	0.3	0.24	12.64	12.61	9.53
T_9(20Gy)	0.5	0.7	0.6	1.60	2.26	2.46	0.04	0.085	0.112	0.20	0.29	0.33	12.50	12.90	13.60
T_{10}(30Gy)	1.3	0.8	1.2	1.50	1.94	2.34	0.035	0.061	0.098	0.19	0.25	0.31	12.47	12.73	13.38
T_{11}(40Gy)	1	0.4	0.3	1.48	1.97	2.24	0.031	0.058	0.081	0.18	0.24	0.28	11.90	12.22	12.71
T_{12}(50Gy)	0.6	0.2	0.3	1.47	1.90	1.96	0.025	0.045	0.056	0.16	0.21	0.24	10.76	11.16	12.07

Table 8 : Effect of different doses of gamma irradiation on Plant height (cm)

Treatment	Range			Mean			Variance			S.D.			CV (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	DAS 60	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1(Control)	0	0	0	20.7	31.37	43.26	0.52	1.3	4.17	0.72	1.14	2.04	3.48	3.63	4.72
T_2(10Gy)	4.3	2.79	4.1	19.41	30.2	41.01	8.5	22.3	42.5	2.92	4.72	6.52	15.02	15.64	15.90
T_3(20 Gy)	3.2	3.11	3	18.4	27.23	39.5	4.9	15.5	33.4	2.21	3.94	5.78	12.03	14.46	14.63
T_4(30Gy)	1.8	3.34	2.4	16.52	25.75	38.73	3.9	12.94	29.4	1.97	3.60	5.42	11.95	13.97	14.00
T_5(40Gy)	1.5	2.90	0.9	15.31	23.16	34.13	3.43	10.35	29.4	1.85	3.22	5.42	12.10	13.89	15.89
T_6(50Gy)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7(Control)	0	0	0	19.48	31.34	43.07	0.24	0.72	2.46	0.49	0.85	1.57	2.51	2.71	3.64
T_8(10Gy)	5	3.03	3.7	19.4	30.11	40.93	5.46	15.7	34.2	2.34	3.96	5.85	12.04	13.16	14.29
T_9(20Gy)	3	3.31	2.9	18.35	27.12	39.26	6	11.5	34.8	2.45	3.39	5.90	13.35	12.50	15.03
T_{10}(30Gy)	1.9	3.39	2.3	16.75	25.71	38.55	4	12.3	29.5	2.00	3.51	5.43	11.94	13.64	14.09
T_{11}(40Gy)	1.5	2.78	1.1	15.45	23.24	34.03	4	10.2	22.6	2.00	3.19	4.75	12.94	13.74	13.97
T_{12}(50Gy)	1.4	2.32	1.3	15.25	23.48	33.93	3.3	9.4	20.4	1.82	3.07	4.52	11.91	13.06	13.31

Table 9: Effect of different doses of gamma irradiation on Branches plant^{-1}

Treatment	Range			Mean			Variance			S.D.			CV (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1(Control)	0	0	0	1	1.31	2.17	0	0.009	0.02	0	0.09	0.14	0	7.30	6.52
T_2(10Gy)	1	1	3	1	1.33	2.17	0	0.21	0.6	0	0.46	0.77	0	34.46	35.70
T_3(20Gy)	1	2	2	1	1.83	3.17	0	0.42	1.29	0	0.65	1.14	0	35.41	35.83
T_4(30Gy)	2	1	2	1.53	3.53	3.5	0.24	1.65	1.86	0.49	1.28	1.36	32.02	36.39	38.97
T_5(40 Gy)	2	1	1	1.61	4.42	4.29	0.29	3.06	2.99	0.54	1.75	1.73	33.45	39.58	40.31
T_6(50Gy)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7(Control)	0	0	0	1	1.23	2.07	0	0.007	0.05	0	0.08	0.22	0	6.80	10.80
T_8(10Gy)	1	2	3	1	1.83	2	0	0.36	0.45	0	0.60	0.67	0	32.79	33.54
T_9(20Gy)	1	2	2	1	1.73	3.07	0	0.36	1.18	0	0.60	1.09	0	34.68	35.38
T_{10}(30Gy)	2	1	1	1.1	3.4	3.43	0.11	1.45	1.54	0.33	1.20	1.24	30.15	35.42	36.18
T_{11}(40Gy)	3	2	1	2.18	3.78	4.55	0.46	2.23	2.83	0.68	1.49	1.68	31.11	39.51	36.97
T_{12}(50Gy)	3	1	1	2.67	5.5	4.67	1.02	5.7	4.99	1.01	2.39	2.23	37.83	43.41	47.83

