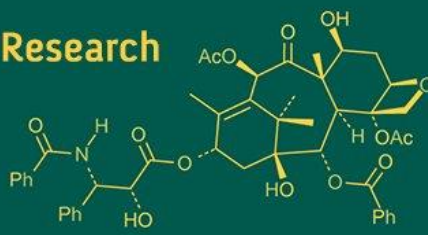


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(8): 1871-1876
www.biochemjournal.com
Received: 02-06-2026
Accepted: 05-07-2026

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Mutation induction through Gamma irradiation and evaluation of *Amaranthus* (*A. tricolor* and *A. viridis*) mutant lines for yield attributes

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i8Su.9687>

Abstract

The present investigation entitled “Induction of mutation through physical mutagen and characterization of mutant lines in *Amaranthus* (*A. tricolor* and *A. viridis*)” was conducted during Rabi and Summer seasons of 2021-22, 2022-23 and 2023-24 at the Horticultural Research and Instructional Farm, Department of Horticulture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. Fourteen amaranthus lines were evaluated in a Randomized Block Design with three replications for germination, establishment, vegetative growth, flowering, inflorescence characteristics, dry matter accumulation and yield attributes. Considerable variability was observed among the mutant lines for all major traits. MT₁₂ recorded the highest foliage yield (1.69 kg plot⁻¹) and biological yield (16.93 t ha⁻¹). MT₆ was identified as the earliest flowering line, whereas MT₉ exhibited delayed flowering. MT₁₀ recorded the maximum plant height at maturity (137.58 cm), longest spikelet length (33.10 cm), seed yield per plant (18.91 g) and seed yield (2.03 t ha⁻¹), demonstrating its superior performance for seed production. MT₅ recorded the highest dry matter accumulation (31.63 g), while MT₃ exhibited the highest test weight (1.22 g). Overall, the study revealed substantial genetic variability among the amaranthus lines, with different lines showing superiority for specific traits. MT₁₀ emerged as the most promising line for seed production, MT₁₂ for foliage and biomass production.

Keywords: Amaranths, mutation, gamma radiation and physical mutagen

Introduction

Amaranthus (*Amaranthus* spp. L.) an herbaceous plant mostly annual and some species are perennial in nature. The genus *Amaranthus*, native to different parts of North, Central and South America, includes wild (common weed), grain and ornamental species, mostly with monoecious inflorescences bearing both male and female flowers (Trucco and Tranel, 2011)^[21]. Nearly 60 species found in genus amaranthus out of which four cultivated for grain (*A. hypochondriacus* L., *A. cruentus* L., *A. caudatus* L. and *A. edulis*pegazzini L.) (Singh, H. and Thomas, T. A., 1978)^[19]. Some species (*A. tricolor*, *A. dubius* and *A. blitum*) are mostly cultivated as leafy vegetable (Yadav *et al.*, 2014)^[25].

India is well-known for its vegetable growing areas. India is second largest producer of vegetable next to China. India produced 217797.00 thousand MT of vegetable from 11791.00 thousand ha area according to the Ministry of Agriculture and Farmers Welfare (Anon. 2025). In Chhattisgarh, 498.953 thousand ha area is under vegetable cultivation and production is 6892.501 thousand MT according to the state Department of Horticulture and Farm Forestry. Chhattisgarh has expanded its leafy vegetable cultivation to 8025 ha, generating a total production of 76509 MT according to official state horticulture statistics (Anon. 2023). The major leafy vegetable producing states are Orissa, Uttar Pradesh, Bihar, West Bengal, Karnataka, Kerala, Maharashtra and Chhattisgarh. In Chhattisgarh, it is cultivated in Raigarh, Bilaspur, Raipur and Durg, Rajnandgaon, Balod, Korba, Narayanpur, Baster, Kanker, Kawardha and Dhamtari districts. *Amaranthus* plants are broad-leaved. Leaves are oblong to elliptical with light to dark green and/or red in colour. The plants height varies from 0.3 to 2 m. The inflorescence is very prominent, colourful, terminal and axial and contains one male flower per glomerule. Flowers are unisexual, small with stamens at the apex of the glomerules and pistils.

Pollination is predominantly autogamous in amaranth (Chandravanshi *et al.*, 2016) [7]. *Amaranthus* follows the C4 cycle photosynthetic pathway. It has a high rate of photosynthesis and excellent water use efficiency at high temperatures and high radiation intensity. The small seeds of the leafy amaranths are usually very shiny and dark brown to black in colour.

