



RESEARCH ARTICLE

Engineering genetic diversity: Optimising gamma ray mutagenesis in yam bean variety RM-1 for future trait development

Bharath D A¹, Ninitha N C^{1*}, Seeja G¹, P Murugesan², Beena T¹ & Sreehari S¹

¹Department of Genetics and Plant Breeding, College of Agriculture, Kerala Agricultural University, Vellayani, Thiruvananthapuram 695 522, Kerala, India

²Division of Crop Improvement, ICAR-Central Tuber Crops Research Institute, Sreekariyam, Thiruvananthapuram 695 017, Kerala, India

*Correspondence email - ninithanath.c@kau.in

Received: 31 December 2025; Accepted: 12 March 2026; Available online: Version 1.0: 16 April 2026

Cite this article: Bharath DA, Ninitha NC, Seeja G, Murugesan P, Beena T, Sreehari S. Engineering genetic diversity: Optimising gamma ray mutagenesis in yam bean variety RM-1 for future trait development. Plant Science Today. 2025; 13(sp3): 1-7. <https://doi.org/10.14719/pst.13464>

Abstract

Yam bean (*Pachyrhizus erosus* L. Urban) is an underutilised legume-tuber crop valued for its high root yield, rich nutritional composition and ability to enhance soil fertility through biological nitrogen fixation. Its seeds also contain rotenone, a natural insecticide, adding to its agricultural relevance. Due to its drought tolerance and adaptability, yam bean is considered a promising crop for sustainable and climate-resilient agriculture. However, progress in its improvement is constrained by a narrow genetic base. Given the absence of mutant varieties in India, the present study evaluated the effects of gamma radiation on the yam bean variety RM-1. Dry seeds were irradiated with doses ranging from 50 to 200 Gy to determine the lethal dose 50 (LD₅₀). Based on the seedling vigour index (SVI), which showed a strong inverse dose-response correlation and up to 85 % reduction compared to the control, the LD₅₀ was estimated at 177.13 Gy. Subsequent M₁ field evaluation (140–200 Gy) indicated a similar decline in seedling survival, reaffirming gamma-induced genotoxic effects. The M₁ generation exhibited considerable variation in stem colour (e.g., green with brown stripes) and leaf morphology (obcordate, narrow, or wrinkled). The greatest morphological diversity appeared at 180–200 Gy, while chlorophyll mutants-mainly xantha and chlorina-were more frequent at 140 Gy, indicating mutant saturation at higher doses. These findings highlight gamma radiation, particularly 180–200 Gy, as effective for generating genetic variability in *P. erosus* to support future breeding of high-yield, semi-dwarf lines.

Keywords: gamma radiation; lethal dose 50 %; mutation breeding; *Pachyrhizus erosus*; RM-1

Introduction

The global imperative to sustainably nourish a projected nine billion people by 2050 has placed an unprecedented strain on agricultural systems, mandating a 50–60 % increase in crop production to mitigate widespread food insecurity (1). In this critical context, the identification and cultivation of resilient, nutrient-dense crops is paramount. This research focuses on the yam bean (*Pachyrhizus erosus* L. Urban), an underutilised leguminous tuberous root crop whose comprehensive value extends beyond its nutritional profile. Its tubers are highly prized for being a rich source of protein, carbohydrates, folic acid, Vitamin C and essential minerals including zinc and iron (2). Its seeds contain rotenone, a potent natural insecticide effective against key agricultural pests such as aphids (3); however, its application is limited by significant toxicity and regulation concerns, restricting its wider use in biopesticide development. Furthermore, the yam bean provides significant ecological and agronomic benefits, contributing substantially to soil fertility through efficient biological nitrogen fixation (4).

Taxonomically, the yam bean (*P. erosus*) belongs to the family Leguminosae (Fabaceae) and is classified within the subtribe Diocleinae (5). This placement establishes a close phylogenetic

relationship with highly significant global food crops in the subtribes Glycininae and Phaseolinae, which encompass vital legumes such as soybean and the common bean, respectively (6, 7). The genus *Pachyrhizus* is indigenous to Mexico and Central America. However, its robust adaptability has facilitated its extensive cultivation throughout many tropical and subtropical regions worldwide. In India, its cultivation is primarily concentrated in the states of Odisha, West Bengal and parts of Andhra Pradesh, underscoring its established, yet regionally focused, importance within local food systems (8).

Despite its significant potential, the widespread commercialisation of the yam bean is constrained by its narrow genetic base. All currently cultivated yam bean species are diploid ($2n = 2x = 22$) (9). While they exhibit self-compatibility and are capable of interspecific hybridisation, this inherent low natural genetic variation presents a major impediment to efficient crop improvement (10). To surmount this genetic limitation, mutation breeding, an innovative approach utilising spontaneous or induced mutations, offers a powerful pathway to create the necessary variation. This technique employs three primary forms of mutagenesis: physical, chemical and biological mutagens. Among these, gamma irradiation has been extensively utilised and proven

highly effective for mutation breeding across diverse crop species (11, 12). Notably, gamma irradiation is the critical tool responsible for developing the majority of officially released mutant varieties globally (13, 14), establishing its vital role in improving the desirable characteristics of the yam bean.