Table 10: Effect of different doses of gamma irradiation on mortality percentage (%) & leaf abnormalities percentage (%)

Treatment	Mortality Percentage (%)			leaf abnormalities percentage (%)		
	60 DAS	120 DAS	180 DAS	60 DAS	120 DAS	180 DAS
T_1 (Control)	4.96	0	0	0	0	0
T_2 (10 Gy)	14.81	1.53	0	0	0	0
T_3 (20 Gy)	11.6	9.49	0	0	0	0
T_4 (30 Gy)	19.86	8.51	0	0	10.63	11.6
T_5 (40 Gy)	34.61	33.33	20	0	8.3	40
T_6 (50 Gy)	0	0	0	0	0	0
T_7 (Control)	10.69	0	0	0	0	0
T_8 (10 Gy)	16.36	4.81	0	0	0	0
T_9 (20 Gy)	15.42	13.19	2.58	0	0	0
T_{10}(30 Gy)	20.45	22.22	4.25	0	9.87	12.7
T_{11}(40 Gy)	33.3	29.16	7.14	0	16.6	28.57
T_{12} (50 Gy)	40	33.3	33.3	0	50	100

Table 11: Effect of different doses of gamma irradiation on colour of leaves & on per cent survival (%)

Treatment	Colour of leaves	Per cent survival (%)
T_1 (Control)	Pale green	89.61
T_2 (10 Gy)	Light green	67.48
T_3 (20 Gy)	Light green	51.88
T_4 (30 Gy)	Dark green	44.56
T_5 (40 Gy)	Dark green	10.56
T_6 (50 Gy)	No colour	0
T_7 (Control)	Pale green	68.83
T_8 (10 Gy)	Light green	58.2
T_9 (20 Gy)	Light green	51.88
T_{10} (30 Gy)	Light green	24.59
T_{11} (40 Gy)	Dark green	18.8
T_{12} (50 Gy)	Dark green	7.14

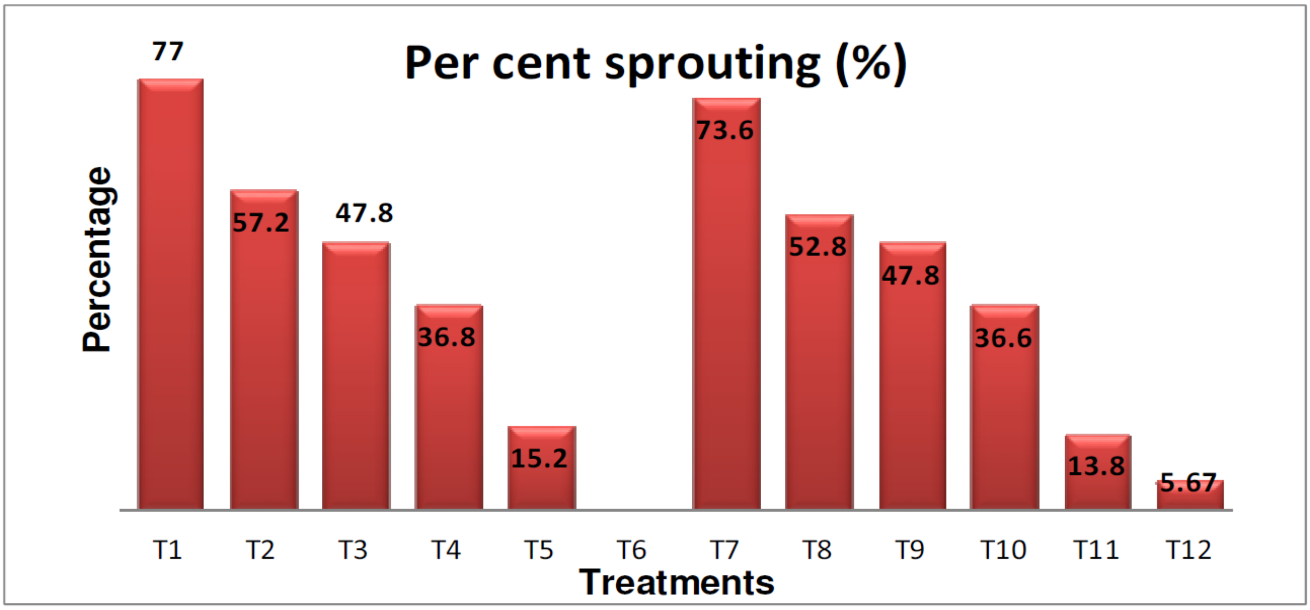

Fig. 1 : Effect of different doses of gamma irradiation on per cent sprouting (%)