As *Amaranthus spp.* is underutilized leafy vegetable has promising economic and nutritional value. The 100 g of amaranthus leaves contains, nearly protein (upto 4%), minerals (Fe (7.6 mg), Mn (3.4 mg) and Zn (2.9 mg)) and antioxidants like beta-carotenoid (10.43 mg) and ascorbic acid (about 28 mg) (Varalakshmi, 2011) [22]. Amaranth leaves, sprouts and seeds also contain flavonoids (*e.g.*, rutin, isoquercitrin, nicotiflorin, vitexin, isovitexin, morin) and phenolic acids (gallic acid, vanillic acid, syringic and ferulic acids). Flavonoids and phenolic acids act as powerful antioxidants that neutralize harmful free radicals and reduce oxidative stress with key benefits like anti-inflammatory effects and disease prevention (Chlopicka *et al.*, 2012) [8]. Amaranthus seed is superior in protein content (13-19%; sometimes up to ~21-22%, depending on species and growing conditions) to the conventional cereals like wheat (12-14%), rice (7-10%), maize (9-10%) and other widely consumed cereals and millets. It also contains high amino acid, lysine (~5-8 g per 100 g protein) which seems to be lacking in cereals. It is, therefore, a nutritional complement to conventional cereals.

Breeding mechanism in amaranths is highly variable due to variability and versatility of inflorescence ratio and distribution of male and female flower in inflorescence and variability of matting system ranging from obligate out-crossing, relatively greater outcrossing to relatively greater self-pollination. Several useful breeding traits have been identified in amaranths like, increased seed protein, resistance to seed shattering, increased seed size, reduced plant height and high yield, improved pest resistance etc. The work on genetic improvement has been done so far mostly applying conventional selection method from cultivars, landraces, and hybrids with genetic variability. Several new improved varieties have been developed. Beside conventional breeding methods, application of non-conventional breeding strategies like induced mutation breeding techniques, genetic engineering and biotechnological approaches are gaining importance.

In amaranth, mutation breeding has been effectively used for cultivar improvement and generating polygenic variability (Joshi *et al.*, 2018) [12]. More often, these genetic changes are induced by mutagenic agents such as x-rays, gamma rays, beta rays, neutrons, chemicals, high temperature and low pH (Nwankwo *et al.*, 2018) [17]. Mutation could help to create amaranth variability; it may have potential to produce high biomass, improved pest and disease resistance. Naturally, an enlarged mutation spectrum as well as increased mutation frequency would enhance the chances of isolating beneficial mutants (Madhusudan, K., 1990) [15]. This can be achieved by identifying efficient mutagens and by understanding the various parameters that influence the pre and post mutational sieves. Among the different mutagens, gamma radiation is one of the most widely used physical mutagens because of its high penetration power, ease of application, and effectiveness in inducing heritable changes. Gamma rays can produce mutations at the DNA level, leading to variation in

morphological, physiological, and yield-related traits. In amaranthus, such variation may be useful for improving leaf yield, biomass, branching pattern, days to maturity, seed traits, and tolerance to environmental stress. A great majority of mutant varieties (64%) were developed by the use of gamma rays (Ahloowalia *et al.*, 2004) [1].

Therefore, it is essential to determine the optimum irradiation dose for creating useful mutations while maintaining acceptable plant survival and performance. Studies on amaranthus and related crops indicate that gamma radiation can significantly influence plant height, leaf number, and other agro-morphological traits, which are directly associated with growth and yield.

Materials and Methods

Present study entitled "Induction of mutation through physical mutagen and characterization of mutant lines in *Amaranthus* (*A. tricolor* and *A. viridis*)" The experiment was conducted on amaranthus (*Amaranthus spp.*) using two genotypes, C.G. Laalbhaji-1 and C.G. Chaulai-1, at the Horticultural Instructional-cum-Research Farm, Department of Horticulture, IGKV, Raipur (Chhattisgarh). In 2021-22, seeds of both genotypes were exposed to γ -radiation doses of 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100 and 1200 Gy, with untreated seeds as control. The irradiated seeds were obtained through the irradiation facility of the Mutation Breeding Unit, Nuclear Agriculture and Biotechnology Division, BARC, Trombay, Mumbai. The treated seeds were directly sown under open-field conditions. The experiment was laid out in Randomized Block Design (RBD) with three replications. In 2022-23, 14 selected mutant lines (M_3/M_4 generation) along with controls were evaluated in RBD with three replications. The net plot size was 0.70 × 0.90 m, with 15 cm row spacing and 5 cm plant spacing. A recommended dose of fertilizer (20:40:20 kg N:P:K ha⁻¹) was applied. Observations on germination, growth, flowering, inflorescence, dry matter and yield-related traits were recorded from randomly selected plants using standard procedures.

