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RESEARCH ARTICLE

Response of gamma rays on flower quality, vase life and morphological changes in gladiolus

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Abstract

The study investigated the response of gamma rays on flower quality, vase life and morphological changes in gladiolus. Five cultivars American Beauty, Dull Queen, Saffron, Candyman and Summer Sunshine were exposed to varying gamma ray doses (0, 15, 25, 35, 45 and 55 Gy) using a ^60Co source in a factorial randomized block design. The results revealed a dose-dependent response, where low to moderate doses (15–35 Gy) enhanced key parameters such as spike length, rachis length, blooming period, vase life and water uptake, whereas higher doses (≥45 Gy) induced physiological inhibition and morphological abnormalities. The 15 Gy dose produced the longest (≈73.95 cm), an extended blooming period and maximum vase life, whereas 55 Gy led to stunted spikes, reduced longevity and increased floral deformities. Varietal variation was evident, with Candyman and Saffron showing superior tolerance and responsiveness to irradiation. Several stable floral mutants were also isolated, including pink and light-pink variants of Candyman and yellowish-green and pale-yellow mutants of Summer Sunshine, confirming the mutagenic potential of gamma rays generating novel ornamental types. Taken together, the findings demonstrate that controlled gamma irradiation, particularly at 15-35 Gy, is an effective tool for inducing useful variability and enhancing the aesthetic and commercial value of gladiolus cultivars.

Keywords: floral characters; gamma irradiation; gladiolus; mutants; vase life

Introduction

Gladiolus grandiflorus L., a member of the family Iridaceae, is one of the most commercially important cut flowers cultivated worldwide for its vibrant spikes, color range and long vase life. In India and several tropical countries, gladiolus occupies a prominent position in the floriculture industry owing to its high aesthetic and economic value (1). However, the genetic improvement of gladiolus through conventional breeding has been constrained by factors such as low seed set, high heterozygosity, cross-incompatibility and its vegetative mode of propagation (2). These limitations necessitate alternative breeding approaches to induce variability and enhance desirable traits.

Mutation breeding using physical mutagens, particularly gamma radiation, has proven to be an effective tool for developing novel variants in ornamental crops within a shorter period of time compared to traditional methods. Induced mutations create wide, stable variation in a single step, especially for flower colour, form and novelty traits that molecular tools cannot easily target. They are inexpensive, do not require sophisticated regeneration systems and work perfectly with vegetatively propagated ornamentals. Unlike molecular methods, mutation-derived varieties face no genetic modified organisms (GMO) restrictions and can be commercialized immediately.

Gamma rays, being high-energy electromagnetic radiations, can induce point mutations or chromosomal rearrangements that lead to phenotypic variability without introducing foreign DNA of elite cultivars (3). In vegetatively propagated crops such as gladiolus, induced mutations are stable and easily identifiable across generations. Previous studies have demonstrated that low to moderate doses of gamma rays can positively influence vegetative growth, spike length and floret development, whereas higher doses tend to reduce sprouting, plant vigor and floral quality (1, 4).

The post-harvest attributes of gladiolus such as vase life, number of open florets and duration of floret retention are highly sensitive to irradiation dose (4). The specific physiological and morphological responses to gamma irradiation are cultivar-dependent, indicating the need for systematic evaluation under controlled conditions (2). Despite several reports on gamma-ray-induced variability in gladiolus, information on its integrated effect on flowering behavior, post-harvest longevity and morphological modification remains limited.

Therefore, the present investigation was undertaken to assess the influence of varying doses of gamma radiation on flowering traits, post-harvest life and morphological characteristics in *Gladiolus grandiflorus*. The study aims to determine the optimal irradiation dose capable of inducing beneficial variations without compromising plant vigor and floral quality. Gamma-ray–induced mutagenesis will generate greater phenotypic and genetic variability than tissue culture or molecular approaches in gladiolus. This variability will include stable and commercially desirable traits such as improved flower quality, colour and spike architecture. Therefore, gamma irradiation is expected to be the most efficient and practical method for ornamental improvement in this crop to quantify the effect of gamma irradiation on morphological, flowering and post-harvest traits in gladiolus.

Materials and Methods

Experimental site and location

The present investigation was carried out at the Floriculture Research Farm, Department of Floriculture and Landscape Architecture, Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh, India. The experimental site is situated in the tropical climate zone of central India at an altitude of approximately 298 m above mean sea level, lying at 21°14′ N latitude and 81°38′ E longitude. Soil type is red sand loamy soil, pH is 6.88 (Neutral) with 0.31% organic carbon. The region is characterized by a sub-humid tropical climate with hot summers, mild winters and an average annual rainfall of around 1200-1300 mm, predominantly received from June to September.

The experiment utilized five commercially important *Gladiolus* (*Gladiolus grandiflorus* L.) cultivars, namely: V_1 - American Beauty, V_2 - Dull Queen, V_3 - Saffron, V_4 - Candyman and V_5 - Summer Sunshine.

Source of corms

Corms were obtained from the IGKV Floriculture Research Farm. Immediately after harvesting, the corms were sterilized using 2 % copper oxychloride and then cured for four months in cold storage prior to irradiation. Irradiation was carried out on hydrated corms.

