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Multivariate studies in kodo millet (*Paspalum scrobiculatum* L.) using a principal component analysis approach

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Abstract
The study evaluated genetic variability induced by gamma radiation in 250 M_5 mutant lines of Kodo millet (*Paspalum scrobiculatum* L.) derived from the Indira Kodo-1 variety, along with three check varieties, at the Instructional cum Research Farm, Shaheed Gundadhur College of Agriculture and Research Station, Jagdalpur, during *kharif* 2025. Principal Component Analysis (PCA) identified substantial variability, with the first Six principal components having eigenvalues greater than one and explaining 78.8% of the total variation. PC1 (22.5%) was primarily associated with grain yield per plant, biological yield per plant, grain weight per raceme, productive tillers per plant, and test weight, highlighting the importance of yield-related traits. PC2 (15.6%) was influenced by days to 50% flowering and days to maturity, PC3 (13.0%) reflected variation mainly due to productive tillers per plant, whereas PC4 (11.1%) was associated with test weight, flag leaf length, and raceme length. PC5 (8.7%) was characterized by harvest index and raceme length, while PC6 (7.9%) was mainly influenced by flag leaf width and plant height. The results confirm that gamma radiation effectively induces genetic variability in Kodo millet, with PCA serving as a robust tool to identify key traits contributing to this variability.

Keywords: Kodo millet, gamma radiation, M_5 generation, PCA, genetic variability

Introduction

Small millets, commonly known as nutri-cereals, are climate-resilient crops that play a vital role in sustainable agriculture and nutritional security under changing environmental conditions (Sharma *et al*., 2017) [22]. Their global importance has been further emphasized by the United Nations declaration of 2023 as the "International Year of Millets" to promote their cultivation and consumption (FAO/UN, 2021) [7]. Millets are rich in dietary fibre, minerals, and essential micronutrients, making them nutritionally superior to many staple cereals and highly suitable for rainfed and marginal agro-ecosystems (Rao *et al*., 2017) [18]. Among small millets, Kodo millet (*Paspalum scrobiculatum* L.) is an important yet underutilized, drought-tolerant cereal widely cultivated in India, particularly in tribal and resource-poor regions. It is well adapted to marginal soils and low-input agricultural conditions, making it a suitable crop for sustainable farming systems in semi-arid environments. Kodo millet is predominantly cultivated under rainfed and upland conditions where few alternative kharif crops can be successfully grown, highlighting its significance as a climate-resilient cereal (Kumar *et al*., 2018) [13]. Kodo millet is a self-pollinated tetraploid species with chromosome number 2n = 4x = 40, belonging to the family Poaceae (de Wet *et al*., 1983) [6]. Despite its ecological adaptability and long domestication history of nearly 3000 years (Arendt & Dal, 2008) [3], its productivity remains low due to a narrow genetic base and limited genetic improvement efforts. Crop improvement in Kodo millet is constrained by restricted genetic variability in cultivated germplasm. In this context, induced mutation breeding through gamma irradiation is an effective approach for generating novel heritable variability in crops with limited genetic diversity (Ahloowalia *et al*., 2004; Oladosu *et al*., 2016) [1, 17]. Advanced generations such as M_5 are crucial for identifying stable and superior genotypes. Moreover, Principal Component Analysis (PCA) is widely used to assess genetic variability and identify key traits contributing to yield and diversity (Jolliffe & Cadima, 2016) [11]. Therefore, the present study evaluates gamma radiation-induced M_5 mutant lines of Kodo millet using PCA to assess genetic variability and identify promising genotypes for crop improvement.