Results

The present investigation revealed considerable phenotypic variability among the fourteen amaranthus mutant lines (MT₁-MT₁₄) evaluated during M₃ and M₄ generations. Significant differences were observed for inflorescence characteristics, dry matter accumulation and yield attributes. The pooled results of both years are presented below.

4.1 Spikelet length (cm)

In M₃ generation (1st year) among the amaranthus treatment lines, spikelet length was recorded maximum in treatment line MT₁₀ (33.67 cm), followed by treatment MT₅ (24.84 cm), MT₆ (22.06 cm) and MT₂ (20.82 cm), while lowest was recorded in treatment MT₈ (9.41 cm).

In M₄ generation (2nd year) among the amaranthus treatment lines, spikelet length was recorded maximum in treatment MT₁₀ (32.53 cm), followed by treatment MT₅ (24.18 cm), MT₆ (21.42 cm) and MT₂ (20.34). While lowest was recorded in treatment MT₈ at 60 DAS (4.72 cm), 90 DAS (6.95 cm) and at maturity (9.31 cm).

The pooled data showed that the spikelet length was recorded maximum in treatment MT₁₀ (33.10 cm), followed by treatment MT₅ (24.51 cm), MT₆ (21.74 cm) and MT₂ (20.58 cm). While, lowest was recorded in MT₈ (9.36 cm).

The exceptionally high spikelet length in MT₁₀ is noteworthy. The box-plot analysis also demonstrated greater dispersion for spikelet length than for several vegetative traits, indicating the presence of exceptional mutant phenotypes. Behera and Patnaik (1979) [5] reported that viable γ -ray-induced mutations affecting leaves and inflorescences in *Amaranthus hypochondriacus*, including prominent fasciation of the floral axis. Similar results also reported by Hudym *et al.* (2021) [11].

4.2 Dry matter content (g)

In M₃ generation (1st year) among the amaranthus treatment lines, dry matter content was recorded maximum in treatment MT₁₀ at 60 DAS (17.33 g) followed by MT₅ (16.85 g), MT₆ (15.66 g) and MT₁₁ (15.52 g). At 90 DAS, maximum dry matter content was recorded in treatment MT₅ (24.65 g) followed by MT₆ (23.06 g), MT₁₀ (22.88 g) and MT₂ (22.13 g). Whereas, treatment lines MT₁₁ (22.12 g) and MT₁₂ (21.62 g) recorded at par. At maturity, maximum dry matter content was observed in treatment line MT₅ (32.45 g), followed by treatment MT₆ (30.46 g), MT₂ (29.63 g) and MT₁₂ (28.92 g). While, lowest was recorded in treatment MT₁₃ at 60 DAS (3.67 g), 90 DAS (8.17 g) and at maturity (12.67 g).

In M₄ generation (2nd year) among the amaranthus treatment lines, dry matter content was recorded maximum in treatment MT₁₀ at 60 DAS (17.53 g) followed by MT₅ (16.86 g), MT₆ (16.29 g) and MT₁₁ (15.99 g). At 90 DAS, maximum dry matter content was recorded in treatment MT₅ (24.97 g) followed by MT₁₀ (24.02 g), MT₆ (23.65 g) and MT₁₁ (22.78 g). Whereas, treatment lines MT₂ (22.46 g) and MT₁₂ (21.48 g) recorded at par. At maturity, maximum dry matter content was observed in treatment line MT₅ (30.82 g), followed by treatment MT₆ (28.24 g), MT₁₁ (27.86 g) and MT₂ (27.74 g). Whereas, treatment lines MT₁₀ (27.01 g) and MT₁₂ (26.76 g) was recorded at par. While, lowest was recorded in treatment MT₁₃ at 60 DAS (3.78 g), 90 DAS (8.42 g) and at maturity (12.29 g).