Despite the global need for crop enhancement and the proven efficacy of mutation breeding, the development of high-yielding and semi-dwarf yam bean varieties with traits highly desirable for modern cultivation remains a critical requirement. Crucially, no officially released mutant varieties of yam bean have been developed in India. The feasibility of using mutagens to achieve these goals, however, is supported by international precedents. Prior reports indicated that both gamma rays and ethyl methane sulfonate (EMS) successfully induced desirable dwarf phenotypes and higher tuber yield mutants (15). More recently, research in 2022 demonstrated the successful application of gamma radiation-induced mutation in the yam bean variety Koda Padaga in Indonesia (16). Based on these successful precedents and the need to establish a systematic understanding of the process in Indian germplasm, the present experiment was designed to specifically investigate the effects of gamma radiation on the yam bean, focusing on key quantitative parameters including germination, seedling vigour and subsequent morphological variation.

Materials and Methods

Study area and experimental conditions

The study was carried out during the kharif season of 2025 at the College of Agriculture, Vellayani, Kerala, India. This location is situated within the Southern coast plains agro-climatic unit of Kerala (17). The research site is characterised by specific environmental parameters, including mean annual rainfall of 2360 mm, 80 % of average relative humidity and mean annual temperature of 27.6 °C (17). The soil at the site exhibited a slightly acidic pH of 6.4.

Determination of the lethal dose

The investigation utilised the yam bean variety RM-1, released by Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar. To determine the LD₅₀, dry seeds were subjected to four doses of gamma radiation (50, 100, 150 and 200 Gy) using a Cobalt-60 gamma irradiator. The irradiation was performed in the gamma chamber at the Radiotracer Laboratory, College of Agriculture, Vellankkara, Thrissur. Following irradiation, the treated seeds, along with an untreated control, were germinated under laboratory conditions using the paper towel method. The experiment comprised a total of 500 seeds distributed among 5 treatments (4 radiation doses plus an untreated control) with four replications. Each treatment consisted of 100 seeds, with 25 seeds per replication. The growth of the seedling was measured on the 12th day after sowing. The immediate biological responses were assessed based on germination percentage, vigour index, seedling length and plumule development.

Seedling vigour index was calculated using the formula below:

$$\text{SVI} = \text{Germination percentage} \times \text{Seedling length (cm)} \quad (\text{Eqn. 1})$$

The LD₅₀ value was calculated from the SVI data using probit analysis in the KAU GRAPES software package. This determination was critical for selecting appropriate and effective radiation doses for the subsequent M₁ generation study.

Field evaluation of M₁ generation

The M₁ generation study was conducted using a randomized block design (RBD) with 5 treatments and 4 replications. The treatments consisted of the untreated control and seeds irradiated with 140, 160, 180 and 200 Gy, selected based on the results derived from the previously estimated LD₅₀ value. The experimental field was thoroughly prepared by assessing the soil pH, followed by proper tillage and uniform incorporation of farmyard manure (FYM). The irradiated seeds and the untreated control were sown in the open field at a uniform spacing of 30 × 30 cm. The RBD was employed to minimise experimental error resulting from field heterogeneity, thereby enhancing the precision of treatment comparisons. Standard agronomic and intercultural practices were uniformly followed for all experimental units in accordance with the Kerala Agricultural University Package of Practices Recommendations for pulse crops. These practices included recommended nutrient management, timely weeding and earthing up. Prophylactic and need-based plant protection measures were adopted to manage pests and diseases throughout the crop growth period. During the crop cycle, observations were recorded to assess the biological and morphological effects of the irradiation in the M₁ generation. Key parameters evaluated included seedling germination percentage on the 15th day after sowing, seedling survival percentage at the branching stage and the frequency of induced chlorophyll mutants and chimeric sectors.

Results

Determination of lethal dose 50 (LD₅₀)

The effectiveness of mutation induction depends on accurate dose estimation. The LD₅₀ was estimated to establish a critical baseline for assessing the seed's tolerance to gamma irradiation, defined as the dose causing a 50 % inhibitory effect. Since germination percentage remained relatively high across treatments and was not sufficiently discriminatory across radiation doses, the SVI was utilised as the primary and most sensitive critical endpoint for LD₅₀ determination. As germination percentage remained relatively high and did not sufficiently discriminate among radiation doses, the SVI was used as the primary and most sensitive endpoint for LD₅₀ determination. This index integrates root and shoot lengths, which were measured on the 12th day after germination (Fig. 1). This composite index exhibited a strong negative correlation with the applied radiation dose (Table 1). The LD₅₀ value was precisely estimated as 177.13 Gy through probit analysis, a standard statistical method for linearising dose-response data, which was performed using the KAU GRAPES analysis package (Fig. 2).

