Original research paper

Induction of physical mutations in *Gladiolus grandiflorus* L. through gamma irradiation

Abstract

Gladiolus is one of the most popular cut flowers cultivated in India, and it is excellent for inducing physical mutagenesis. The present study was carried out to determine the optimal lethal dose for gamma rays and to induce mutations through gamma irradiation in two gladiolus varieties, Arka Amar and Arka Thilak. The corms of both varieties were irradiated with gamma ray of doses 25, 40, 55 and 70 Gy using a gamma chamber with ^{60}Co as the radiation source. The mortality rate of the plants increased significantly with increasing radiation doses, with Arka Thilak showing higher sensitivity. The LD_{50} (lethal dose) values were determined as 58.22 Gy for Arka Amar and 58.31 Gy for Arka Thilak through probit analysis. Based on the LD_{50}, the effective doses were fixed as 45, 50, 55, 60 and 65 Gy, along with a control, for both varieties. Corms of gladiolus varieties were then treated with the selected doses of gamma radiation to induce physical mutation. Six treatments of each variety were evaluated in factorial completely randomized design with three replications. The characters like number of leaves per plant, length and diameter of the floret, and plant height were highest in Arka Thilak treated with 45 Gy. The number of spikes per plant and spike length were highest in the same variety treated with 50 Gy. In Arka Amar, the length of leaf blade and field life were maximum at 45 Gy, and a greater number of florets per spike was observed at 50 Gy. Among the treatments, lower doses promoted better growth, whereas higher doses had detrimental effects. Attractive colour mutants were obtained in Arka Amar at higher doses. The study suggest the ability of gamma irradiation to induce beneficial mutations in gladiolus, creating opportunities for breeding new varieties with improved ornamental traits.

Keywords: Gladiolus, corms, gamma rays, LD_{50}, mutant

1. Introduction

Gladiolus (*Gladiolus grandiflorus* L.), an important flower crop from the Iridaceae family, is highly popular as a cut flower in both local and international markets. It is known as the queen of bulbous flowers because of its beauty, glamorous appearance, elegant and delicate florets in various forms. This plant is relatively easy to cultivate and ideal for garden beds and display purposes [1]. It originates from South Africa and Asia Minor. The genus *Gladiolus* comprises 180 species with ploidy levels varying from 2n=2x=30 to 2n=12x=180. Modern cultivars were developed from a few wild species and are typically tetraploids. The currently cultivated gladiolus varieties originated from 20 to 25 species and are grown in nearly all countries where spring and summer conditions are suitable [2]. It is propagated vegetatively by corms or cormels, and mutation induction has great potential for its improvement.

Induced mutagenesis techniques have successfully produced and commercialized numerous promising varieties of different crops worldwide, including ornamental plants. The improvements achieved through mutation breeding in these plants include compact growth, attractive variegated leaves, and novel flower colours and shapes [3]. Ornamental plants are well-suited for mutation induction because economically valuable traits like flower characteristics, can be easily observed after mutagenic treatment. Additionally, many ornamental plants are heterozygous and often propagated vegetatively, allowing for the early detection, selection, and preservation of mutants in the M1 generation. Gladiolus, with its highly heterozygous genetic makeup, is a promising material for testing induced physical mutagenesis.

In mutation breeding, the initial step is to determine the sensitivity of the plant to the mutagen. This is typically performed by identifying the LD_{50} value [4]. Survival of the irradiated material in M_1 generation is considered as one of the important criteria to estimate the dose levels for particular mutagen. When death rate reaches 50% of the total treated material (LD_{50}), such dose or concentration is considered as optimum one [5]. The material is then treated with the optimum dose to minimize excessive loss of experimental material. Once a mutation has been induced and identified, the vegetatively propagated plants have the distinct advantage of being able to fix and preserve the created variation [4].

Among physical mutagens, gamma radiation is more effective for inducing mutations in both seed and vegetatively propagated crops. It consists of high-frequency rays with high-energy protons and it is commonly used because they cause minimal damage to entire plants or plant parts, including pollen, and offer good penetration and precise dosimetry [6]. The most common gamma source is cobalt-60 (^{60}Co), though cesium-137 (^{137}Cs) is also effective. Gamma rays can penetrate deeply into cells and interact with atoms or molecules to produce free radicals, which can damage or modify essential plant components depending on the level of irradiation [7]. Hence, this experiment was carried out to find the lethal dose for gamma rays and to induce variability in gladiolus using the same physical mutagen.

2. Materials and methods

The investigation was carried out in the Department of Genetics and Plant Breeding, College of Agriculture, Vellayani during 2023. The research programme involved 2 experiments. First experiment was the determination of LD_{50} for gamma rays and second was the induction of physical mutation through gamma irradiation in gladiolus.