Materials and Methods

A field experiment was conducted during the *kharif* season of 2025 at the Instructional-cum-Research Farm, Shaheed Gundadhur College of Agriculture and Research Station, Jagdalpur, Bastar, Chhattisgarh, India (19°05′ N latitude, 82°02′ E longitude, altitude 554 m) in the Bastar Plateau agro-climatic zone. The experimental material comprised 250 M_5 mutant lines of Kodo millet (*Paspalum scrobiculatum* L.) developed from the variety IK-01 (Indira Kodo-1) through gamma irradiation. The experiment was arranged in an Augmented Complete Block Design with five blocks; three check varieties were replicated across all blocks, while mutant lines were grown unreplicated and randomly assigned within each block. Sowing was performed on 15th June 2025, maintaining a spacing of 22.5 cm between rows and 10 cm between plants. Thirteen quantitative traits were recorded: days to 50% flowering, days to maturity, plant height, flag leaf length, flag leaf width, productive tillers per plant, length of raceme, number of grains per raceme, grain weight per raceme, biological yield per plant, harvest index, test weight, and grain yield per plant. The collected data were subjected to statistical analysis to assess genetic variability and trait inter-relationships. Principal Component Analysis (PCA) was employed as a multivariate data reduction technique to summarize overall variability, using eigenvalues, percentage of variance, eigenvector loadings, and biplot analysis to interpret the contribution of traits to genetic divergence among mutant lines (Rao, 1952) [19].

Results and Discussion

Principal Component Analysis (PCA) transforms a group of correlated variables into a smaller set of uncorrelated and meaningful components known as principal components, without losing its original variability (Sharma *et al*. 2022) [21]. In the Present study, PCA revealed that first six PCs with eigen value greater than 1.0, accounted for 78.8% of the total variability among 250 mutant lines of Kodo millet evaluated for 13 traits (Table 1). PC1 showed the highest eigenvalue of 2.922 and individually explaining 22.5% of the total genetic variance followed by PC2 with an eigenvalue of 2.032 and15.6% of the total phenotypic variation. PC3 recorded an eigenvalue of 1.689 and accounted for 13.0% of the genetic diversity among the Kodo millet lines, while PC4 displayed an eigenvalue of 1.438, contributing 11.1% to the overall observed variation. The final two significant components retained under the criterion, PC5 and PC6, registered eigenvalues of 1.128 and 1.031, capturing 8.7% and 7.9% of the remaining variance, respectively.

The present findings are in agreement with earlier reports in millets. Chaudhary *et al*. (2015) [4] reported that six principal components accounted for 77.7% of the total variability among 66 pearl millet genotypes. Kumari *et al*. (2018) [14] reported 78.0% total variability explained by six principal components in finger millet [*Eleusine coracana* (L.) Gaertn.]. Monika *et al*. (2025) [16] reported 76.64% of the total variation explained by six principal components in finger millet.

Loading Factors (Trait Contributions to Principal Components)

Characters associated with high positive loadings contribute most to the variation captured by the principal components. (Das *et al*. 2024) [5]. In PC1, (Table 2) high positive loadings were observed for grain yield per plant (0.565), biological yield per plant (0.515), grain weight per raceme (0.434), number of grains per raceme (0.276), productive tillers per plant (0.268), and test weight (0.230). Positive loadings were also recorded for flag leaf width (0.106) and harvest index (0.091). Negative loadings were observed for days to 50% flowering (-0.057), days to maturity (-0.055), flag leaf length (-0.012), and length of raceme (-0.001), whereas plant height (0.005) showed a negligible loading. The high positive loadings of grain yield per plant, biological yield per plant, grain weight per raceme, number of grains per raceme, productive tillers per plant, and test weight indicate that PC1 was primarily associated with yield and yield-attributing traits, suggesting their importance in differentiating the mutant lines. Similar findings were reported by Joshi *et al*. (2025) [12], where productive tillers per plant, number of grains per raceme, biological yield, test weight, grain yield per raceme, and harvest index showed positive loadings in PC1.

In PC2, high positive loadings for days to maturity (0.630) and days to 50% flowering (0.628), followed by test weight (0.289), flag leaf length (0.194), and grain weight per raceme (0.172). Negative loadings were observed for productive tillers per plant (-0.146), number of grains per raceme (-0.077), biological yield per plant (-0.045), and flag leaf width (-0.033). The component was mainly represented by days to maturity and days to 50% flowering. Consistent with the present findings, Chaudhary *et al*. (2015) [4] identified days to maturity (0.236) and days to 50% flowering (0.243) as the major contributors to PC2 in pearl millet. In PC3, high positive loadings for productive tillers per plant (0.607) and biological yield per plant (0.282), followed by days to maturity (0.210), days to 50% flowering (0.205), grain yield per plant (0.149), and plant height (0.068). Negative loadings were observed for grain weight per raceme (-0.449), number of grains per raceme (-0.295), harvest index (-0.276), and test weight (-0.257), in agreement with the findings of Ladumor *et al*. (2021) [15] in finger millet.