Uniform, healthy and disease-free corms of medium size (4.0 -4.5 cm diameter) were selected for the experiment. The corms were exposed to gamma radiation at doses of 0 (control), 15, 25, 35, 45 and 55 Gy using a Cobalt-60 (^60Co) gamma irradiator at the National Radiation Facility. The exposure rate and irradiation duration were standardized to achieve the desired dose levels.

The experiment was laid out in a factorial randomized block design (FRBD) with three replications. Each replication contained all treatment combinations of five cultivars and six irradiation doses, making a total of 30 treatment combinations (5 × 6). Corms were planted at a spacing of 30 × 20 cm and a depth of 8 cm in well-prepared beds. Each plot consisted of 15 plants, maintaining uniform field conditions throughout the experiment.

All standard horticultural and cultural practices recommended for gladiolus cultivation were uniformly applied to ensure optimal crop growth. This included regular irrigation, manual weeding, pest and disease control and earthing-up at appropriate stages. No growth regulators or additional treatments were applied to avoid interference with the mutagenic effects. Before planting, farmyard manure (FYM) at the rate of 5 kg/m^2 was thoroughly incorporated into the soil. For all treatments, the recommended fertilizer doses included nitrogen (150 kg/ha), phosphorus (100 kg/ha) and potassium (80 kg/ha). At the time of planting, the full doses of phosphorus and potassium were applied as basal applications. Nitrogen was applied in two split doses at the 3-leaf and 6-leaf growth stages.

Regular and systematic observations were recorded on morphological, flowering and post-harvest parameters across all treatment combinations. The key parameters included:

- Vegetative traits: plant height, number of leaves per plant, leaf length and leaf width
- Flowering traits: days to first floret opening, spike length, number of florets per spike and floret diameter
- Post-harvest attributes: vase life, floret withering rate and water uptake

Any morphological abnormalities or variations observed in irradiated plants were carefully noted, including color mutations, floret deformities, dwarfness or changes in spike architecture.

Statistical analysis

The recorded data were subjected to analysis of variance (ANOVA) appropriate for a FRBD using standard statistical procedures (5). The mean values of each parameter were computed and compared using the least significant difference (LSD) test at a 5 % level of significance ($p \leq 0.05$) to determine treatment effects.

Results and Discussion

Spike length (cm)

Gamma irradiation significantly influenced the spike length of gladiolus in both vM_1 and vM_2 generations (Table 1). In the vM_1 generation, the longest spikes (73.95 cm) were recorded at 15 Gy, which was statistically on par with 25 Gy, 35 Gy and the control. However, a sharp reduction in spike length occurred at higher doses, with 55 Gy producing the shortest spikes (53.32 cm). The vM_2 generation showed a similar pattern, with the maximum spike length (72.08 cm) again observed at 15 Gy, while the minimum (56.51 cm) occurred at 55 Gy.

A dose-dependent reduction in spike length beyond an optimum threshold has also been reported in earlier studies, where low or moderate gamma doses induced slight stimulation of vegetative and floral growth, while higher doses caused physiological inhibition due to cell and chromosomal injury (1, 6, 7). The greater average reduction observed in vM_1 compared with vM_2 agrees with previous findings of more pronounced morphological suppression in the first mutant generation, attributed to immediate

Table 1. Effect of gamma irradiation on spike length in different varieties of gladiolus

	Spike length (cm)													
	vM1 generation (2018-19)							vM2 generation (2019-20)						
Treatment Variety	**0 Gy**	**15 Gy**	**25 Gy**	**35 Gy**	**45 Gy**	**55 Gy**	**Mean**	**0 Gy**	**15 Gy**	**25 Gy**	**35 Gy**	**45 Gy**	**55 Gy**	**Mean**
American Beauty	48.00	52.26	51.40	52.03	45.62	38.67	48.00	59.44	56.44	45.00	42.86	42.75	43.25	48.29
Dull Queen	59.53	64.37	53.73	54.47	48.87	40.00	53.49	49.92	54.39	58.47	55.00	43.33	45.83	51.16
Saffron	73.67	74.43	78.80	80.37	67.63	59.00	72.32	77.67	81.33	75.44	84.86	77.58	71.78	78.11
Candy man	89.13	82.03	92.13	94.07	93.29	78.14	88.13	91.53	87.22	88.00	92.11	85.00	72.28	86.02
Summer Sunshine	94.50	101.07	94.42	81.40	59.99	50.82	80.37	72.22	81.03	58.78	72.31	50.92	49.42	64.11
Mean	72.97	74.83	74.10	72.47	63.08	53.32		70.16	72.08	65.14	69.43	59.92	56.51	
	Sem. ±	**LSD (0.05)**						**Sem. ±**	**LSD (0.05)**					
Treatment	1.13	3.19						1.05	2.99					
Variety	1.03	2.92						0.96	1.36					
Treatment x Variety	2.52	7.15						2.36	6.70					

vM1 = vegetative mutant generation 1 (2018–19), vM2 = vegetative mutant generation 2 (2019–20),Gy = gray (unit of gamma irradiation dose)
Sem. ± = standard error of mean, LSD (0.05) = least significant difference at 5 % level of significance.

cellular damage that is partly recovered in subsequent generations (8).

Varietal differences were also significant in both generations. Candyman recorded the highest mean spike length (88.13 cm in vM_1 and 86.02 cm in vM_2), followed by Summer Sunshine and Saffron, whereas American Beauty consistently produced the shortest spikes (48.00 cm and 48.28 cm, respectively). Similar varietal variations in mutagenic responses suggested that genetic constitution and inherent radio-tolerance influence the plant's recovery from radiation stress (9, 10).