In the first experiment, the corms of gladiolus varieties Arka Amar and Arka Thilak were irradiated with gamma rays at doses of 25, 40, 55 and 70 Gy. Each dosage was applied to eight corms of both varieties. Gamma irradiation was done in the gamma chamber installed at the Radiotracer Laboratory, College of Agriculture, Vellanikkara, Thrissur, where ^{60}Co serves as the source of gamma rays. The irradiated corms were then planted in pots along with control to determine LD_{50}. LD_{50} values were estimated from probit analysis based on the mortality percentage of gladiolus seedlings. Probit analysis was done using the software, GRAPES (General R-based Analysis Platform Empowered by Statistics) [8] provided by Kerala Agricultural University.

In the second experiment, corms of gladiolus varieties Arka Amar and Arka Thilak were treated with effective doses of gamma radiation (0, 45, 50, 55, 60 and 65 Gy) as estimated from the first experiment to induce physical mutation. These treatments were evaluated in factorial completely randomized design (FCRD) with three replications. Potting mixture was prepared by mixing sand, soil, FYM, and coco pit in the ratio 1:2:1:1. Management and intercultural operations were undertaken as per package of practices recommendations of Kerala Agricultural University [9].

The observations obtained from the experiments were subjected to one-way analysis of variance (ANOVA). The mean values were compared at a $p < 0.05$ significance level. The traits under study were days to sprouting, number of leaves per plant, length of leaf blade (cm), width of leaf blade (cm), plant height (cm), days to spike initiation, number of spikes per plant, spike length (cm), length of the floret (cm), diameter of the floret (cm), number of florets per spike, field life (number of days), corm weight (g) and number of cormels per corm. Statistical analysis of the data was performed using the software, GRAPES [8].

3. Results and discussion

3.1. Determination of Lethal Dose (LD_{50})

LD_{50} value was determined through probit analysis based on the mortality percentage of gladiolus seedlings, and the mean value is given in table 1. The dose-response curve is given in Fig. 1 and Fig. 2. The mortality rate ranged from 0 to 62.5% with different doses of gamma rays including control. Similar results were obtained by Pal et al. [4] in gamma irradiated cultivars of dahlia. The higher mortality observed at increased mutagen doses may be due to disruptions at the cellular level, which can occur either physiologically or physically, including chromosomal damage. Maximum mortality was observed in Arka Thilak (32.5%) compared to Arka Amar (30%).

From probit analysis the LD_{50} value obtained was 58.22 Gy and 58.31 Gy for Arka Amar and Arka Thilak respectively. Varietal differences in radiosensitivity, measured as LD_{50}, varied widely for various vegetatively propagated crops like gladiolus, chrysanthemum, and others, ranging from 50 Gy to 150 Gy [10]. A similar pattern of mortality in treated materials and variation in radiation sensitivity among different cultivars has also been observed by Dwivedi and Banerji [11], Koh et al. [12], Pal et al. [4], and Kayalvizhi et al. [13].

Table 1. Effect of gamma radiation on mortality percentage in gladiolus varieties

Gamma ray doses (Gy)	Mortality percentage		Mean
	Arka Amar	Arka Thilak	
0	0	0	0
25	12.5	25	18.75
40	25	37.5	31.25
55	50	37.5	43.75
70	62.5	62.5	62.5
Mean	30	32.5	