Table 1. Effect of gamma radiation on seedling vigour index on the 12th day after sowing

Treatment	Germination percentage	Shoot length (cm)	Root length (cm)	Total seedling length (cm)	Seedling vigour index
T ₁ - 0 Gy	87	11.42	12.6	24.02	2041.7
T ₂ - 200 Gy	65	5.12	8.8	14.4	941.5
T ₃ - 150 Gy	71	7.4	9.8	17.2	1222.6
T ₄ - 100 Gy	78	8.3	10.7	19	1482
T ₅ - 50 Gy	81	10	11.5	21.5	1741.5



Fig. 1. Effect of gamma radiation on germination 1st, 5th and 12th days after sowing.

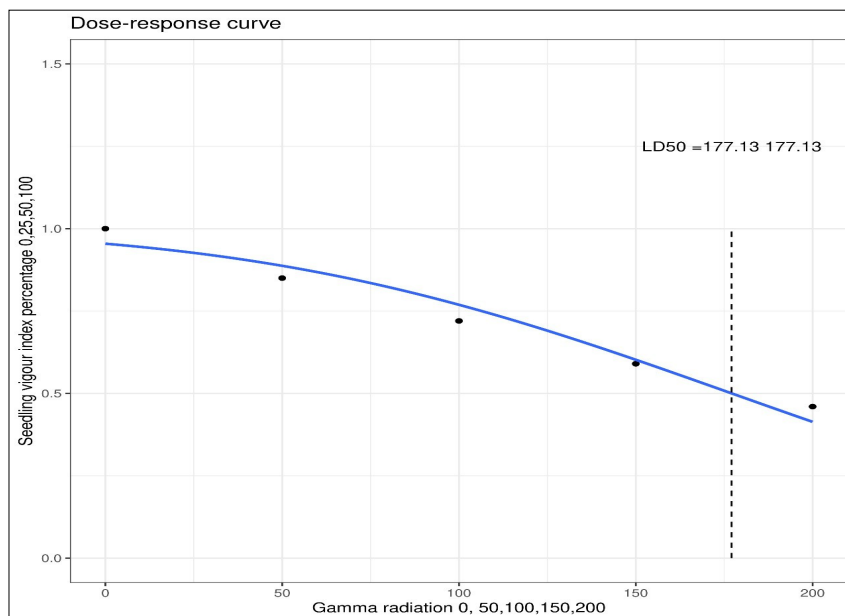


Fig. 2. Probit analysis curve of gamma radiation versus seedling vigour index.

Effect of gamma radiation on shoot and root development

The seedling vigour index (SVI), which integrates both shoot and root lengths, proved to be a highly sensitive and reliable indicator of radiation-induced stress. Across the treatments, SVI demonstrated a clear, inverse and dose-dependent relationship with the applied gamma radiation. This reduction reflects cumulative damage to the essential physiological and cellular processes critical for successful

post-germinative growth (Fig. 3). Compared to the untreated control (0 Gy), the SVI showed a clear decline with increasing radiation doses. Specifically, SVI values decreased to 85, 72, 59 and 46 % of the control at 50, 100, 150 and 200 Gy, respectively (Table 1). These findings demonstrate an inverse relationship between gamma radiation dose and seedling vigour, with higher doses causing progressively greater reductions.