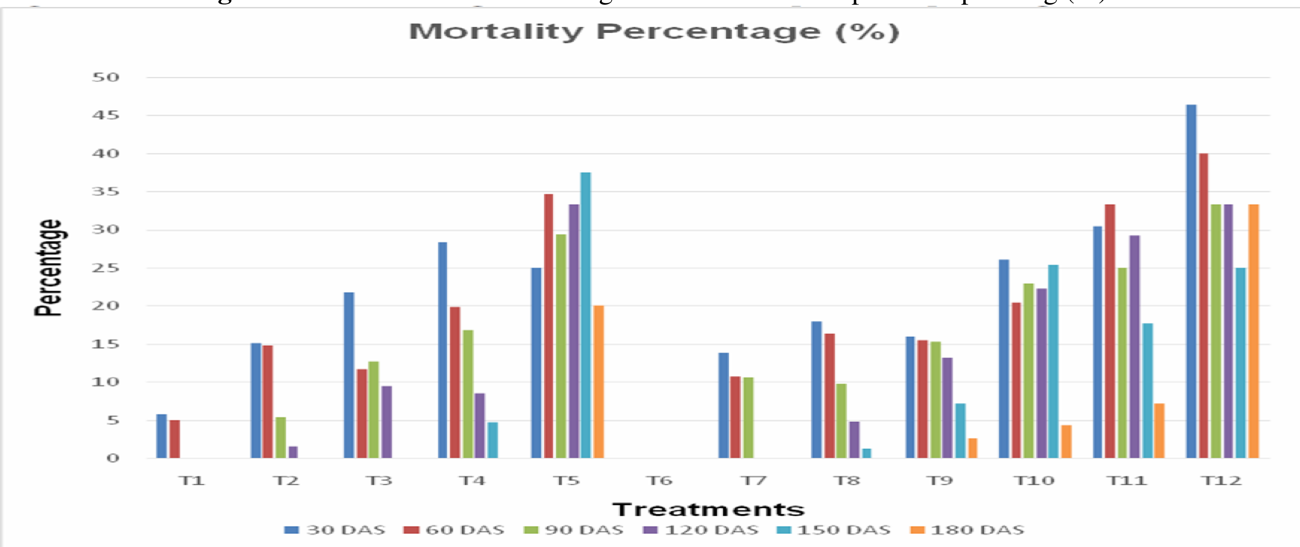

Fig. 2: Effect of different doses of gamma irradiation on mortality percentage (%)