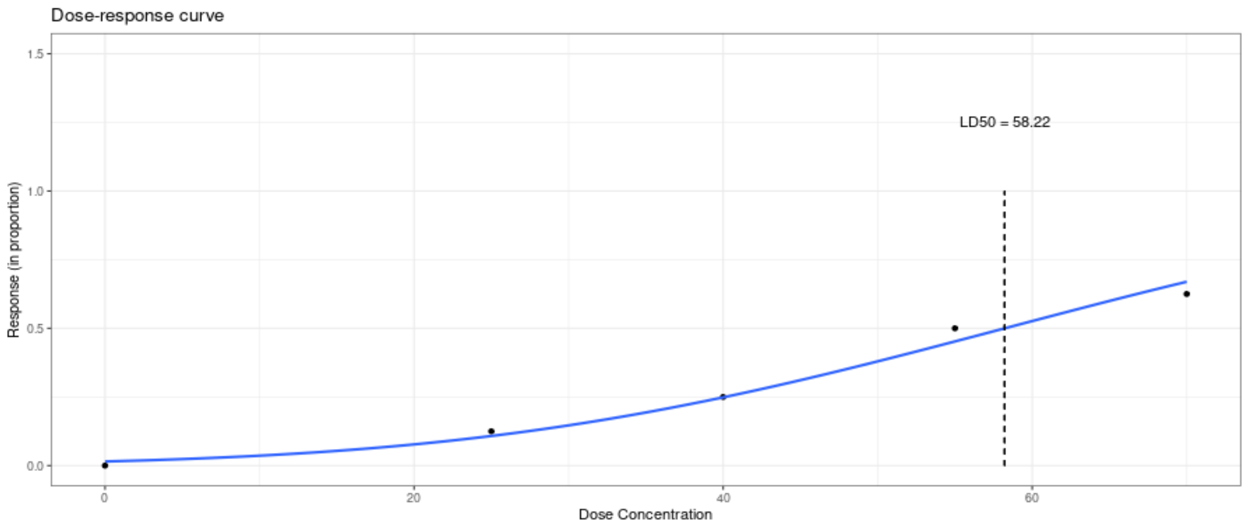

Fig. 1. Dose-response curve of Arka Amar

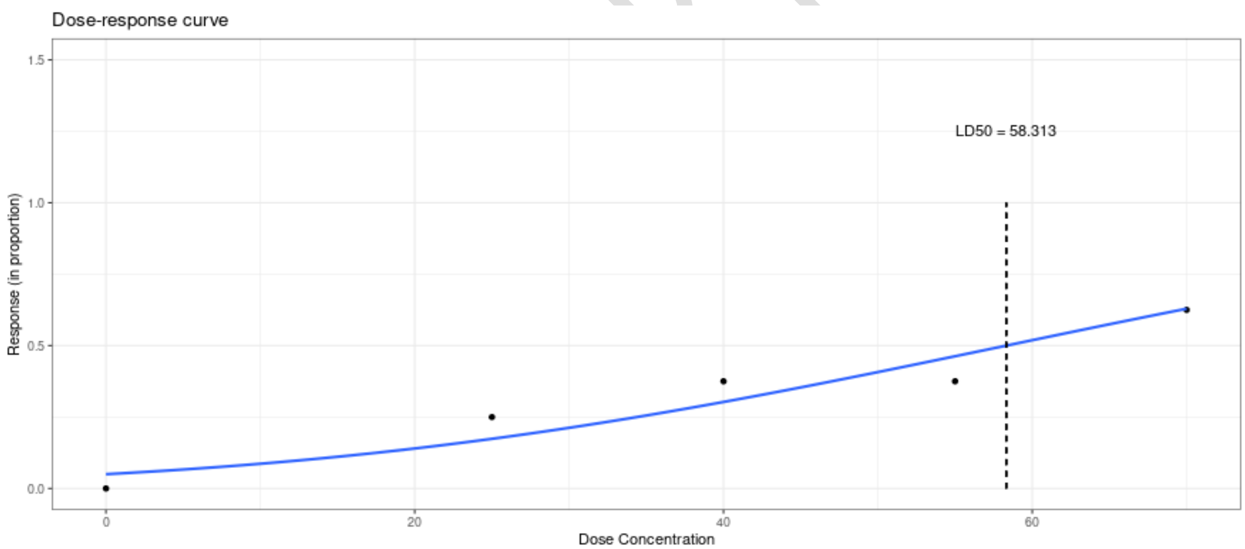

Fig. 2. Dose-response curve of Arka Thilak

3.2. Induction of physical mutation through gamma irradiation

Number of days to sprouting increased as the dose of gamma rays increased (Table 2). Maximum number of days for sprouting was recorded in Arka Thilak (17.67 days) at 65 Gy and minimum number of days for sprouting was recorded in Arka Amar (5.67 days), which was untreated. Among treatments, 65 Gy showed maximum number of days for sprouting (16.17 days), which was on par with 60 Gy (15.83). Among varieties, Arka Thilak exhibited maximum number of days for sprouting (14.50 days), which was significantly differed with variety Arka Amar, 11.44 days. Interaction effect between varieties and treatment was non-significant. This was in close agreement with the results of Patil and Dhaduk [14], Patel et al. [15] and Pawadashetti et al. [16] in mutation induced gladiolus. Singh and Kumar [1] reported that gladiolus plant treated with 70 Gy took maximum days to sprouting. Lower levels of mutagens do not directly stimulate sprouting; rather, it is the substances like enzymes released by irradiation and low doses that cause this stimulation, as these enzymes are crucial for plant metabolism [17]. On the other hand, higher radiation doses may negatively affect auxins and other growth substances, potentially impacting chromosomes and plant tissue [18].

A significant difference in number of leaves per plant (Table 2) was noted with respect to varieties and treatments. The highest number of leaves per plant was observed in Arka Thilak (9.67) treated with 45 Gy and lowest number was observed in Arka Amar (4.67) treated with 65 Gy. Treatment 45 Gy showed maximum number of leaves with a mean value of 9.00 followed by control plants (7.50). Both varieties also showed significant differences with maximum number of leaves in Arka Thilak (7.17). As the gamma radiation increased from 45 Gy, the number of leaves decreased. This was in accordance with the findings of Patil and Dhaduk [14] in mutation induced gladiolus. This may be due to the activation of physiological substances within the corms at lower doses, while higher doses inhibit cell division by halting mitosis and negatively affecting auxins.