The interaction between varieties and radiation doses significantly affected spike length. In the vM_1 generation, the maximum spike length (101.07 cm) was recorded in Summer Sunshine x 15 Gy, which was statistically similar to Summer Sunshine x 25 Gy and Candyman x 25 Gy or 35 Gy. The shortest spikes (38.67 cm) were obtained in American Beauty x 55 Gy. In vM_2, the maximum spike length (92.11 cm) occurred in Candyman x 35 Gy, followed closely by Candyman x 15 Gy, 25 Gy and the control, while American Beauty x 45 Gy produced the minimum (42.75 cm). The trend clearly indicates an optimum stimulatory range (15-35 Gy) beyond which deleterious effects dominate. This pattern of initial enhancement followed by decline corresponds well with findings of that reported similar dose-response curves in gamma-irradiated gladiolus (1, 6, 7).

The reduction in spike length at higher gamma doses is likely due to physiological and cytological disruptions caused by ionizing radiation. Gamma rays produce free radicals that interact with biomolecules, impairing DNA integrity, enzyme systems and hormonal regulation of cell division and elongation (8, 11, 12). These effects manifest as decreased mitotic activity, reduced photosynthetic efficiency and stunted spike growth. The partial restoration in vM_2 indicates selection for less-affected genotypes and potential repair of sub-lethal DNA lesions during vegetative propagation (1). Results confirm that moderate gamma doses (15-35 Gy) can enhance spike length and morphological quality in certain cultivars, while excessive doses (≥ 45 Gy) result in severe growth retardation. The varietal specificity of these responses highlights the importance of genotype-dependent optimization in mutation breeding of gladiolus.

Rachis length

The influence of gamma irradiation on rachis length was found to be highly significant in both the vM_1 and vM_2 generations (Table 2). In the vM_1 generation, plants treated with 35 Gy exhibited the longest rachis (40.68 cm), which was statistically comparable with 25 Gy. In the vM_2 generation, the maximum rachis length (44.36 cm) was recorded at 15 Gy, surpassing the untreated control (41.46 cm). Further increases in irradiation dose produced a marked reduction in rachis length in both generations, with the shortest rachis (29.00 cm in vM_1 and 33.51 cm in vM_2) recorded at 55 Gy.

This pattern of initial stimulation followed by inhibition aligns with the hormetic response commonly reported in mutation breeding, where low to moderate gamma doses enhance growth while higher doses induce physiological stress (1, 6, 7). Reduction in rachis length at high doses may result from radiation-induced disturbances in cell division and hormonal regulation, especially auxin and gibberellin metabolism (10, 11).

Varietal differences in rachis length were also significant. In the vM_1 generation, Candyman produced the longest rachis (44.42 cm), statistically at par with Saffron, while Dull Queen recorded the minimum (22.26 cm). In vM_2, Saffron showed the greatest rachis length (51.96 cm), closely followed by Candyman, whereas American Beauty had the shortest (28.46 cm). These results reflect inherent genotypic variability in radiation tolerance and growth potential, as also reported by in gladiolus (8, 9).

The interaction between varieties and gamma doses was highly significant in both generations. In vM_1, Candyman x 35 Gy exhibited the maximum rachis length (55.92 cm), which was statistically comparable with Candyman x 45 Gy and Summer Sunshine x 25 Gy. The shortest rachis (17.67 cm) occurred in Dull Queen x 55 Gy. In vM_2, the maximum rachis length (55.61 cm) was again noted in Candyman x 35 Gy, followed by Candyman x 15 Gy, 25 Gy, 45 Gy and Saffron x 15-35 Gy, while the minimum (21.83 cm) was obtained in American Beauty x 55 Gy. This confirms that moderate irradiation (15-35 Gy) is beneficial in enhancing rachis elongation in tolerant varieties, whereas excessive doses cause severe retardation due to cumulative cellular damage. Similar interactions between variety and radiation dose have been observed in *G. psittacinus* and *G. grandiflorus* (1, 7).

The overall decline in rachis length with higher irradiation levels may be attributed to altered auxin metabolism or inactivation

Table 2. Effect of gamma irradiation on rachis length in different varieties of gladiolus

Treatment Variety	Rachis length (cm)													
	vM1 generation (2018-19)							vM2 generation (2019-20)						
	0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean	0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean
American Beauty	29.68	22.15	26.85	32.78	23.33	21.74	26.09	33.28	34.65	27.67	26.43	26.90	21.83	28.46
Dull Queen	25.58	23.32	24.15	22.42	20.42	17.67	22.26	30.25	30.00	30.47	33.83	32.25	25.83	30.44
Saffron	34.60	45.03	44.90	46.23	42.00	38.80	41.93	49.17	54.56	50.94	55.56	52.81	48.72	51.96
Candyman	41.12	46.75	38.18	55.92	48.08	36.47	44.42	49.56	52.11	50.78	55.61	50.72	40.92	49.95
Summer Sunshine	35.22	33.42	48.33	46.03	25.75	30.33	36.51	45.06	50.47	45.08	39.22	35.83	30.22	40.98
Mean	33.24	34.13	36.48	40.68	31.92	29.00		41.46	44.36	40.99	42.13	39.70	33.51	
	Sem. ±	**LSD (0.05)**						**Sem. ±**	**LSD (0.05)**					
Treatment	1.38	3.91						0.83	2.37					
Variety	1.26	3.57						0.76	2.16					
Treatment x Variety	3.09	8.74						1.87	5.30					

vM1 = vegetative mutant generation 1 (2018–19), vM2 = vegetative mutant generation 2 (2019–20),Gy = gray (unit of gamma irradiation dose) Sem. ± = standard error of mean, LSD (0.05) = least significant difference at 5 % level of significance.