The pooled data showed that among the amaranthus treatment lines, the dry matter content was recorded maximum in treatment MT₁₀ at 60 DAS (17.43 g) followed by MT₅ (16.85 g), MT₆ (15.97 g) and MT₁₁ (15.75 g). At 90 DAS, maximum dry matter content was recorded in treatment MT₅ (24.81 g) followed by MT₁₀ (23.45 g), MT₆ (23.35 g) and MT₁₁ (22.45 g). Whereas, treatment lines MT₂ (22.30 g) and MT₁₂ (21.55 g) recorded at par. At maturity, maximum dry matter content was recorded in treatment line MT₅ (31.63 g), followed by treatment MT₆ (29.35 g), MT₂ (28.69 g) and MT₁₁ (28.29 g). Whereas, treatment lines MT₁₂ (27.84 g) and MT₁₀ (27.72 g) was recorded at par. While, lowest was recorded in treatment MT₁₃ at 60 DAS (3.73 g), 90 DAS (8.29 g) and at maturity (12.48 g).

The progressive increase in dry matter from 60 DAS to maturity might be attributed to the cumulative production of photosynthates and their subsequent partitioning into leaves, stems, branches and reproductive structures. As plants advanced in age, increased leaf area, leaf number, branching and canopy development would have increased the photosynthetic surface, resulting in greater accumulation of structural and storage materials. The present result is in agreement with Ashalata, *et al.* (2022) [14].

4.3 Test weight (g)

Among the amaranthus treatment lines the highest mean test weight of seeds was observed under treatment line MT₃ (1.20 g), followed by MT₇ (1.05 g), MT₈ (1.00 g) and MT₆

(0.99 g), whereas MT₇ (1.05 g) was at par. while minimum was recorded under treatment line MT₉ (0.78 g).

Regarding treatment lines during M₄ generation (2nd year) test weight was recorded highest in MT₃ (1.23 g), followed by MT₇ (1.01 g), MT₈ (1.01 g) and MT₆ (1.0 g), while minimum was recorded under MT₉ (0.77 g).

The pooled data showed that test weight of amaranthus treatment lines, it ranged from 1.22 g to 0.77 g with an average mean of 0.99 g. Among the amaranthus treatment lines, maximum was recorded under treatment MT₃ (1.22 g) followed by MT₇ (1.03 g), MT₈ (1.01 g) and MT₆ (1.0 g), while minimum was recorded under treatment MT₉ (0.77 g). Variation in seed weight is an important indication of altered reproductive performance. Gamma-induced mutations could modify assimilate partitioning and seed development, producing mutants with either increased or decreased seed size. Similar findings were reported by Vesela *et al.* (2020), reported stable superiority of the irradiation-derived amaranth variety Zobor for 1000-seed weight over its non-irradiated control and Gowthami *et al.* (2016) [9] in rice.

4.4 Foliage yield per plot (kg plot⁻¹)

Among the amaranthus leaves of treatment lines the highest mean foliage yield kg per plot was recorded under treatment line MT₁₂ (1.66 kg plot⁻¹), followed by MT₁₁ (1.59 kg plot⁻¹), MT₃ (1.53 kg plot⁻¹) and MT₂ (1.47 kg plot⁻¹), whereas MT₇ (1.44 kg plot⁻¹), MT₈ (1.41 kg plot⁻¹) and MT₉ (1.40 kg plot⁻¹) was at par. while minimum was recorded under treatment line MT₉ (0.98 kg plot⁻¹).

Regarding treatment lines during M₄ generation (2nd year) foliage yield kg per plot was recorded highest in MT₁₂ (1.73 kg plot⁻¹), followed by MT₃ (1.59 kg plot⁻¹), and MT₁₁ (1.54 kg plot⁻¹), while minimum was recorded under MT₉ (0.96 kg plot⁻¹).

The pooled data showed that foliage yield kg per plot of amaranthus treatment lines, it ranged from 1.69 kg plot⁻¹ to 0.97 kg plot⁻¹ with an average mean of 1.33 kg plot⁻¹. Among the amaranthus treatment lines, maximum was recorded under treatment MT₁₂ (1.69 kg plot⁻¹) followed by MT₁₁ (1.57 kg plot⁻¹), MT₃ (1.56 kg plot⁻¹) and MT₂ (1.47 kg plot⁻¹), while minimum was recorded under treatment MT₉ (0.97 kg plot⁻¹).