PC4 was characterized by high positive loadings for test weight (0.498), flag leaf length (0.412), and length of raceme (0.303). Positive loadings were also observed for productive tillers per plant (0.078), flag leaf width (0.066), biological yield per plant (0.027), grain yield per plant (0.014), and harvest index (0.002). Negative loadings were recorded for number of grains per raceme (-0.545), plant height (-0.313), days to 50% flowering (-0.204), days to maturity (-0.194), and grain weight per raceme (-0.068). Comparable results were reported by Ratnam and Latha (2024) [20], where test weight, panicle length, and productive tillers per plant showed positive loadings. PC5 and PC6 were mainly associated with morphological and yield-related traits. PC5 exhibited high positive loadings for length of raceme (0.404), biological yield per plant (0.235), and plant height (0.201), whereas PC6 was characterized by high negative loadings for flag leaf width (-0.717) and plant height (-0.665).

PCA Biplot Analysis

The biplot (Fig. 1) displays the first two principal components (PC1 and PC2), which capture the majority of the variability among the 250 M_5 mutant lines of Kodo millet. Each data point represents an observation plotted in this reduced-dimensional space using its factor scores. Variables are depicted as vectors radiating from the origin, where the direction of each arrow indicates the contribution of that variable to the principal components, and the length reflects the strength of this influence. Longer arrows correspond to variables with a greater impact on explaining variance within the data, emphasizing their importance (Shashibhushan *et al*., 2022, Gabriel, 1971) [23, 8]. The angles between arrows reveal correlations among variables: small angles indicate strong positive correlations, perpendicular arrows signify no correlation, and arrows pointing in opposite directions denote negative correlations. The projection of individual observations onto these vectors further illustrates how strongly each observation is associated with specific variables, offering insight into the relationships between genotypes and traits (Wedlake, 2008, Gower & Hand, 1995, Holland, 2008) [25, 9, 10].In this study, yield-related traits such as grain yield per plant, biological yield per plant, grain weight per raceme, number of grains per raceme, productive tillers per plant, and test weight cluster together with long vectors, confirming their significant and positively correlated contribution to PC1 and overall genetic variability, while phenological traits like days to 50% flowering and days to maturity align closely with PC2, highlighting their role in phenotypic differentiation among the mutant lines. Similar interpretations of PCA biplots, where trait vectors indicated the magnitude of contribution to variability and the association among traits, were reported by Sulthana *et al*. (2021) [24] and Akshaya *et al*. (2024) [2].

Table 1: Eigenvalues and variance explained for the first six principal components

Characters	Eigenvalues	Proportion	Cumulative Proportion
PC1	2.922	0.225	0.225
PC2	2.032	0.156	0.381
PC3	1.689	0.130	0.511
PC4	1.438	0.111	0.622
PC5	1.128	0.087	0.708
PC6	1.031	0.079	0.788

Table 2: Factor loadings of quantitative traits with respect to the first six principal components

Characters	PC1	PC2	PC3	PC4	PC5	PC6
Days to 50% flowering	-0.057	0.628	0.205	-0.204	-0.016	0.046
Days to maturity	-0.055	0.630	0.210	-0.194	-0.022	0.028
Plant height (cm)	0.005	0.054	0.068	-0.313	0.201	-0.665
Flag leaf length (cm)	-0.012	0.194	-0.007	0.412	-0.135	-0.095
Flag leaf width (cm)	0.106	-0.033	-0.086	0.066	-0.309	-0.717
Productive tillers per plant	0.268	-0.146	0.607	0.078	-0.266	0.021
Length of raceme (cm)	-0.001	0.090	-0.024	0.303	0.404	-0.093
Number of grains per raceme	0.276	-0.077	-0.295	-0.545	0.051	0.102
Grain weight per raceme(g)	0.434	0.172	-0.449	-0.068	0.137	0.039
Biological yield per plant (g)	0.515	-0.045	0.282	0.027	0.235	0.011
Harvest index (%)	0.091	0.127	-0.276	0.002	-0.712	0.081
Test weight (g)	0.230	0.289	-0.257	0.498	0.127	-0.046
Grain yield per plant (g)	0.565	0.012	0.149	0.014	-0.106	0.051