of growth hormones, leading to suppression of internodal elongation (11). Ionizing radiation generates free radicals that damage cell membranes and nucleic acids, thereby impairing physiological processes responsible for normal elongation growth. The comparatively smaller reduction in vM_2 suggests a diminishing residual effect of gamma rays and selection of physiologically resilient plants (1). The present findings emphasize that while moderate gamma irradiation can enhance rachis development through stimulatory effects on growth regulators, high doses (> 45 Gy) adversely affect cell division and elongation.

Blooming period (days)

The blooming period was significantly influenced by gamma irradiation treatments and varietal differences in gladiolus during both generations of observation (Table 3). During the first generation (vM_1), treatment with 25 Gy resulted in the maximum duration of flowering (14.05 days), which was statistically at par with the 15 Gy treatment and significantly higher than other doses. In contrast, the shortest blooming period (9.00 days) was observed at the highest dose (55 Gy). In the vM_2 generation, the 15 Gy dose showed the maximum duration of flowering (14.27 days), which was significantly higher than 25 and 35 Gy treatments, including the control, while 45 Gy produced the minimum blooming period (12.22 days).

Varietal differences were also highly significant. In the vM_1 generation, cultivar Candyman (13.24 days) exhibited the longest duration of flowering, statistically at par with Saffron and Dull Queen, while Summer Sunshine recorded the shortest period (10.48 days). During the vM_2 generation, Saffron had the longest blooming period (15.23 days), followed by Candyman, American Beauty and Dull Queen, whereas Summer Sunshine again showed the minimum duration (11.75 days).

Interaction effects between gamma irradiation and variety were also significant in both generations. The combination of 25 Gy with Candyman resulted in the maximum flowering duration (15.73 days) during vM_1, statistically at par with 35 Gy in Candyman and 15-35 Gy in Saffron. The shortest duration (7.53 days) was recorded for 55 Gy with Summer Sunshine. During vM_2, 35 Gy in Saffron produced the longest flowering duration (17.18 days), comparable with 15 Gy and 45 Gy in Saffron and 35 Gy in Candyman, whereas 55 Gy with Aldebaran recorded the minimum (8.89 days).

The adverse effects of higher gamma doses on plant growth may contribute to reduced blooming and postharvest longevity due to physiological and biochemical alterations. At higher radiation levels, reduced auxin activity, disturbance of physiological processes and DNA damage can inhibit cell division and delay flower development (13, 14). Conversely, lower doses appear to stimulate physiological responses and hormonal balance, enhancing flowering duration and spike longevity (12, 18). Similar findings were observed in *G. grandiflorus* cv. White Friendship, where 30 Gy

Table 3. Effect of gamma irradiation on blooming period in different varieties of gladiolus

Treatment Variety	Blooming period (days)													
	vM1 generation (2018-19)							vM2 generation (2019-20)						
	0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean	0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean
American Beauty	16.13	13.93	13.73	12.20	9.40	7.80	12.20	16.47	15.74	13.17	10.01	12.06	13.18	13.44
Dull Queen	15.47	14.00	13.80	12.87	14.13	10.03	13.38	13.11	11.46	14.73	12.58	9.39	11.96	12.20
Saffron	11.53	15.53	14.47	12.20	12.47	9.67	12.64	14.48	16.16	14.28	17.18	15.87	13.43	15.23
Candyman	14.00	12.53	14.93	15.73	11.67	11.60	13.41	13.31	14.09	13.72	16.50	13.55	13.72	14.15
Summer Sunshine	13.40	11.80	12.00	9.43	8.70	7.53	10.48	11.51	13.90	12.96	13.02	10.22	8.89	11.75
Mean	14.11	13.56	13.79	12.49	11.27	9.33		13.77	14.27	13.77	13.86	12.22	12.24	
	Sem. ±	**LSD (0.05)**						**Sem. ±**	**LSD (0.05)**					
Treatment	0.370	1.04						0.34	0.96					
Variety	0.338	0.95						0.31	0.88					
Treatment x Variety	0.828	2.34						0.76	2.15					

vM1 = vegetative mutant generation 1 (2018–19), vM2 = vegetative mutant generation 2 (2019–20),Gy = gray (unit of gamma irradiation dose) Sem. ± = standard error of mean, LSD (0.05) = least significant difference at 5 % level of significance.

increased spike longevity while doses beyond 50 Gy reduced it (15). Other studies in *G. psittacinus* and *G. hybridus* also reported that moderate gamma irradiation (1–3 kR) enhanced blooming period and vase life, while higher doses caused inhibition (16, 17). Overall, these results suggest that moderate doses (15-35 Gy) promote an optimal physiological response by maintaining hormonal balance, whereas excessive irradiation (≥45 Gy) exerts detrimental effects on flowering duration due to stress-induced metabolic disruptions.