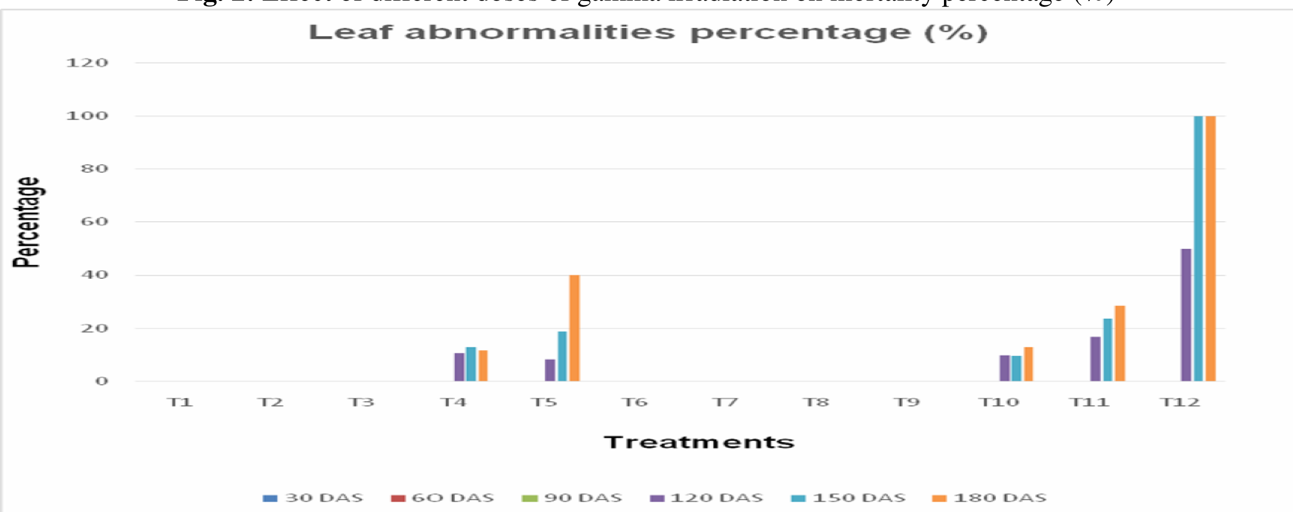

Fig. 3: Effect of different doses of gamma irradiation on leaf abnormalities percentage (%)

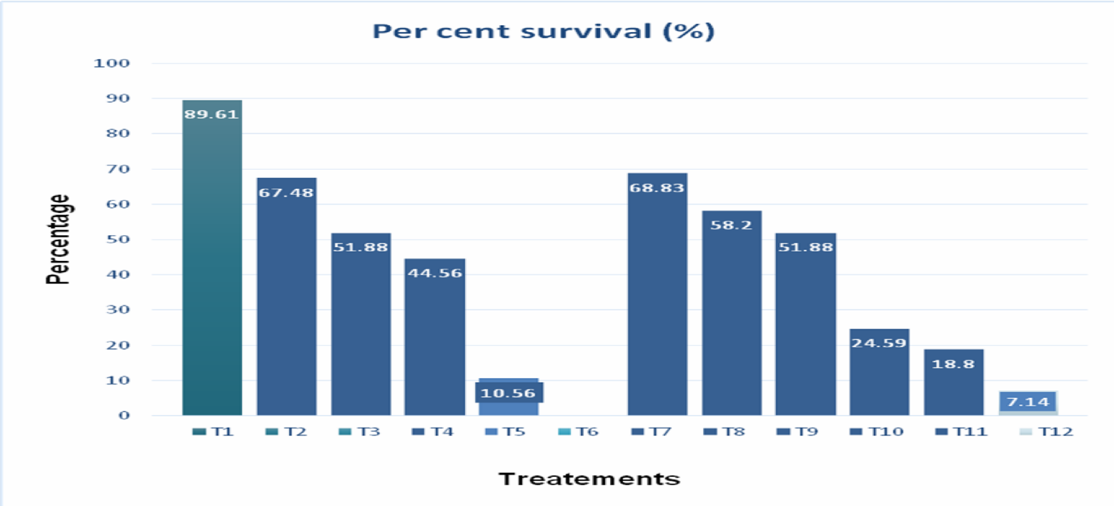

Fig. 4: Effect of different doses gamma irradiation on per cent survival (%)

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

References

Ahmad, W., Farooqi, W. A., & Sattar, A. (1992). Effect of gamma irradiation on the morphology of Kinnow seedlings. In *Procedings of the 1st International Symposium on Citriculture Pakistan,* **1**, 163-168.

Anon. (2022) A report of Indian Horticulture database published by National Horticulture Board (NHB), Gurgaon.

Anon., (2021). A report of Indian Horticulture database published by National Horticulture Board (NHB), Gurgaon.

Batra, A., & Dwivedi, A. K. (2015). Mutational studies on Chrysanthemum cv. Maghi' with particular reference to induction of flower colour mutation. *Agrica*, **4**(2), 93-101

Bermejo, A., Pardo, J., & Cano, A. (2011). Influence of gamma irradiation on seedless citrus production, pollen germination and fruit quality. *Food and Nutrition Sciences*, **2**(3), 169-180.

Brar, H. S., & Bal, J. S. (2003). Studies on the use of gamma rays on the performance of guava buddlings. *Annals of Agri Bio Res*earch, **8**(2), 213-218.

Dhatt, A. S., Rattanpal, H.S., Khokhar, R .and Singh, S.N. 2000. Standardising LD_{50} dose of gamma rays and EMS in Kinnow seeds. *Journal of Research Punjab Agricultural University.* **37**(3/4), 194-197.

Dwivedi, A. K., & Banerji, B. K. (2008). Effects of gamma irradiation on Dahlia cv.'Pinki' with particular reference to induction of somatic mutation. *J. Orn. Hort.*, **11**(2),148-151.