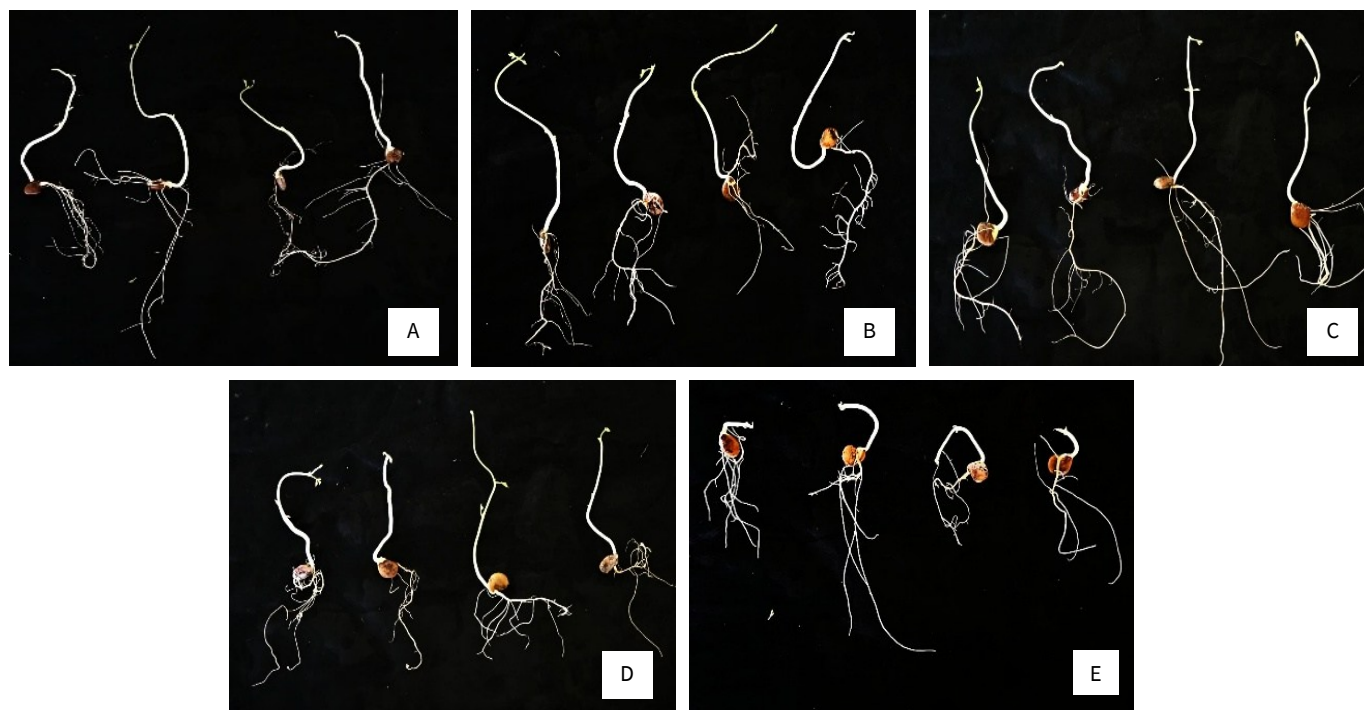


Fig. 3. Germination and seedling growth of yam bean treated with different doses of gamma radiation. A. 0 Gy (control); B. 50 Gy; C. 100 Gy; D. 150 Gy; E. 200 Gy.

This substantial decline in vigour, which correlated strongly with observable physical developmental traits such as plumule suppression, reduced elongation and stunted seedlings, confirms that the genotoxic effects of gamma irradiation extend beyond simple germination rate, significantly impairing the seedlings capacity for robust establishment and early vegetative growth.

Based on the calculated LD₅₀ value, a range of gamma radiation dosages 140, 160, 180 and 200 Gy, was strategically selected for the subsequent M₁ generation experiment. This selection aims to effectively induce and screen for a wide spectrum of genetic variability while maintaining a sufficient survival rate for mutation breeding efforts.

Effect of gamma radiation on M₁ generation

Seedling germination percentage

The control group exhibited the highest germination percentage, while the remaining treatments showed a decreasing trend. Following the control, the treatments in order of decreasing germination percentage were 140, 160, 180 and 200 Gy, with the 200 Gy treatment demonstrating the lowest germination percentage. The specific data is detailed in Table 2.

Table 2. Effect of gamma radiation on seedling germination percentage

Treatment	Mean	Grouping
T ₁ - 0 Gy	84.74	a
T ₂ - 140 Gy	79.16	ab
T ₃ - 160 Gy	66.66	ab
T ₄ - 180 Gy	59.72	bc
T ₅ - 200 Gy	43.05	c
CD (0.05)	7.786	

Treatment with the same letters is not significantly different.

Seedling survival percentage at the branching stage

Among all treatments, T₂ (140 Gy) exhibited the highest seedling survival of 75.69 %, following the control at 82.96 %. T₃ (160 Gy), T₄ (180 Gy) and T₅ (200 Gy) showed 60.40, 52.77 and 44.44 %, respectively (Table 3).

Table 3. Effect of gamma radiation on seedling survival percentage

Treatment	Mean	Grouping
T ₁ - 0 Gy	82.96	a
T ₂ - 140 Gy	75.69	ab
T ₃ - 160 Gy	60.4	bc
T ₄ - 180 Gy	52.77	c
T ₅ - 200 Gy	44.44	c
CD (0.05)	6.087	

Treatment with the same letters is not significantly different.

Presence of chlorophyll mutants

Chlorophyll mutations served as vital indicators for evaluating the biological effects of gamma radiation treatment in the M₁ generation. Two distinct types of chlorophyll mutants were observed during early germination: xantha (seedlings characterised by a yellow colour) and chlorina (seedlings characterised by a light green colour). Various sectorial chimaeras were also observed during the early seedling stage (Fig. 4). Both the xantha and chlorina mutants were observed only at the 140 Gy gamma radiation dose. However, mutant frequency did not increase with dose; on the contrary, the data indicated an inverse relationship where lower doses of gamma radiation created a higher frequency of chlorophyll mutants in the M₁ generation.

Effect of gamma radiation on morphological traits

Gamma radiation induced visible variation in stem colour in the M₁ generation compared to the control, which exhibited uniform normal green stem colour. The induced stem colour variants included green with striped brown and dark brown (Fig. 5). The maximum variation was observed at the 180 Gy dose, where all three stem colour phenotypes: green, green with striped brown and dark brown were recorded. Within this treatment, the normal green phenotype occurred most frequently, followed by green with brown stripes, while dark brown was least frequent. The 160 Gy dose also showed variation, but only the green with brown striped and normal green colours were observed. However, the treatments at 200, 140 Gy and the untreated control plants exhibited only normal green stem colour.

Leaf variation in the M₁ generation

Leaf variation was assessed at 2 distinct stages of plant development.