Vase life (days)

Data on vase life revealed that gamma irradiation significantly influenced vase longevity in both vM_1 and vM_2 generations (Table 4). In the vM_1 generation, the maximum vase life (12.50 days) was observed with 15 Gy, which was statistically comparable to 25 Gy and the untreated control, whereas the shortest vase life occurred at the highest dose of 55 Gy. In vM_2, the highest vase life (9.80 days) was similarly recorded at 15 Gy, which was significantly greater than other treatments. These findings demonstrate a dose-dependent effect, in which low-to-moderate gamma doses enhance post-harvest longevity, while higher doses reduce it (12, 13).

Varietal differences were also significant. During vM_1, Candyman exhibited the longest vase life (12.51 days), statistically at par with Saffron, Summer Sunshine and Dull Queen. In vM_2, Saffron showed the maximum vase life (12.17 days), followed by Candyman, American Beauty, Summer Sunshine and Dull Queen, while the shortest vase life was recorded in Dull Queen.

The interaction between gamma dose and variety significantly affected vase life in both generations. In vM_1, the combination of 25 Gy x Candyman yielded the maximum vase life (14.17 days), which was statistically comparable to 15 Gy, 35 Gy and control in Candyman as well as 15, 25, 45 Gy and control in Saffron. Conversely, the shortest vase life (8.00 days) was observed in 55 Gy x Dull Queen. In vM_2, 35 Gy x Saffron resulted in the highest vase life (13.67 days), comparable to 15, 25, 45 Gy x Saffron and 35 Gy x Candyman, whereas 55 Gy x Dull Queen recorded the minimum (4.67 days).

The observed increase in vase life at lower gamma doses may be attributed to stimulation of physiological processes, including enhanced hormone activity (kinetin and gibberellins), improved sugar metabolism and differentiation of conductive tissues in the floral spike (12-14). High doses, however, cause cellular and DNA damage, leading to reduced flower longevity and accelerated senescence (15,16). Similar patterns have been reported in tuberose, chrysanthemum and gladiolus, where low-dose irradiation extended post-harvest life, whereas higher doses shortened it (17, 18).

Water uptake of cut gladiolus

The gamma irradiation treatments and varietal differences significantly influenced water uptake by gladiolus spikes in vase solutions during both generations (Table 5). In the vM_1 generation, the maximum water uptake (63.33 mL) was observed with 35 Gy, which was statistically comparable to 15 Gy, whereas the minimum water uptake (50.60 mL) was recorded at 45 Gy. In vM_2, the highest water uptake (67.00 mL) occurred at 15 Gy, statistically comparable to the control and 35 Gy treatments, while the lowest uptake (50.00 mL) was noted at 55 Gy. These results suggest that moderate gamma doses enhance water absorption, whereas higher doses impair physiological mechanisms responsible for water transport (12, 13).

Varietal differences were significant in both generations. Summer Sunshine exhibited the highest water uptake (89.78 mL in vM_1 and 92.94 mL in vM_2), significantly higher than other varieties, whereas American Beauty (vM_1, 21.94 mL) and Dull Queen (vM_2, 39.33 mL) recorded the lowest water absorption. This reflects inherent varietal differences in spike physiology and xylem efficiency, consistent with earlier reports in gladiolus and other cut flowers (1, 17).

The interaction between gamma dose and variety was also significant. In vM_1, the combination 15 Gy x Summer Sunshine resulted in the maximum water uptake (93.67 mL), while 55 Gy x American Beauty recorded the minimum (16.33 mL). During vM_2, 35 Gy x Summer Sunshine produced the highest uptake, statistically comparable to 15, 25 Gy and control interactions with Summer Sunshine, whereas 55 Gy × Dull Queen showed the lowest water absorption (27.33 mL). These findings suggest that both genotype and moderate gamma irradiation synergistically improve water uptake, which is critical for maintaining turgor and prolonging vase life (13, 18).

Enhanced water uptake at lower gamma doses may be attributed to improved xylem conductivity, increased sugar levels and higher TSS (total soluble solids) in the floral tissues, which facilitate osmotic water absorption and delay senescence. Similar observations were reported in cut roses, where low-dose irradiation

Table 4. Effect of gamma irradiation on vase life in different varieties of gladiolus

Treatment Variety	Vase life (days) vM1 generation (2018-19) 0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean	vM2 generation (2019-20) 0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean
American Beauty	11.22	12.47	11.72	8.72	9.83	8.57	10.42	10.00	11.00	9.00	6.67	6.00	6.33	8.17
Dull Queen	11.11	12.28	11.11	12.67	10.83	8.00	11.00	6.67	5.67	6.67	5.67	7.00	4.67	6.06
Saffron	12.33	12.78	13.17	11.94	12.39	10.50	12.19	11.00	12.33	12.00	13.67	12.00	12.00	12.17
Candyman	13.83	13.00	14.17	12.72	11.28	10.06	12.51	10.00	11.00	9.33	12.00	9.67	9.33	10.22
Summer Sunshine	12.50	12.00	11.06	11.39	10.11	9.28	11.06	8.67	9.00	9.00	7.33	7.00	6.00	7.83
Mean	12.20	12.50	12.24	11.49	10.89	9.28		9.27	9.80	9.20	9.07	8.33	7.67	
	Sem. ±	**LSD (0.05)**						**Sem. ±**	**LSD (0.05)**					
Treatment	0.25	0.71						0.33	0.93					
Variety	0.23	0.65						0.30	0.85					
Treatment x Variety	0.56	1.60						0.73	2.09					

vM1 = vegetative mutant generation 1 (2018–19), vM2 = vegetative mutant generation 2 (2019-20),Gy = gray (unit of gamma irradiation dose) Sem. ± = standard error of mean, LSD (0.05) = least significant difference at 5 % level of significance.