The superiority of MT₁₂ could be explained by its combination of high branching, high leaf number and large vegetative biomass. The accumulation of these components results in greater harvestable foliage. Gamma radiation might produce useful mutations affecting plant architecture, leaf production and biomass accumulation. Beyaz and Yildiz (2017) [16] reported that gamma irradiation could induce permanent genetic changes and alter physiological processes through ROS-mediated signaling. Similar findings were reported by Rawat *et al.* (2017) and Harivendra *et al.* (2024) [10, 18].

4.5 Seed yield per plant (g plant⁻¹)

In M₃ generation among the different mutant lines, highest seed yield per plant was recorded under MT₁₀ (18.45 g), followed by MT₅ (17.10 g), MT₆ (16.23 g) and MT₂ (15.98 g), while the lowest was recorded under treatment line MT₈ (5.73 g).

During M₄ generation among the various mutant lines, seed yield per plant was recorded highest under MT₁₀ (19.37 g), followed by treatment MT₆ (16.88 g). While the lowest seed

yield per plant was recorded under treatment MT₈ (5.90 g). The pooled data showed that seed yield per plant was recorded highest under MT₁₀ (18.91 g), followed by MT₅ (16.76 g), MT₆ (16.55 g). While, the lowest seed yield per plant was recorded under treatment MT₈ (5.82 g).

The highest seed yield per plant recorded in MT₁₀ indicates that this treatment might contain a favourable combination of mutations affecting reproductive growth. The high seed yield of MT₁₀ is particularly noteworthy because the same treatment also exhibited exceptional mature plant height and spikelet length. Rawat *et al.* (2017) [18] reported higher yield per plant under an intermediate γ -radiation treatment in *A. caudatus*, supporting the possibility that appropriate irradiation could generate beneficial yield variation.

4.6 Seed yield per ha (t/ha)

In M₃ generation among the different mutant lines, highest seed yield per ha was recorded under MT₁₀ (2.08 t/ha), followed by MT₆ (1.78 t/ha), MT₂ (1.61 t/ha) and MT₁ (1.50 t/ha), while the lowest was recorded under MT₈ (0.57 t/ha).

During M₄ generation among the various mutant lines, highest seed yield per ha was recorded highest under MT₁₀ (1.99 t/ha), followed by MT₆ (1.81 t/ha). While the lowest seed yield per plant was recorded under treatment MT₈ (0.58 t/ha).

The pooled data showed that seed yield per plant was recorded highest under MT₁₀ (2.03 t/ha), followed by MT₆ (1.81 t/ha). While, the lowest seed yield per ha was recorded under treatment MT₈ (0.58 t/ha).

The superiority of MT₁₀ for seed yield per hectare demonstrates that the radiation-induced variation was expressed not only at the individual-plant level but also at the field-production level. Such consistency strengthens the breeding value of MT₁₀. Rawat *et al.* (2017) [18] similarly demonstrated improved yield performance of selected γ -irradiated *A. caudatus* populations. The results of Veselá *et al.* (2020, 2021) [23, 24] further demonstrate that γ -ray-derived amaranth mutants could possess stable improvements in quantitative seed traits.

4.7 Biological yield per ha (t ha⁻¹)

In M₃ generation among the different mutant lines, highest biological yield per ha was recorded under treatment MT₁₂ (16.60 t/ha), followed by MT₁₁ (15.90 t/ha), MT₃ (15.30 t/ha) and MT₂ (14.70 t/ha). Whereas, MT₇ (14.40 t/ha), MT₈ (14.10 t/ha) and MT₉ (14.00 t/ha) were recorded at par, while the lowest was recorded under MT₄ (9.80 t/ha).

During M₄ generation among the various mutant lines, biological yield per ha was recorded highest under MT₁₂ (17.26 t/ha), followed by MT₁₁ (15.42 t/ha), MT₃ (15.91 t/ha) and MT₈ (14.52 t/ha). While, the lowest biological yield per ha was recorded under treatment MT₄ (9.60 t/ha).

The pooled data showed that biological yield per ha was recorded highest under MT₁₂ (16.93 t/ha), followed by MT₁₁ (15.66 t/ha), MT₃ (15.61 t/ha) and MT₂ (14.48 t/ha). Whereas, treatment MT₈ (14.31 t/ha) was recorded at par. While, the lowest biological yield per ha was recorded under treatment MT₄ (9.70 t/ha).