Table 2. Effect of gamma radiation on days to sprouting and number of leaves per plant in gladiolus varieties

Gamma ray doses	Days to sprouting			Number of leaves per plant		
	Arka Amar	Arka Thilak	Mean	Arka Amar	Arka Thilak	Mean
0 Gy	5.67	8.33	7	6.67	8.33	7.5
45 Gy	9.33	12.33	10.83	8.33	9.67	9
50 Gy	11.67	14.67	13.17	6.67	7.33	7
55 Gy	13	16.67	14.83	6.33	7	6.67
60 Gy	14.33	17.33	15.83	5.67	5.67	5.67
65 Gy	14.67	17.67	16.17	4.67	5	4.83
Mean	11.44	14.5		6.39	7.17	
	S.E (m) (Standard Error)	C.D (5%) (Critical Difference)		S.E (m)	C.D (5%)	
Variety	0.15	0.43		0.14	0.41	
Treatment	0.26	0.74		0.25	0.72	
Variety× Treatment	0.36	NA		0.35	NA	

The highest length of leaf (Table 3) was found in plants treated with 45 Gy (73.28 cm) which was followed by 50 Gy gamma ray dose (66.32 cm). The interactions between treatment and varieties were found to be highly significant, where the highest leaf length found in Arka Thilak treated with 45 Gy (75.53 cm) followed by Arka Amar treated with 45 Gy (71.03 cm). Maximum leaf width was observed in untreated corm (3.47 cm), followed by those treated with 45 Gy (3.28 cm). Among interactions, the highest width of leaf was found in untreated variety Arka Thilak (3.60 cm) which was on par with the same variety treated with 45 Gy (3.57 cm). The lowest leaf length and width observed in higher dose of gamma radiation, 65 Gy. Similar results were reported by Srivastava et al. [18] in mutation induced gladiolus, where he observed that the size of the leaf was negatively impacted by the irradiation, significantly decreasing as the radiation doses increased.

Table 3. Effect of gamma radiation on length and width of leaf blade in gladiolus varieties

Gamma ray doses	Length of leaf blade (cm)			Width of leaf blade (cm)		
	Arka Amar	Arka Thilak	Mean	Arka Amar	Arka Thilak	Mean
0 Gy	64.37	59.83	62.10	3.33	3.60	3.47
45 Gy	71.03	75.53	73.28	3.00	3.57	3.28
50 Gy	66.03	66.60	66.32	2.60	2.93	2.77
55 Gy	58.00	55.50	56.75	2.47	2.53	2.50
60 Gy	55.77	54.93	55.35	2.37	2.40	2.38
65 Gy	54.23	50.77	52.50	2.00	2.03	2.02
Mean	61.57	60.53		2.63	2.84	
	S.E (m)	C.D (5%)		S.E (m)	C.D (5%)	
Variety	0.16	0.47		0.03	0.08	
Treatment	0.28	0.81		0.05	0.13	
Variety×Treatment	0.39	1.14		0.06	0.18	

The highest plant height (Table 4) was observed in Arka Thilak (98.12 cm) which was significantly different from Arka Amar with a mean value of 79.09 cm. Treatment means and interaction effects also showed high significant difference. Among treatments, highest plant height was observed in 45 Gy (113.13 cm) which was followed by 50 Gy (103.80 cm). Among the combinations of varieties and treatments, maximum plant height observed in Arka Thilak (134.93) treated with 45 Gy followed by the dose 50 Gy (120.67) in the same variety. Minimum plant height was also observed in Arka Thilak (59.23) treated with 65 Gy. Plant height reduced at higher levels of gamma radiation. This observation was similar to the findings of Patil and Dhaduk [14], Singh and Kumar [1], and Singh and Sisodia [19] in irradiated gladiolus varieties. A decrease in plant height at higher doses of gamma irradiation may be due to a reduction in the number of vertical cell layers, leading to shorter internodes, fewer internodes, or a combination of these factors.

Significant differences were observed in number of days to spike initiation (Table 4) in both varieties with respect to different doses of gamma rays. Maximum number of days to spike initiation observed in Arka Thilak (86.44 days) compared with Arka Amar (82.89 days). The treatment means were in the range of 69.33 days to 95 days. Spike initiation was fastest in control plants (71.33 days) and longest in plants treated with 65 Gy (93.83 days), which was followed by 60 Gy (91.83 days). Minimum number of spike initiation found in untreated Arka Amar (69.33 days) and maximum found in Arka Thilak treated with 65 Gy (95.00 days). A similar stimulatory effect was observed in studies by Misra and Bajpai [20] with 2 kR and 3 kR doses across nine gladiolus varieties. A delay in spike emergence at higher doses might result from disruptions in biochemical pathways that are affected during the radiation process, and these pathways are directly or indirectly connected to the flowering physiology [21]. Raghava et al. [22] and Negi et al. [23] observed that in several varieties of gladiolus, flowering was significantly delayed at the 50 Gy treatment level. This delay was attributed to increased chromosomal aberrations or the synthesis of toxic substances by mutagens that negatively impact cell division.