Table 5. Effect of gamma irradiation on water uptake in different varieties of gladiolus

Treatment Variety	Water uptake (ml) vM1 generation (2018-19) 0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean	vM2 generation (2019-20) 0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean
American Beauty	21.00	21.67	31.00	21.67	20.00	16.33	21.94	47.33	46.67	51.33	37.00	33.67	30.00	41.00
Dull Queen	35.67	39.00	32.67	38.33	24.00	22.00	31.94	48.67	53.67	38.33	33.33	34.67	27.33	39.33
Saffron	79.00	83.00	75.33	91.00	72.00	85.00	80.89	67.67	80.33	72.00	77.00	81.00	73.00	75.17
Candyman	71.00	71.33	57.00	72.33	50.33	61.00	63.83	58.33	58.67	55.33	73.33	76.00	40.33	60.33
Summer Sun-shine	91.33	93.67	90.00	93.33	86.67	83.67	89.78	95.33	95.67	94.33	100.00	84.00	88.33	92.94
Mean	59.60	61.73	57.20	63.33	50.60	53.60		63.47	67.00	62.27	64.13	61.87	51.80	
	Sem. ±	**LSD (0.05)**						**Sem. ±**	**LSD (0.05)**					
Treatment	1.220	3.45						1.44	4.09					
Variety	1.114	3.15						1.32	3.74					
Treatment x Variety	2.728	7.72						3.23	9.16					

vM1 = vegetative mutant generation 1 (2018–19), vM2 = vegetative mutant generation 2 (2019–20),Gy = gray (unit of gamma irradiation dose) Sem. ± = standard error of mean, LSD (0.05) = least significant difference at 5 % level of significance.

combined with sucrose treatment improved water absorption and prolonged vase life (18, 19). Conversely, high doses of gamma radiation reduce water uptake due to cellular damage and impaired vascular function, leading to early senescence and reduced post-harvest longevity.

Abnormalities in floral morphology

The effect of gamma irradiation on floral abnormalities in gladiolus was significant in both vM_1 and vM_2 generations (Table 6; Fig. 1, 2). The frequency of abnormal spikes increased with higher doses of gamma radiation. In the vM_1 generation, the maximum percentage of abnormal spikes (12.33 %) was observed at 55 Gy, whereas in vM_2, the highest frequency (10.00 %) also corresponded to 55 Gy. Lower doses induced fewer abnormalities, indicating a dose-dependent effect of gamma rays on floral development.

Varietal differences were also significant for abnormal spikes. Summer Sunshine exhibited the highest frequency of abnormalities (8.61 % in vM_1 and 8.33 % in vM_2), whereas American Beauty recorded the lowest (6.39 % in vM_1 and 4.72 % in vM_2). However, the interaction effect between gamma dose and variety was generally non-significant, suggesting that while both factors individually influenced abnormalities, their combined effect was not statistically additive. Notably, in the vM_1 generation, the highest incidence of abnormal spikes occurred in Summer Sunshine and Dull Queen at 55 Gy (15.00 % each). In the vM_2 generation, the effects of varieties and their interaction with gamma rays on abnormal spikes were non -significant. Gamma irradiation induced distinct flower color mutations in several gladiolus varieties, which were successfully isolated and characterized:

Candyman mutants

- CM_1: Isolated at 45 Gy, this mutant exhibited pink florets, distinct from the original *Candyman* variety, which has purplish pink tepals according to the Royal Horticultural Society (RHS) colour chart. The mutant's tepals corresponded to red purple group 63C, representing a stable, pure mutant (Table 7).
- CM_2: Identified at 25 Gy, this was a chimeric mutant, exhibiting light pink tepals in only one floret. The original *Candyman* has dark pink tepals, whereas the mutant matched light pink on the RHS chart (Fig. 3, 4).

Summer sunshine mutants

- SS_1: Isolated at 55 Gy from vM_1, this mutant displayed yellowish green tepals, differing from the original yellow tepals of *Summer Sunshine*. Tepal color corresponded to Red Group 39D on the RHS chart.
- SS_2: Also isolated at 55 Gy, this pure mutant exhibited creamish-yellow tepals, distinct from the original variety, corresponding to Purple Violet Group 86C on the RHS chart. Quantitative traits of

Table 6. Effect of gamma irradiation on Abnormalities in floral colour, size, shape and number of floral organs in different varieties of gladiolus