Leaf variation at the seedling stage

Initial variation was prominently observed at the germination stage, where four different types of primary leaf variations were noted: deformed primary leaves, obcordate leaves, broad leaf mutants and narrow leaf mutants (Fig. 6). All gamma radiation doses induced some degree of leaf variation. The maximum leaf variation was observed at the 200 Gy dose, which displayed a combination of broad, narrow, obcordate and normal leaf types. In contrast, the 140 Gy treatment exhibited the least variation, with all seedlings having normal leaves, similar to the control.

Leaf variation at a later growth stage

In the later growth stages, several structural and colour variants were recorded. These included dark green leaves, dark green leaves with wrinkling, light green leaves, narrow leaves with light yellow midribs and narrow wrinkled leaves with yellow midribs (Fig. 7). All treatments, including the control, showed plants with the normal

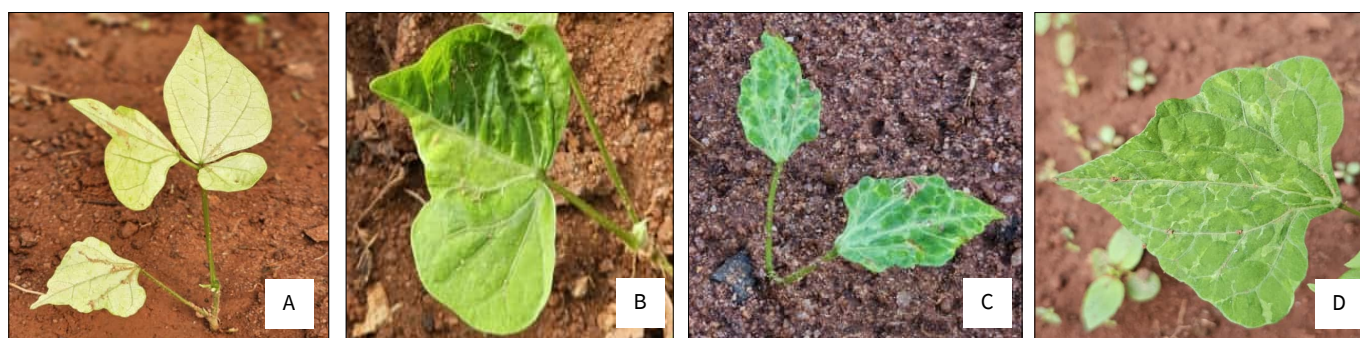


Fig. 4. Chimera and chlorophyll mutant leaves. A. Xantha; B. Chlorina; C, D. Sectorial chimeras.



Fig. 5. Effect of gamma radiation on stem. A. Green (control); B. Green with brown stripes; C. Dark brown.

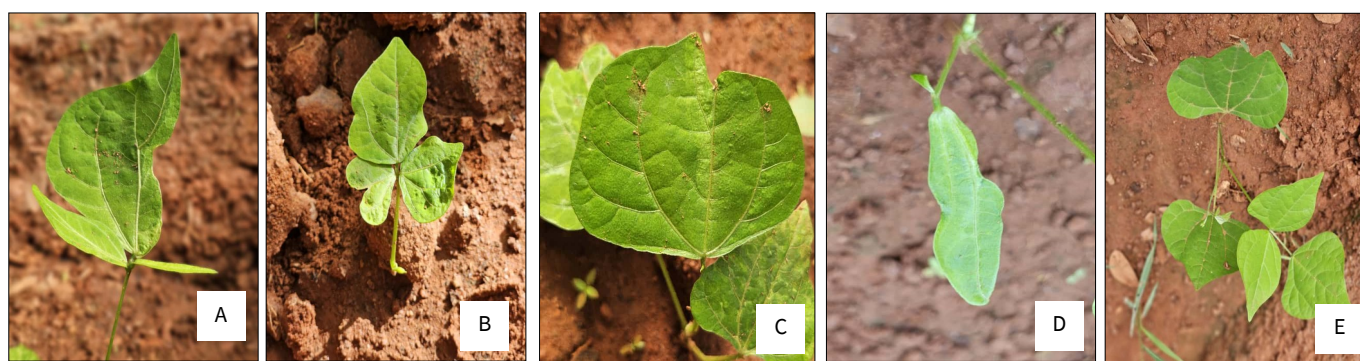


Fig. 6. Effect of gamma radiation on leaves structure during initial stage. A. Deformed primary leaf; B. Leaf alternation to obcordate; C. Broad leaf mutant; D. Narrow leaf mutant; E. Normal leaf (control).