Table 4. Effect of gamma radiation on plant height and days to spike initiation in gladiolus varieties

Gamma ray doses	Plant height (cm)			Days to spike initiation		
	Arka Amar	Arka Thilak	Mean	Arka Amar	Arka Thilak	Mean
0 Gy	83.27	102.87	93.07	69.33	73.33	71.33
45 Gy	91.33	134.93	113.13	76.33	81.33	78.83
50 Gy	86.93	120.67	103.80	81.33	86.00	83.67
55 Gy	78.50	94.73	86.62	87.00	90.00	88.50
60 Gy	70.70	76.30	73.50	90.67	93.00	91.83
65 Gy	63.80	59.23	61.52	92.67	95.00	93.83
Mean	79.09	98.12		82.89	86.44	
	S.E (m)	C.D (5%)		S.E (m)	C.D (5%)	
Variety	0.30	0.86		0.34	0.98	
Treatment	0.51	1.49		0.58	1.70	
Variety × Treatment	0.72	2.11		0.82	NA	

Maximum number of spikes per plant (Table 5) was observed in Arka Thilak treated with 50 Gy (5.67) and minimum number observed in the same variety treated with 65 Gy (1.00). Highest number of spikes observed in plants treated with 50 Gy (3.33), which was on par with the 55 Gy (2.83) treatment. There were no significant differences among varieties and interactions between varieties and treatments. The increase in the number of spikes may be due to a slight enhancement in photosynthetic activity stimulated by the irradiations [14]. Lowest number found in high doses of gamma radiation (65 Gy). Similar findings were reported by Patil [24], who observed that 6 kR and 7 kR doses significantly reduced spike yield in the cultivar American Beauty, and little to no flowering occurred in Nova Lux and Eurovision. Additionally, Raghava et al. [22] observed no flowering at 10 kR and 15 kR doses of gamma radiation, which may be due to alterations in plant metabolic activities and the negative response of plant hormones to irradiation.

The spike length (Table 5) differed significantly with respect to treatments, varieties and their interactions. Arka Thilak (51.21 cm) recorded highest spike length compared to Arka Amar (50.11 cm). Every treatments differed significantly with highest spike length in 50 Gy (58.13 cm) treated plants, followed by 45 Gy (55.93 cm) treatment and lowest found in 65 Gy (39.53 cm) gamma ray dose. Among interactions between treatments and varieties, maximum length was found in Arka Thilak treated with 50 Gy (61.00 cm), followed by the same variety treated with 45 Gy (57.87 cm). Minimum length was also noticed in the same variety treated with 65 Gy (37.43 cm). This was in close agreement with the findings of Patil and Dhaduk [14] and Srivastava et al. [18]. A decrease in spike length might result from a decline in internal auxin production, which subsequently reduces plant growth. Jyothi and Singh [25] also reported a gradual decrease in spike length as the doses of gamma irradiation increased in the mutant tuberose varieties.

Table 5. Effect of gamma radiation on number of spikes per plant and spike length in gladiolus varieties

Gamma ray doses	Number of spikes per plant			Spike length (cm)		
	Arka Amar	Arka Thilak	Mean	Arka Amar	Arka Thilak	Mean
0 Gy	1.33	1.67	1.50	52.43	56.40	54.42
45 Gy	2.33	2.67	2.50	54.00	57.87	55.93
50 Gy	3.00	3.67	3.33	55.27	61.00	58.13
55 Gy	3.33	2.33	2.83	50.67	54.30	52.48
60 Gy	1.67	1.33	1.50	46.67	40.27	43.47
65 Gy	1.33	1.00	1.17	41.63	37.43	39.53
Mean	2.17	2.11		50.11	51.21	
	S.E (m)	C.D (5%)		S.E (m)	C.D (5%)	
Variety	0.16	NA		0.27	0.78	
Treatment	0.27	0.79		0.46	1.35	
Variety×Treatment	0.39	NA		0.66	1.92	

Higher doses of gamma radiation caused significant reductions in both floral length and diameter (Table 6). 65 Gy treated plants had the lowest length with a mean value of 7.92 cm and highest length noticed in plants treated with 45 Gy (11.02 cm), followed by control plants (10.42 cm), which was on par with the 50 Gy (10.32 cm) treatment. Among varieties, the highest and lowest floral lengths were observed in Arka Thilak (10.26 cm) and Arka Amar (8.99 cm) respectively. Arka Thilak treated with 45 Gy (11.57 cm) showed maximum length of floret which was followed by the same variety treated with 50 Gy (11.17 cm) and minimum length observed in Arka Amar treated with 65 Gy (7.60 cm). Similar variations were observed in the diameter of florets with respect to floral length. 65 Gy treated plants have the lowest diameter with a mean value of 8.30 cm and highest diameter noticed in plants treated with 45 Gy (11.40 cm), followed by control plants (10.77 cm), which was on par with the 50 Gy (10.70 cm) treatment. Interaction effects were found to be highly significant with minimum diameter observed in Arka Amar treated with 65 Gy (7.93 cm). Arka Thilak treated with 45 Gy (12.03 cm) showed maximum diameter of floret which was followed by the same variety treated with 50 Gy (11.63 cm). This was in agreement with the findings of Singh and Sisodia [19] in mutant gladiolus. Kapadiya et al. [26] reported that higher gamma rays doses reduced the size of the florets, while lower doses led to an increase in their size in chrysanthemum variety 'Maghi'.