Treatment Variety	Abnormalities in floral colour, size, shape and number of floral organs vM1 generation (2018-19) 0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean	vM2 generation (2019-20) 0 Gy	15 Gy	25 Gy	35 Gy	45 Gy	55 Gy	Mean
American Beauty	0.00	5.00	5.00	6.67	8.33	6.67	5.28	0.00	5.00	5.00	5.00	10.00	5.00	5.00
Dull Queen	0.00	6.67	6.67	8.33	8.33	13.33	7.22	0.00	6.67	6.67	8.33	10.00	11.67	7.22
Saffron	0.00	6.67	8.33	6.67	6.67	11.67	6.67	0.00	6.67	8.33	6.67	6.67	10.00	6.39
Candyman	0.00	6.67	6.67	10.00	8.33	8.33	6.67	0.00	10.00	6.67	8.33	6.67	8.33	6.67
Summer Sunshine	0.00	6.67	6.67	10.00	10.00	11.67	7.50	0.00	8.33	6.67	8.33	10.00	11.67	7.50
Mean	0.00	6.33	6.67	8.33	8.33	10.33		0.00	7.33	6.67	7.33	8.67	9.33	
	Sem. ±	**LSD (0.05)**						**Sem. ±**	**LSD (0.05)**					
Treatment	0.85	2.41						NS	NS					
Variety	NS	NS						0.72	2.05					
Treatment x Variety	NS	NS						NS	NS					

vM1 = vegetative mutant generation 1 (2018–19), vM2 = vegetative mutant generation 2 (2019–20),Gy = gray (unit of gamma irradiation dose) Sem. ± = standard error of mean, LSD (0.05) = least significant difference at 5 % level of significance.

Fig. 1. Spike abnormalities developed after gamma irradiation in different gladiolus varieties.

Fig. 2. Flower spike abnormalities developed after gamma irradiation in different gladiolus varieties.

Table 7. Performance of mutants isolated after gamma irradiation in gladiolus variety Candyman

S. No.	Characters	Candyman (parent)	CM1	CM2
1	Floret colour	Red purple group (vivid purplish pink) A 66	Red group (deep purplish pink) D N 66	Red group (light purplish pink)
2	Stability		Stable	Stable
3	Gamma ray dose		45 Gy	25 Gy
4	Plant height (cm)	76.44	73.00	73.00
5	Number of leaves	10.56	8.00	8.00
6	Leaf length (cm)	52.78	46.77	50.00
7	Leaf width (cm)	3.40	3.18	2.51
8	Number of tillers per plant	1.50	1.00	1.00
9	Days to spike initiation	81.50	78.22	80.00
10	Diameter of first floret	91.00	87.53	81.67
11	Number of florets	15.11	13.00	13.00
12	Spike length (cm)	91.53	89.13	93.29
13	Rachis length (cm)	49.56	41.12	48.08
14	Blooming period	13.31	12.00	13.00
15	Number of spikes per plant	1.64	1.00	1.00
16	Number of corms per plant	1.33	1.00	1.00
17	Weight of corm (g)	65.89	58.94	55.67
18	Diameter of corm (cm)	5.82	5.58	4.41
19	Number Cormels per plant	42.67	39.33	23.87
20	Weight of cormels (g)	65.14	56.22	34.61

CM1= Candymen mutant 1, CM1 = Candymen mutant 2.

Fig. 3. Effect of gamma irradiation on gladiolus cv. Candyman.

Fig. 4. Effect of gamma irradiation on gladiolus cv. Candyman.

this mutant are detailed in Table 8 and Fig. 5.

These results indicate that gamma irradiation induces both qualitative and quantitative variations in floral traits, particularly tepals color, flower size and organ number. The isolation of stable mutants, such as CM_1, CM_2, SS_1 and SS_2, demonstrates the potential gamma irradiation for generating novel ornamental varieties with distinct floral characteristics. Similar observations have been reported in gladiolus and other ornamental species, where mutagenic treatments produced variations in flower color, morphology and organ number, which can be utilized for breeding improved cultivars (1, 18).

Table 8. Performance of mutants isolated after gamma irradiation in gladiolus variety Summer Sunshine

S. No.	Characters	Summer Sunshine (parent)	SS1	SS2
1	Floret colour	Yellow group (brilliant greenish yellow) A 4	Greenish yellow group (brilliant greenish yellow) A 1	Yellow group (pale yellow green) D 4
2	Stability		Stable	Stable
3	Gamma ray dose		55 Gy	55 Gy
4	Plant height (cm)	90.89	75.00	54.27
5	Number of leaves	10.56	9.00	10.13
6	Leaf length (cm)	64.67	57.00	72.53
7	Leaf width (cm)	3.73	3.06	2.50
8	Number of tillers per plant	2.17	1.00	2.07
9	Days to spike initiation	82.07	76.00	15.47
10	Diameter of first floret	84.96	80.42	69.66
11	Number of florets	8.81	7.00	9.44
12	Spike length (cm)	72.22	70.50	59.99
13	Rachis length (cm)	45.06	31.00	25.75
14	Blooming period	11.51	10.00	8.70
15	Number of spikes per plant	1.82	1.00	1.33
16	Number of corms per plant	1.56	1.00	2.00
17	Weight of corm (g)	83.64	80.56	40.11
18	Diameter of corm (cm)	5.59	5.52	45.55
19	Number Cormels per plant	36.33	33.00	25.89
20	Weight of cormels (g)	78.69	72.16	4.79

SS_1 = Summer Sunshine mutant 1, SS_2 = Summer Sunshine mutant 2.