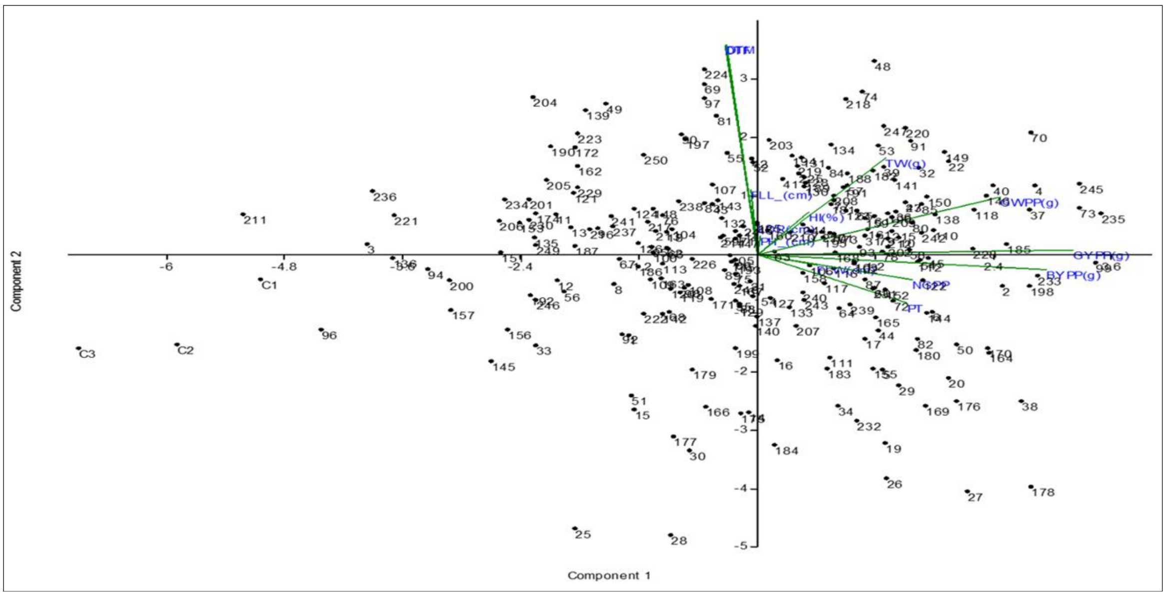

Fig 1: PCA biplot showing relationships among yield and related traits in Kodo millet

Conclusion

The present study revealed that gamma radiation effectively induced substantial genetic variability among 250 M_5 mutant lines of Kodo millet. Principal Component Analysis (PCA) extracted six principal components with eigenvalues greater than one, explaining 78.8% of the total phenotypic variation, indicating the effectiveness of PCA in summarizing genetic diversity. The first principal component was mainly influenced by grain yield per plant, biological yield per plant, grain weight per raceme, number of grains per raceme, productive tillers per plant, and test weight, highlighting their major contribution to yield improvement. Strong associations among yield-related traits suggest their key role in determining genetic divergence and overall productivity. Induced mutagenesis proved to be an effective approach for broadening the genetic base in Kodo millet. Grain yield per plant, biological yield per plant, grain weight per raceme, productive tillers per plant, and test weight can be considered reliable selection criteria for identifying superior mutant lines.