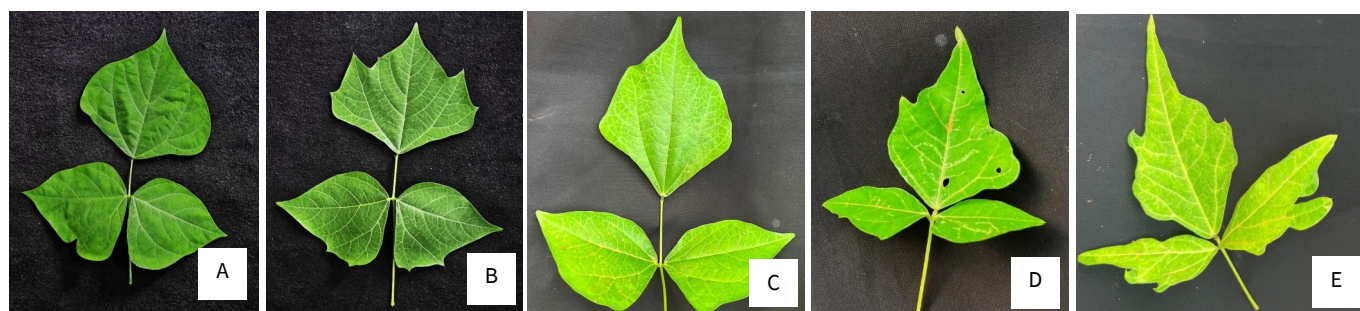


Fig. 7. Effect of gamma radiation on leaves structure at later stage. A. Dark green leaves; B. Dark green leaves with wrinkling; C. Light green leaves; D. Narrow leaf with light yellow mid rib; E. Narrow wrinkle leaves with yellow mid rib.

dark green colour and the wrinkled leaf types. However, the 160 Gy dose was unique in producing only the light green colour variant in addition to the normal and wrinkled leaf phenotypes. The higher doses of 180 and 200 Gy specifically induced the novel phenotypes, such as narrow leaves with light yellow midribs and narrow wrinkled leaves with yellow midribs. These observations indicate a dose-dependent effect of gamma radiation on leaf morphology and colour, with higher doses generating a greater spectrum of variants.

Discussion

Dose selection and physiological effects of gamma radiation

The selection of gamma radiation doses was guided by studies that established the lethal dose (LD_{50}) for yam bean between 150 and 176 Gy, identifying the 150–200 Gy range as optimal for inducing genetic variability while maintaining sufficient plant survival (16). Research in related legumes indicated that higher doses, particularly 200–300 Gy, increased mutation frequency and improved key quality traits (18). Gamma radiation caused DNA damage, chromosomal breaks and oxidative stress, which reduced seedling vigour and survival at higher doses but promoted

beneficial mutations at moderate levels. Collectively, these findings informed a dosage strategy that balanced the trade-off between maintaining a viable M_1 population and maximising the induction of useful genetic variations. The empirical determination of the LD_{50} value, assessed via the SVI, was established at 177.13 Gy. This finding demonstrated a clear and critical dose-dependent inverse correlation, where escalating gamma doses progressively diminished both seed germination and subsequent seedling survival percentages. This phenomenon is consistent with the established genotoxic effects of ionising radiation, which cause cumulative cellular damage. This observed reduction in viability, along with developmental abnormalities such as plumule suppression and stunted elongation, aligns closely with findings in other economically important legumes, such as the African yam bean (19, 20) and the 'Cota Padang' variety of *P. erosus* (16). Similar mitodepressive effects evidenced by the reduced germination following increased irradiation have been well-documented in soybean studies (21) and effects on shoot and root length were observed in African yam bean (22) and groundnut (23). Collectively, these findings validate the effective range of mutagenic stress applied and confirm the sensitivity of *P. erosus* to gamma irradiation, providing a robust foundation for the evaluation of M_1 generation traits.

Chlorophyll and morphological mutation frequency

The frequency of induced chlorophyll mutations serves as a standard measure for evaluating the genetic effectiveness of mutagens (24). In the present research, the specific mutant types noted were xantha (yellow) and chlorina (light green), an observation consistent with reports in related legumes like soybean (25), where a broader spectrum, including waxy, viridis and variegated mutants, has also been reported (14). A significant finding in our study was the inverse relationship between gamma radiation dose and chlorophyll mutant frequency: the lower 140 Gy dose produced more chlorophyll mutants than higher doses. This decline at elevated concentrations is likely due to mutant saturation and the elimination of highly damaged cell lines (such as lethal xantha phenotypes). The same trend of decreased chlorophyll mutants at higher mutagen doses was previously reported in cowpea following gamma radiation treatment (26).

The induction of stable morphological variation served as an excellent indicator of effective mutagenesis, with leaf and stem alterations exhibiting a clear dose-dependent effect. Various leaf variations encompassing colour changes (dark green to light green), shape (wrinkled leaves) and pigmentation (yellow midribs) were consistently recorded, with the most extensive variation noted at the higher gamma radiation doses. This finding is well-supported by prior research on yam bean (*Koda Padaga* variety), where treatments in the 150 to 200 Gy range induced similar phenotypes (16). The high variability at 180 Gy and 200 Gy also aligns with reports in soybean (27) and lentil (28), confirming these dose levels as optimal for inducing morphological changes across diverse legumes. Similarly, stem variation exhibited three distinct colours—light green, green with striped brown and dark brown—with maximum variation again noted at the higher gamma doses, directly comparable to observations in the *Koda Padaga* yam bean variety at 150 to 200 Gy (16). The consistent induction of these highly variable and novel phenotypes at higher doses underscores the efficacy of these gamma radiation levels for increasing genetic diversity in *P. erosus* germplasm.