The higher biological yield of MT₁₂ may be attributed to its greater vegetative development, particularly leaf and branch production. The result agrees with Rawat *et al.* (2017) [18], who observed enhanced growth and yield in γ -irradiated *A. caudatus*. Andrew-Peter-Leon *et al.* (2021) also reported increased biological yield in γ -ray-derived wheat mutants.

Table 1: Mean performance of spikelet length (cm) influenced by amaranthus mutant lines: Year 2022-24 (M₃ and M₄ generation)

Treatments	Spikelet length (cm)		
	At maturity		
	1 st year	2 nd year	Pooled
MT ₁	15.29	15.44	15.36
MT ₂	20.82	20.34	20.58
MT ₃	12.99	12.99	12.99
MT ₄	11.26	11.12	11.19
MT ₅	24.84	24.18	24.51
MT ₆	22.06	21.42	21.74
MT ₇	12.54	12.04	12.29
MT ₈	9.41	9.31	9.36
MT ₉	15.05	14.85	14.95
MT ₁₀	33.67	32.53	33.10
MT ₁₁	15.61	15.42	15.52
MT ₁₂	18.30	18.40	18.35
MT ₁₃	11.53	11.39	11.46
MT ₁₄	11.52	11.73	11.62
SEm±	1.12	1.13	1.13
CD(0.05)	3.26	3.29	3.27
CV	11.58	11.87	11.72

Table 2: Mean performance of dry matter content (g) influenced by amaranthus mutant lines: Year 2022-24 (M₃ and M₄ generation)

Treatment s	Dry matter content (g)								
	60 DAS			90 DAS			At maturity		
	1 st year	2 nd year	Pooled	1 st year	2 nd year	Pooled	1 st year	2 nd year	Pooled
MT ₁	10.34	10.86	10.60	17.74	18.63	18.18	25.14	23.88	24.51
MT ₂	14.63	14.74	14.68	22.13	22.46	22.30	29.63	27.74	28.69
MT ₃	9.05	9.41	9.23	15.75	16.38	16.07	22.45	21.55	22.00
MT ₄	7.60	7.75	7.68	14.40	14.35	14.38	21.20	20.78	20.99
MT ₅	16.85	16.86	16.85	24.65	24.97	24.81	32.45	30.82	31.63
MT ₆	15.66	16.29	15.97	23.06	23.65	23.35	30.46	28.24	29.35
MT ₇	10.12	10.29	10.21	17.42	18.29	17.86	24.72	23.48	24.10
MT ₈	7.87	8.11	7.99	14.17	14.26	14.22	20.47	19.86	20.16
MT ₉	9.89	10.09	9.99	15.19	15.49	15.34	20.49	20.08	20.29
MT ₁₀	17.33	17.53	17.43	22.88	24.02	23.45	28.43	27.01	27.72
MT ₁₁	15.52	15.99	15.75	22.12	22.78	22.45	28.72	27.86	28.29
MT ₁₂	14.32	14.23	14.27	21.62	21.48	21.55	28.92	26.76	27.84
MT ₁₃	3.67	3.78	3.73	8.17	8.42	8.29	12.67	12.29	12.48
MT ₁₄	4.76	5.00	4.88	10.46	10.98	10.72	16.16	15.35	15.76
SEm±	0.76	0.78	0.77	1.17	1.28	1.22	1.59	1.47	1.53
CD(0.05)	2.21	2.28	2.24	3.40	3.72	3.56	4.61	4.27	4.44
CV	11.71	11.80	11.75	11.36	12.11	11.74	11.25	10.92	11.09

Table 3: Mean performance of test weight (g) and foliage yield per plot (kg plot⁻¹) influenced by amaranthus mutant lines: Year 2022-24 (M₃ and M₄ generation)