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References

1. Ahloowalia BS, Maluszynski M, Nichterlein K. Global impact of mutation-derived varieties. Euphytica. 2004;135(2):187-204.
2. Akshaya M, Geetha K, Nirmalakumari A, Sharavan PT, Sivakumar C, Parasuraman P. Genetic variability, correlation and principal component analysis for yield related traits in pigeonpea [*Cajanus cajan* (L.) Millsp.]. Legume Res. 2024;47(7):1094-1098.
3. Arendt E, Dal Bello F. Gluten-free cereal products and beverages. Cambridge: Academic Press; 2008.
4. Chaudhary S, Sagar P, Hooda BK, Arya RK. Multivariate analysis of pearl millet data to delineate genetic variation. Forage Res. 2015;40(4):201-208.
5. Das A, Pal S, Chakraborty N, Hasanuzzaman M, Adak MK. Regulation of reactive oxygen species metabolism and oxidative stress signaling by abscisic acid pretreatment in rice (*Oryza sativa* L.) seedlings through sub1A QTL under salinity. Plant Stress. 2024;11:100422.
6. de Wet JM, Brink DE, Rao KP, Mengesha MH. Diversity in Kodo millet (*Paspalum scrobiculatum*). Econ Bot. 1983;37(2):159-163.
7. Food and Agriculture Organization of the United Nations. World food and agriculture - Statistical yearbook 2021. Rome: FAO; 2021.
8. Gabriel KR. The biplot graphic display of matrices with application to principal component analysis. Biometrika. 1971;58(3):453-467.
9. Gower JC, Hand DJ. Biplots. Boca Raton: CRC Press; 1995.
10. Holland SM. Principal components analysis (PCA). Athens: Department of Geology, University of Georgia; 2008.
11. Jolliffe IT, Cadima J. Principal component analysis: a review and recent developments. Philos Trans A Math Phys Eng Sci. 2016;374(2065):20150202.
12. Joshi T, Datta A, Kar S, Nag NK, Kumar P. Multivariate approaches for evaluating phenotypic variability and trait associations in M4 generation of Kodo millet (*Paspalum scrobiculatum* L.) mutants obtained by gamma radiation. Int J Adv Biochem Res. 2025;9(9 Suppl):36-42.
13. Kumar P, Sao A, Thakur AK, Yadav SC, Sahu P. Resourceful photosynthesis system and stem reserve accumulation plays decisive role in grain yield of Kodo millet (*Paspalum scrobiculatum*). Indian J Hill Farm. 2018;31(1):1-8.
14. Kumari WMR, Pushpakumara DKNG, Weerakoon WMW, Senanayake DMJB, Upadhyaya HD. Morphological characterization of local and introduced finger millet (*Eleusine coracana* (L.) Gaertn) germplasm in Sri Lanka. Trop Agric Res. 2018;29(2):167-183.
15. Ladumor VL, Patil HE, Modha KG. Genetic diversity in finger millet (*Eleusine coracana* (L.) Gaertn) using principal component analysis. Pharma Innov J. 2021;10(9):1827-1831.
16. Monika S, Vanniarajan C, Meena S, Vetriventhan M, Sakthivel K, Ramesh T. Exploring the agro-morphological performance of mini core collection of finger millet [*Eleusine coracana* (L.) Gaertn] germplasm under sodic condition. Genet Resour Crop Evol. 2025;72(Suppl 1):S673-S696.
17. Oladosu Y, Rafii MY, Abdullah N, Hussin G, Ramli A, Rahim HA, *et al*. Principle and application of plant mutagenesis in crop improvement: a review. Biotechnol Biotechnol Equip. 2016;30(1):1-16.
18. Rao BD, Bhaskarachary K, Arlene Christina GD, Sudha Devi G, Tonapi AA. Nutritional and health benefits of millets. Hyderabad: ICAR-Indian Institute of Millets Research (IIMR); 2017. p. 38-57.
19. Rao CR. Advanced statistical methods in biometric research. New York: John Wiley and Sons; 1952.
20. Ratnam TV, Latha LM. Genetic diversity studies for yield and physiological traits using principal component analysis in little millet. Electron J Plant Breed. 2024;15(4):986-997.
21. Sharma N, Bandyopadhyay BB, Chand S, Pandey PK, Baskheti DC, Malik A, *et al*. Determining selection criteria in finger millet (*Eleusine coracana*) genotypes using multivariate analysis. Indian J Agric Sci. 2022;92(6):763-768.
22. Sharma D, Jamra G, Singh UM, Sood S, Kumar A. Calcium biofortification: three-pronged molecular approaches for dissecting complex trait of calcium nutrition in finger millet (*Eleusine coracana*) for devising strategies of enrichment. Front Plant Sci. 2017;7:20.
23. Shashibhushan D, Kumar CS, Kondi RKR. Principal component analysis for yield and yield-related traits in pearl millet cultivars. Ecol Environ Conserv. 2022;28(Suppl):S104-S107.
24. Sulthana SJ, Chitra S, Thirumurugan T, Jeyaprakash P, Geethanjali S. Identification of selection indices for the

yield enhancement in cowpea (*Vigna unguiculata* (L.) Walp) under sodic condition. Electron J Plant Breed. 2021;12(3):956-962.
25. Wedlake RS. Robust principal component analysis biplots [doctoral dissertation]. Stellenbosch: Stellenbosch University; 2008.