Table 6. Effect of gamma radiation on length and diameter of the florets in gladiolus varieties

Gamma ray doses	Length of the floret (cm)			Diameter of the floret (cm)		
	Arka Amar	Arka Thilak	Mean	Arka Amar	Arka Thilak	Mean
0 Gy	10.10	10.73	10.42	10.33	11.20	10.77
45 Gy	10.47	11.57	11.02	10.77	12.03	11.40
50 Gy	9.47	11.17	10.32	9.77	11.63	10.70
55 Gy	8.33	10.47	9.40	8.70	10.90	9.80
60 Gy	7.97	9.37	8.67	8.30	9.70	9.00
65 Gy	7.60	8.23	7.92	7.93	8.67	8.30
Mean	8.99	10.26		9.30	10.69	
	S.E (m)	C.D (5%)		S.E (m)	C.D (5%)	
Variety	0.04	0.11		0.04	0.12	
Treatment	0.07	0.20		0.07	0.21	
Variety×Treatment	0.10	0.28		0.10	0.29	

A significant difference in number of florets per spike (Table 7) was noted with respect to varieties and treatments. More flowers found in Arka Amar treated with 50 Gy (16.67) and less in Arka Thilak treated with 65 Gy (6.33). The highest and lowest numbers of flowers were found in Arka Amar (12.28) and Arka Thilak (11.17) respectively. Among treatments, 50 Gy (16.17) showed highly significant difference with more number of flowers, followed by 45 Gy (15.00). The least number of flowers observed in 65 Gy (7.00), which was on par with 60 Gy (7.50) treatment. A similar variation was observed by Devi et al. [21] in gladiolus. A study by Sahariya et al. [27] demonstrated that higher doses of gamma rays led to a decrease in the number of florets per spike, while lower doses resulted in an increase in florets per spike across 10 gladiolus varieties. Higher doses of irradiation reduced the size and number of florets, and had adverse effects, possibly due to auxin destruction, irregular auxin synthesis, assimilation failures, inhibition of mitosis, chromosomal changes, or secondary physiological damage, supporting the current findings [28].

A significant difference in field life (Table 7) was observed with respect to treatments and the interactions between treatments and varieties. Longest field life recorded in 45 Gy (18.83) treated plants which was on par with 50 Gy (18.50) treatment. Shortest field life was observed in plants treated with 65 Gy (15.50) which was on par with 60 Gy (16.17) and 55 Gy (16.17). Arka Amar treated with 45 Gy (20.33) had longest field life, followed by Arka Thilak treated with 50 Gy (18.67), which was on par with 50 Gy treated Arka Amar (18.33) and untreated Arka Thilak (17.67). Shortest field life was observed in Arka Amar treated with 65 Gy (15.00), which was on par with the same variety treated with 55 Gy (15.33) and 60 Gy (15.67). A similar trend was observed in a study by Pawadashetti et al. [16] on gladiolus varieties. Jyothi and Singh [25] also supported these findings as they observed a significant decrease in flower duration with increasing gamma dose in the case of tuberose. Devi et al. [21] reported that higher doses decreased the vase life of cut spikes, with the shortest vase life recorded at 8.64 days in spikes irradiated with 6 kR.

Table 7. Effect of gamma radiation on number of florets per spike and field life in gladiolus varieties

Gamma ray doses	Number of florets per spike			Field life (number of days)		
	Arka Amar	Arka Thilak	Mean	Arka Amar	Arka Thilak	Mean
0 Gy	13.33	12.33	12.83	17.33	17.67	17.50
45 Gy	15.67	14.33	15.00	20.33	17.33	18.83
50 Gy	16.67	15.67	16.17	18.33	18.67	18.50
55 Gy	12.00	11.67	11.83	15.33	17.00	16.17
60 Gy	8.33	6.67	7.50	15.67	16.67	16.17
65 Gy	7.67	6.33	7.00	15.00	16.00	15.50
Mean	12.28	11.17		17.00	17.22	
	S.E (m)	C.D (5%)		S.E (m)	C.D (5%)	
Variety	0.19	0.55		0.17	NA	
Treatment	0.33	0.95		0.29	0.84	
Variety×Treatment	0.46	NA		0.41	1.19	

There was a gradual decrease in corm weight (Table 8) with increasing gamma radiation dose. Maximum corm weight observed in untreated Arka Amar (14.67g) and minimum corm weight found in 65 Gy treated Arka Thilak (8.00g). Treatment means were in the range of 8.67 to 14.00g with highest corm weight in control plants (14.00g) followed by 45 Gy (12.67g) and lowest in plants treated with 65 Gy (8.67g). Arka Amar (11.78g) had the highest corm weight compared to