Conclusion

This study successfully established the LD₅₀ for the yam bean variety RM-1 at 177.13 Gy based on the seedling vigour index, confirming the dose-dependent inhibitory effect of gamma radiation on early growth parameters. The optimal dose range (160–200 Gy) effectively induced a wide spectrum of desirable genetic variations, including novel leaf and stem morphological mutants, with maximum morphological variation observed at the higher doses. Conversely, chlorophyll mutation frequency showed an inverse relationship with dose. These findings underscore the high mutagenic efficacy of gamma radiation in the 180 Gy to 200 Gy range for increasing genetic diversity in *P. erosus* germplasm, which is a crucial first step toward developing high-yielding and semi-dwarf varieties for India. Future research should focus on evaluating gamma radiation-induced yam bean mutants for agronomic performance, stress tolerance and nutritional quality, while integrating modern breeding approaches such as gene editing and marker-assisted selection to accelerate the development of high-yielding, disease-resistant and climate-resilient varieties.

Acknowledgements

The authors gratefully acknowledge the Department of Genetics and Plant Breeding, College of Agriculture, Vellayani, Thiruvananthapuram and ICAR- CTCRI, Sreekariyam, Thiruvananthapuram, for providing the necessary facilities, technical support and resources required to carry out this research. Furthermore, we extend our gratitude for the financial support provided by Kerala Agricultural University, Thrissur, which made this study possible.

Authors' contributions

BDA contributed to the development of the methodology, conducted the experimental procedures, carried out data collection and statistical analyses and assisted in drafting the original manuscript. NNC was involved in the conceptualisation and initial design of the study, contributed to methodology development, conducted experimental procedures, performed data collection and statistical analyses and assisted in drafting the manuscript. PM contributed to the conceptualisation and initial study design, participated in methodology development and critically reviewed and revised the manuscript. SS contributed to methodology development and performed data collection and statistical analyses. SG and BT participated in methodology development and were involved in the review and revision of the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Falcon WP, Naylor RL, Shankar ND. Rethinking global food demand for 2050. *Popul Dev Rev.* 2022;48(4):921–57. <https://doi.org/10.1111/padr.12508>
2. Noman AS, Hoque MA, Haque MM, Pervin F, Karim MR. Nutritional and anti-nutritional components in *Pachyrhizus erosus* L. tuber. *Food Chem.* 2007;102(4):1112–8. <https://doi.org/10.1016/j.foodchem.2006.06.055>
3. Kumar S, Gulzar M, Singh NK, Kumar S. Yam bean. Textbook of underexploited vegetable crop. Delhi: P.K. Publishers and Distributors; 2024. p. 376–84.
4. Poi SC, Pal PK. Isolation and characterization of bacteria involved in nodulation and nitrogen fixation in yam bean (*Pachyrhizus erosus*). *J Mycopathol Res.* 2009;47(2):203–6.
5. Sørensen M. A taxonomic revision of the genus *Pachyrhizus* (Fabaceae-Phaseoleae). *Nordic J Bot.* 1988;8(2):167–92. <https://doi.org/10.1111/j.1756-1051.1988.tb00499.x>
6. Tay Fernandez CG, Pati K, Severn-Ellis AA, Batley J, Edwards D. Studying the genetic diversity of yam bean using a new draft genome assembly. *Agron.* 2021;11(5):953. <https://doi.org/10.3390/agronomy11050953>
7. Zanklan AS, Becker HC, Sørensen M, Pawelzik E, Grüneberg WJ. Genetic diversity in cultivated yam bean (*Pachyrhizus* spp.) evaluated through multivariate analysis of morphological and agronomic traits. *Genet Resour Crop Evol.* 2018;65(3):811–43. <https://doi.org/10.1007/s10722-017-0582-5>