Treatments	Test weight (g)			Foliage yield per plot (kg plot ⁻¹)		
	1 st year	2 nd year	Pooled	1 st year	2 nd year	Pooled
MT ₁	0.92	0.91	0.91	1.31	1.24	1.28
MT ₂	0.95	0.93	0.94	1.47	1.43	1.45
MT ₃	1.20	1.23	1.22	1.53	1.59	1.56
MT ₄	0.89	0.88	0.88	0.98	0.96	0.97
MT ₅	0.93	0.92	0.92	1.17	1.12	1.15
MT ₆	0.99	1.00	1.00	1.34	1.39	1.37
MT ₇	1.05	1.01	1.03	1.44	1.37	1.40
MT ₈	1.00	1.01	1.01	1.41	1.45	1.43
MT ₉	0.78	0.77	0.77	1.40	1.37	1.39
MT ₁₀	0.85	0.86	0.86	1.31	1.38	1.34
MT ₁₁	0.80	0.79	0.80	1.59	1.54	1.57
MT ₁₂	0.83	0.84	0.84	1.66	1.73	1.69
MT ₁₃	0.90	0.89	0.89	1.21	1.17	1.19
MT ₁₄	0.82	0.81	0.82	1.09	1.04	1.06
SEm±	0.07	0.05	0.06	0.09	0.08	0.09
CD(0.05)	0.19	0.16	0.18	0.26	0.24	0.25
CV	12.39	10.32	11.36	11.69	10.69	11.19

Table 4: Mean performance of seed yield per plant (g/plant), seed yield per ha (t/ha) and biological yield per ha (t/ha) influenced by amaranthus mutant lines: Year 2022-24 (M₃ and M₄ generation)

Treatment s	Seed yield per plant (g/plant)			Seed yield per ha (t/ha)			Biological yield per ha (t/ha)		
	1 st year	2 nd year	Pooled	1 st year	2 nd year	Pooled	1 st year	2 nd year	Pooled
MT ₁	13.21	12.55	12.88	1.50	1.43	1.47	13.10	12.45	12.77
MT ₂	15.98	15.50	15.74	1.61	1.57	1.59	14.70	14.26	14.48
MT ₃	11.52	11.98	11.75	0.98	1.02	1.00	15.30	15.91	15.61
MT ₄	7.67	7.52	7.59	0.93	0.91	0.92	9.80	9.60	9.70
MT ₅	17.10	16.42	16.76	0.92	0.97	0.95	11.70	11.23	11.47
MT ₆	16.23	16.88	16.55	1.78	1.85	1.81	13.40	13.94	13.67
MT ₇	10.71	10.17	10.44	1.17	1.11	1.14	14.40	13.68	14.04
MT ₈	5.73	5.90	5.82	0.57	0.59	0.58	14.10	14.52	14.31
MT ₉	12.25	12.01	12.13	0.95	0.93	0.94	14.00	13.72	13.86
MT ₁₀	18.45	19.37	18.91	2.08	1.99	2.03	13.10	13.76	13.43
MT ₁₁	14.41	13.98	14.19	0.69	0.67	0.68	15.90	15.42	15.66
MT ₁₂	14.76	15.35	15.06	0.71	0.74	0.73	16.60	17.26	16.93
MT ₁₃	10.03	10.46	10.25	1.35	1.29	1.32	12.10	11.74	11.92
MT ₁₄	8.56	8.29	8.42	1.15	1.11	1.13	10.90	10.36	10.63
SEm±	0.93	0.88	0.90	0.09	0.08	0.08	0.97	0.96	0.97
CD(0.05)	2.71	2.54	2.62	0.26	0.24	0.25	2.82	2.80	2.81
CV	12.78	12.03	12.41	13.06	12.23	12.65	12.44	12.45	12.44

Conclusion

The present investigation demonstrated that gamma-ray irradiation was effective in generating substantial variability among amaranthus mutant lines for inflorescence, dry matter accumulation and yield attributes. Significant

differences among the mutant lines indicated the presence of useful variability that can be exploited for crop improvement.

Among the evaluated lines, MT₁₀ showed superior performance for spikelet length (33.10 cm), seed yield per plant (18.91 g) and seed yield (2.03 t ha⁻¹), and therefore emerged as the most promising mutant for seed production. MT₁₂ recorded the highest foliage yield (1.69 kg plot⁻¹) and biological yield (16.93 t ha⁻¹), making it promising for foliage and biomass production. MT₅ recorded the highest dry matter accumulation (31.63 g), while MT₃ recorded the highest test weight (1.22 g).

Overall, the study identified MT₁₀, MT₁₂, MT₅ and MT₃ as promising mutant lines for specific desirable traits. These lines may be further evaluated in advanced generations for confirmation of their performance and potential utilization in amaranthus varietal improvement and breeding programmes.

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