Arka Thilak (10.72g). Number of cormels per corm (Table 8) differed significantly with respect to treatments, varieties and their interactions. Arka Amar (18.78) recorded more cormels than Arka Thilak (10.33). Maximum number of cormels found in treatment 50 Gy (19.00), followed by 55 Gy (17.00), which was on par with 45 Gy (16.83) gamma ray dose. Minimum number of cormels observed in 65 Gy (9.83) treatment, followed by control (12.17), which was on par with 60 Gy (12.00). Among interactions between treatments and varieties, 55 Gy treated Arka Amar (24.67) showed more number of cormels, which was on par with the same variety treated with 50 Gy (23.33). This was in close agreement with the findings of Rahemi et al. [29], who observed that the corm weight, size, and number of daughter corms decreased as radiation doses increased. However, low doses had a stimulating effect, possibly due to enhanced enzyme activity. In contrast, high doses of gamma irradiation exhibited lethal effects on various vegetative traits.

Table 8. Effect of gamma radiation on corm weight and number of cormels per corm in gladiolus varieties

Gamma ray doses	Corm weight (g)			Number of cormels per corm		
	Arka Amar	Arka Thilak	Mean	Arka Amar	Arka Thilak	Mean
0 Gy	14.67	13.33	14.00	13.67	10.67	12.17
45 Gy	14.00	11.33	12.67	21.33	12.33	16.83
50 Gy	12.00	11.33	11.67	23.33	14.67	19.00
55 Gy	10.67	11.00	10.83	24.67	9.33	17.00
60 Gy	10.00	9.33	9.67	16.33	8.67	12.50
65 Gy	9.33	8.00	8.67	13.33	6.33	9.83
Mean	11.78	10.72		18.78	10.33	
	S.E (m)	C.D (5%)		S.E (m)	C.D (5%)	
Variety	0.18	0.54		0.27	0.79	
Treatment	0.32	0.93		0.47	1.38	
Variety×Treatment	0.45	NA		0.67	1.95	

Colour mutants were obtained in Arka Amar variety at higher doses of gamma radiation (Fig. 3). Control plants had a red flower with golden yellow shade in central portion whereas, 50 Gy showed a light red colour with less yellow shade in central portion, 55 Gy showed pinkish red colour with white colour in central portion and a pinkish red colour flower with golden yellow shade in central portion observed in 60 Gy and 65 Gy treatments. Similar results were obtained by Kumari and Kumar [5], who reported that the frequency of flower colour mutations in gladiolus increased as the gamma ray dose was raised up to 55 Gy, but there was a decrease in mutation frequency at 70 Gy. Rather et al. [30] observed a rise in mutation frequencies at higher doses of gamma irradiation in Dutch Irish.

Control 50 Gy 55 Gy 60 Gy 65 Gy

Fig 3. Mutant gladiolus flowers along with control

Conclusion

In the present investigation, the optimal lethal dose for gamma rays was identified for both varieties, and attractive colour mutants were obtained in one variety through gamma irradiation. Economically important traits such as length and diameter of the floret, number of spikes per plant, spike length, field life, and number of florets per spike were improved in this study. Lower doses of gamma radiation (45 Gy, 50 Gy) promoted better growth and development, while higher doses resulted in the production of colour mutants. Arka Thilak exhibited better growth and development under gamma radiation, especially at 45 Gy, compared to Arka Amar. Higher doses of gamma rays had detrimental effects in both varieties of gladiolus.

Thus, mutation breeding offers a valuable approach for advancing gladiolus cultivation by generating genetic variations that lead to improved ornamental traits. Future studies could explore the development of traits such as winter flowering ability, floral aroma, and resistance to major pests and diseases using the optimal dose of gamma radiation. Integrating gamma ray-induced mutation breeding with modern molecular techniques, such as marker-assisted selection and genome editing, could accelerate the identification and enhancement of desirable ornamental traits, further advancing the quality and diversity of gladiolus cultivars.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