8. Pati K, Zhang F, Batley J. First report of genome size and ploidy of the underutilized leguminous tuber crop yam bean (*Pachyrhizus erosus* and *P. tuberosus*) by flow cytometry. *Plant Genet Resour.* 2019;17(5):456–59. <https://doi.org/10.1017/S1479262119000170>
9. Santayana M, Rossel G, Núñez J, Sørensen M, Delêtre M, Robles R, et al. Molecular characterization of cultivated species of the genus *Pachyrhizus* Rich. ex DC. by AFLP markers: calling for more data. *Trop Plant Biol.* 2014;7(3):121–32. <https://doi.org/10.1007/s12042-014-9143-7>
10. Grüneberg WJ, Freynhagen-Leopold P, Delgado-Vázquez O. A new yam bean (*Pachyrhizus* spp.) interspecific hybrid. *Genet Resour Crop Evol.* 2003;50(7):757–66. <https://doi.org/10.1023/A:1025007918878>
11. Akhtar N. Effect of physical and chemical mutagens on morphological behavior of tomato (*Solanum lycopersicum*) cv. Rio Grande under heat stress conditions. *Plant Breed Seed Sci.* 2014;70:69–79. <https://doi.org/10.1515/plass-2015-0014>
12. Laskar RA, Chaudhary C, Khan S, Chandra A. Induction of mutagenized tomato populations for investigation on agronomic traits and mutant phenotyping. *J Saudi Soc Agric Sci.* 2018;17(1):51–60. <https://doi.org/10.1016/j.jssas.2016.01.002>
13. Ahloowalia BS, Maluszynski M, Nichterlein K. Global impact of mutation-derived varieties. *Euphytica.* 2004;135(2):187–204. <https://doi.org/10.1023/b:euph.0000014914.85465.4f>
14. Nilahayati N, Rosmayati R, Hanafiah DS, Harahap F. Gamma irradiation induced chlorophyll and morphological mutation in Kipas Putih soybean. *Int J Sci Basic Appl Res.* 2016;30(3):74–79.
15. Sørensen M. Yam bean (*Pachyrhizus* DC.). Promoting the conservation and use of underutilized and neglected crops. 2. Gatersleben/Rome: Institute of Plant Genetics and Crop Plant Research/International Plant Genetic Resources Institute; 1996. p. 1–129.
16. Hayati PD, Witari S, Rozen N, Sutoyo S, Widiarsih S. Effect of gamma irradiation on the germination, pollen viability and morpho-agronomic of *Pachyrhizus erosus* cv. Kota Padang. *Biodiversitas J Biol Diversity.* 2022;23(3):1231–38. <https://doi.org/10.13057/biodiv/d230306>
17. Kerala Agricultural University. Package of practices recommendation: crops. 16th ed. Thrissur: Kerala Agricultural University; 2024. p. 435.
18. Mohsen G, Soliman SS, Mahgoub EI, Ismail TA, Mansour E, Alwutayd KM, et al. Gamma-rays induced mutations increase soybean oil and protein contents. *Peer J.* 2023;11:16395. <https://doi.org/10.7717/peerj.16395>
19. Akinyosoye ST, Adetumbi JA, Ukachukwu PC. Impact of sodium azide on maturity, seed and tuber yields in M1 African yam bean [*Sphenostylis stenocarpa* (Hochst ex A. Rich) Harms] generation. *Trop Agric.* 2021;98(1):16–27.
20. Eze CD, Adesoye AI, Adeosun CA. Effect of gamma radiation on morphological and molecular character of *Sphenostylis stenocarpa* (Hoechst. ex A. Rich.) Harms. *Ghana J Sci.* 2021;62(2):79–90. <https://doi.org/10.4314/gjs.v62i2.8>
21. Anas H, Bhupendra K, Subhra S, Pabitra A, Rajib D. Effect of physical and chemical mutagens on the growth performance of two soybean (TGX 1987-62F and TGX 1835-10E) varieties in the M1 generation. *Plant Sci. Today.* 2025;12(4):1–9. <https://doi.org/10.14719/pst.9136>
22. Olawuyi OJ, Inyang VE, Oladele DD, David SC. Mitotic studies, pollen fertility and morphological response of African yam bean (*Sphenostylis stenocarpa* (Hochst. ex A. Rich) Harms) to gamma radiation. *J Crop Sci Biotechnol.* 2023;26(4):499–510. <https://doi.org/10.1007/s12892-023-00194-4>
23. Saibari I, Barrijal S, Mouhib M, Belkadi N, Hamim A. Gamma irradiation-induced genetic variability and its effects on the phenotypic and agronomic traits of groundnut (*Arachis hypogaea* L.). *Front Genet.* 2023;14:1124632. <https://doi.org/10.3389/fgene.2023.1124632>
24. Tulmann Neto A, Ando A, Figueira AV de O, Latado RR, Santos PD, Correa LS, et al. Genetic improvement of crops by mutation techniques in Brazil. *Plant Mutat Rep.* 2011;2(3):24–37.
25. Geetha K, Vaidyanathan P. Studies on induction of chlorophyll mutations in soybean through physical and chemical mutagens. *Agric Sci Digest.* 2001;20(1):33–35.
26. Raina A, Laskar RA, Wani MR, Jan BL, Ali S, Khan S. Comparative mutagenic effectiveness and efficiency of gamma rays and sodium azide in inducing chlorophyll and morphological mutants of cowpea. *Plants.* 2022;11(10):1322. <https://doi.org/10.3390/plants11101322>
27. Hanafiah DS, Trikoesoemoningtyas T, Yahya S, Wirnas D. Induced mutations by gamma ray irradiation to Argomulyo soybean (*Glycine max*) variety. *Nusantara Biosci.* 2010;2(3):121–25. <https://doi.org/10.13057/nusbiosci/n020303>
28. Pramanik B, Debnath S, Rahimi M, Helal MM, Hasan R. Morphometric frequency and spectrum of gamma-ray-induced chlorophyll mutants identified by phenotype and development of novel variants in lentil (*Lens culinaris* Medik.). *PLoS One.* 2023;18(6):e0286975. <https://doi.org/10.1371/journal.pone.0286975>

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.