Ghosh, D. (2001). Efficiency considerations in the additive hazards model with current status data. *Statistica Neerlandica*, **55**(3), 367-376.

Gunckel, J. E., & Sparrow, A. H. (1967). Ionizing radiation, Biochemical, Physiological and Morphological aspects of their effects on plants. Rutgers Univ., New Brunswick, NJ.

Gunckel, J. E., & Sparrow, A. H. 1965. Ionizing radiation, Biochemical, Physiological and Morphological aspects of their effects on plants. In, Ruhland W X (ed) *Encycl Plant Physiol.* Pp. 555-611, Springer- verlag, Berlin

Hearn, C. J. (1984). Development of seedless orange and grapefruit cultivars through seed irradiation. *Journal of the American Society for horticultural Science*, **109**(2), 270-273.

Kamatyanatt, M., Singh, S. K., & Sekhon, B. S. (2021). Mutation breeding in citrus-A review. *Plant Cell Biotechnol. Mol. Biol*, **22**, 1-8.

Kapadiya, D. B., Chawla, S. L., Patel, A. I., & Ahlawat, T. R. (2014). Exploitation of variability through mutagenesis in Chrysanthemum (Chrysanthemum morifolium Ramat.) var. Maghi. *Bioscan*, **9**(4), 1799-1804.

Karsinah, K., Indriyani, N. L. P., & Sukartini, S. (2012). The effect of gamma irradiation on the growth of mango grafted material. *Journal of Agricultural sciences,* **7**(10), 840-44.

Kaur, S., & Rattanpal, H. S. (2010). Effect of mutagens on in vitro seed germination and growth of rough lemon (Citrus jambhiri) seedlings. *Indian Journal of Agricultural Sciences*, **80**(9), 773.

Khalil, S. A., Sattar, A., & Zamir, R. (2011). Development of sparse-seeded mutant kinnow (Citrus reticulata Blanco) through budwood irradiation. *African Journal of Biotechnology*, **10**(65), 14562-14565.

Kiran Kumari, K. K., & Dhatt, K. K. (2015). Effect of gamma rays on growth and vegetative characters of chrysanthemum variety'Thai Chen Queen'.'. Ann. Biol., **31**(2), 261-263.

Lamo, K., Bhat, D. J., Kour, K., & Solanki, S. P. S. (2017). Mutation studies in fruit crops, a review. *International Journal of Current Microbiology and Applied Sciences*, **6**(12), 3620-3633.

Mahure, H. R., Choudhary, M. L., Prasad, K. V., & Singh, S. K. (2010). Mutation in chrysanthemum through gamma irradiation. *Indian journal of horticulture*, **67**(4), 356-358.

Panse, V. G., and Sukhatme, P.V. (1958). Stastical method of Agricultural Workers. ICAR, New Delhi, 84-85.

Rattanpal, H. S., Singh, G., & Gupta, M. (2019). Studies on mutation breeding in mandarin variety Kinnow. *Current Science*, **116**(3), 483-487.

Ravkin, A. S. (1975). Growth characteristics of mutant forms of apples in the nursery. *Agric. Boil.*, **10**, 354-358.

Russo, F., Donini, B., & Starrantino, A. (1982). Mutagenesis applied for citrus improvement.

Sharafi, Y., Rezaei, A., Ghanbari, A., & Naji, A. M. (2013). Gamma irradiation affected phenotypic characteristics of almond (Prunus amygdalus L.). *International journal of Agronomy and Plant Production*. **4**(1), 25-29.

Sutarto, I., Agisimanto, D., & Supriyanto, A. (2009). Development of promising seedless citrus mutants through gamma irradiation. *Induced plant mutations in the genomics era. Food and Agriculture Organization of the United Nations, Rome*, 306-308.

Taheri, S., Abdullah, T.L., Ahmad, Z., Sahebi, M. and Azizi, P. 2016. Phenotypic and molecular effects of chronic gamma irradiation on *Curcuma alismatifolia*, *Eur. J. Hortic. Sci.*, **81**(3), 137-147

Van Harten, A. M. (1998). *Mutation breeding, theory and practical applications* (Vol. 1). Cambridge University Press.137-158.

Zamir, R., Khattak, G.S., Mohammad, T., Shah S.A., Khan. A.J. and Ali, N. 2003. *In-vitro* mutagenesis in guava (*Psidium guajuva* L.) *Pak. J. Bot*., **35**, 825-28.