References

1. Singh AK, Kumar A. Studies of gamma irradiation on morphological characters in gladiolus. Asian J Hortic. 2013;8(1):299-303.
2. Datta SK. Breeding of ornamentals: Gladiolus. Int J Life Sci. 2020;9(2):115-133.
3. Kayalvizhi K, Kumar AR, Sankari A, Anand M. Induction of mutation in flower crops-a review. Int J Curr Microbiol Appl Sci. 2020;9(6):1320-1329.
4. Pal S, Kumar A, Chaturvedi P, Srivastava R, Tripathi S. Determination of lethal dose for gamma rays induced mutagenesis in different cultivars of dahlia. J Hill Agric. 2017;8(3):279-282.
5. Kumari K, Kumar S. Frequency and spectrum of flower colour mutations in gamma irradiated gladiolus varieties. J Pharmacogn Phytochem. 2020;9(4S):227-233.
6. Wi SG, Chung BY, Kim JH, Baek MH, Yang DH, Lee JW, et al. Ultrastructural changes of cell organelles in Arabidopsis stems after gamma irradiation. J Plant Biol. 2005;48:195-200.
7. Puchooa D. In vitro mutation breeding of Anthurium by gamma radiation. Int J Agric Biol. 2005;7(1):11-20.
8. Gopinath PP, Parsad R, Joseph B, Adarsh VS. GRAPES: General Rshiny Based Analysis Platform Empowered by Statistics; 2020. https://www.kaugrapes.com/home. version 1.0.0. DOI: 10.5281/ zenodo.4923220.
9. KAU (Kerala Agricultural University). Package of Practices Recommendations: Crops. 14th Ed. Kerala Agricultural University, Thrissur; 2011.
10. Broertjes C, Van Harten AM. Applied mutation breeding for vegetatively propagated crops. Elsevier; 2013.
11. Dwivedi AK, Banerji BK. Effects of gamma irradiation on Dahlia cv. Pinki with particular reference to induction of somatic mutation. J Ornam Hortic. 2008;11(2):148-151.
12. Koh GC, Kim MZ, Kang SY. Induction of petal colour mutants through gamma ray irradiation in rooted cuttings of rose. Hortic Sci Technol. 2010;28(5):796-801.
13. Kayalvizhi K, Kannan M, Ganga M, Sankari A. Efficiency of physical and chemical mutagens on tuberose (*Polianthes tuberosa* L.). Multilogic in Sci. 2018;7:429- 433.
14. Patil SD, Dhaduk BK. Effect of gamma radiation on vegetative and floral characters of commercial varieties of gladiolus (*Gladiolus hybrida* L.). J Ornam Hortic. 2009;12(4):232-238.
15. Patel D, Patil S, More SJ, Dohiya TP. Comparative effect of physical and chemical mutagens in inducing variability in gladiolus variety 'Psittacinus Hybrid'. Int J Curr Microbiol Appl Sci. 2018;7(1):645-652.
16. Pawadashetti DV, Kumari RV, Shanthala J, Thimmarayappa M. Effect of gamma irradiation on vegetative and floral traits in Gladiolus (*Gladiolus hybrida* L.). Mysore J Agric Sci. 2022;56(4):148-154.
17. Cantor M, Pop I, Körösföy S. Studies concerning the effect of gamma radiation and magnetic field exposure on gladiolus. J Cent Eur Agric. 2002;3(4):277-284.

18. Srivastava P, Singh RP, Tripathi VK. Response of gamma radiation (^{60}Co) on vegetative and floral characters of gladiolus. J Ornam Hortic. 2007;10(2):135-136.
19. Singh AK, Sisodia A. Effect of gamma irradiation on morphological changes, flowering and induced mutants in gladiolus. Indian J Hortic. 2015;72(1):84-87.
20. Misra RL, Bajpai PN. Effect of mutagens on shooting, leaf number, heading, plant height and spike length in gladioli. Indian J Hortic. 1983;40(1&2):107-111.
21. Devi NS, Jamja T, Tabing R, Tagi N. Influence of gamma radiation on growth, flowers and morphological changes in gladiolus. Environ Conserv J. 2023;24(2):301-310.
22. Raghava SPS, Negi SS, Sharma TVRS, Balakrishnan KA. Gamma ray induced mutants in gladiolus. J Nucl Agric Biol. 1988;17(1):5-10.
23. Negi SS, Raghava SPS, Sharma TVRS. Induction of mutations in gladiolus by gamma rays. In: Abstract of contributed paper XV international congress of genetics, Dec. 1983, New Delhi; 1983: 12-21.
24. Patil SD. Gamma rays induced mutations in commercial varieties of gladiolus (*Gladiolus hybrida* L.). Doctoral dissertation, Navsari Agricultural University, Navsari; 2009.
25. Jyothi R, Singh KP. Effect of acute gamma irradiation on flower, bulb characters and stability of mutants in tuberose (*Polianthes tuberosa*). Indian J Agric Sci. 2017;87(7):968-74.
26. Kapadiya DB, Chawla SL, Patel AI, Ahlawat TR. Exploitation of variability through mutagenesis in Chrysanthemum (*Chrysanthemum morifolium* Ramat.) var. Maghi. Bioscan. 2014;9(4):1799-1804.
27. Sahariya K, Kaushik RA, Khan R, Sarolia D. Influence of gamma irradiation on flowering of gladiolus (*Gladiolus hybrida* L.). Int J Curr Microbiol Appl Sci. 2017;6(11):1362-1368.
28. Banerji BK, Dwivedi AK, Datta SK. Gamma irradiation studies on gladiolus. J Nucl Agric Biol. 1996;25(2):63-67.
29. Rahemi MR, Mohammadi M, Azimi MH, Amiripari M, Nori M. Genetic diversity in gladiolus by using gamma rays. J Nucl Res Appl. 2022;2(4): 32-35.
30. Rather ZA, Jhon AQ, Zargar GH. Effect of ^{60}CO gamma rays on Dutch iris-II. J Ornam Hortic. 2002;5(2):1-4.