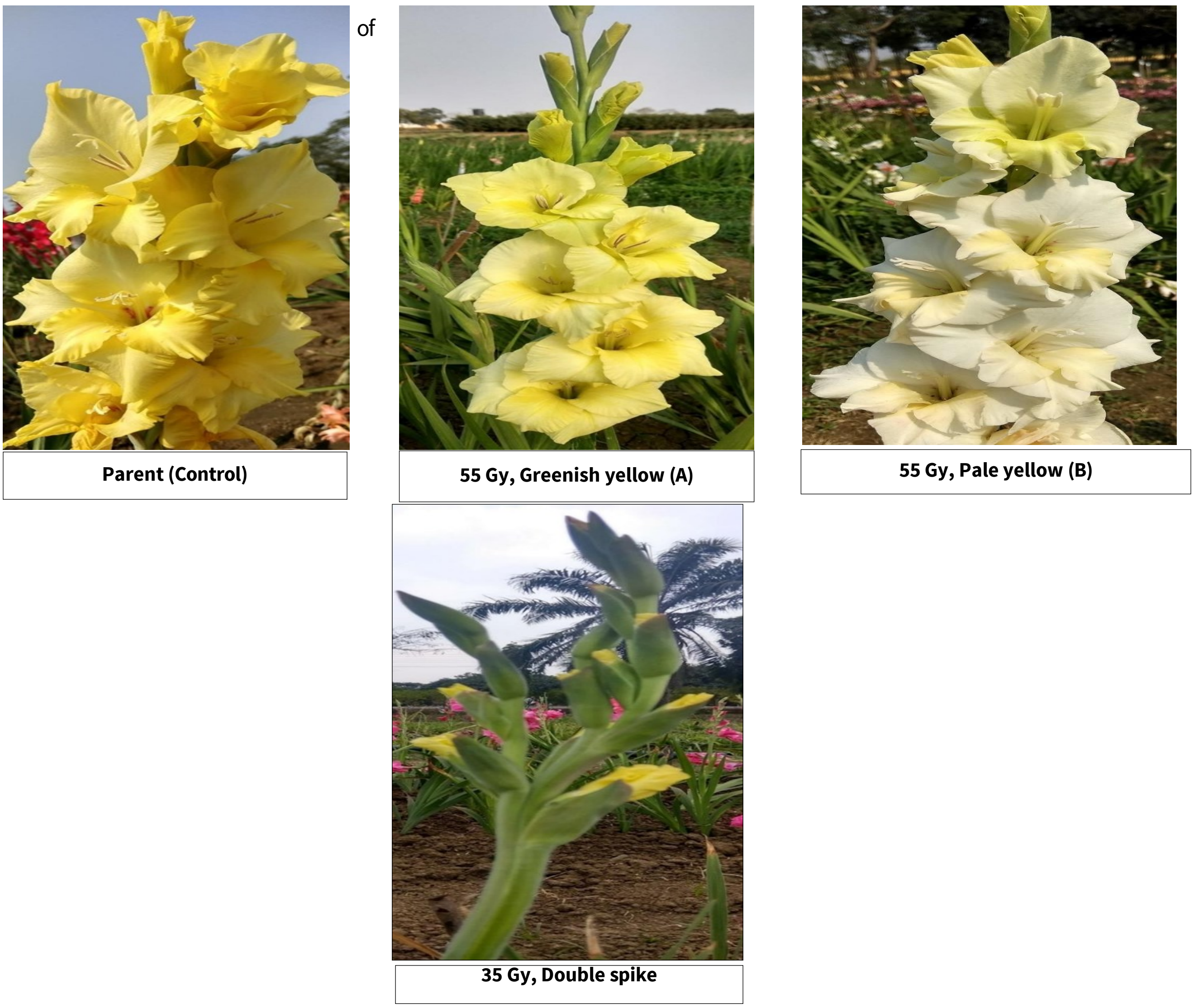

Fig. 5: Effect of gamma irradiation on gladiolus cv. Summer Sunshine.

Conclusion

The present investigation demonstrated that gamma irradiation significantly influences the morphological, flowering and postharvest traits of *G. grandiflorus*. The effects were dose-dependent, with lower doses (15-35 Gy) showing stimulatory responses and higher doses (≥45 Gy) causing inhibitory effects. Among all treatments, 15 Gy proved most effective, enhancing spike length, rachis development, blooming duration, vase life and water uptake, thereby improving overall floral quality. In contrast, higher doses resulted in growth retardation, reduced vigor and increased floral abnormalities due to radiation-induced physiological disruptions. Varietal differences were notable, with Candyman and Saffron showing better adaptability under moderate irradiation. The emergence of stable color mutants, especially in Candyman and Summer Sunshine, highlights the potential of mutation breeding for developing novel gladiolus cultivars. Overall, gamma irradiation offers a promising approach for creating genetic variability and accelerating the development of high-value ornamental varieties.

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Authors' contributions

ES carried out the core literature review, collected primary data and prepared the initial draft of the manuscript. KD assisted in data compilation, contributed to the literature review and supported manuscript drafting and organization. BPKN provided academic supervision, guided the experimental methodology and contributed to data interpretation and manuscript refinement. AK supported data analysis, validated the research findings and assisted in manuscript revision. APD contributed to the study design, provided critical technical insights and reviewed the manuscript for intellectual and scientific accuracy. AB assisted in standardizing the methodology and contributed to reviewing and editing the manuscript. SD supported data interpretation and provided expert suggestions to enhance the clarity of the manuscript. PM offered critical comments on study design and contributed to manuscript revision. BL contributed to statistical analysis, data validation and manuscript improvements. LB assisted in interpreting the results and contributed to the final editing and approval of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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