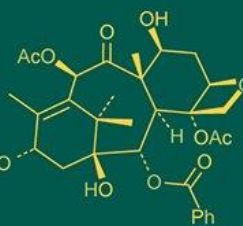
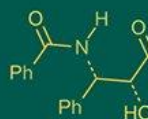


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(8): 356-362
www.biochemjournal.com
Received: 05-05-2026
Accepted: 10-06-2026

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Exploiting EMS-induced genetic variability for agro-morphological improvement in EMS-derived M₆ mutant lines of rice variety 'Gurjari' (*Oryza sativa* L.)

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i8Se.9451>

Abstract

The present investigation was undertaken to evaluate the genetic variability, heritability and genetic advance among EMS-induced M₆ mutant lines of rice (*Oryza sativa* L.) cv. A total of 101 M₆ mutant lines along with the parental variety were evaluated during *Kharif*-2024 at the Regional Rice Research Station, Navsari Agricultural University, Vyara, Gujarat, using a Randomized Block Design with three replications. Thirteen agro-morphological traits were recorded and analyzed through analysis of variance, genotypic and phenotypic coefficients of variation, broad-sense heritability and genetic advance as percent of mean. Analysis of variance revealed significant differences among the mutant lines for all traits, confirming that EMS mutagenesis generated substantial genetic variability. High genotypic and phenotypic variation was recorded for grains per panicle, straw yield and grain yield, while the narrow differences between genotypic and phenotypic coefficients of variation for flowering time, maturity, plant height, panicle length, and 100-grain weight indicated minimal environmental influence on these traits. High heritability coupled with high genetic advance was observed for grains per panicle, straw yield per plant, plant height, panicle length and 100-grain weight, suggesting the predominance of additive gene action and the effectiveness of direct phenotypic selection. Overall, the study demonstrated that EMS mutagenesis effectively broadened the genetic base of the Gurjari rice cultivar and generated useful variability for yield and its associated traits. These findings provide valuable genetic resources for the development of high-yielding rice cultivars through mutation breeding.

Keywords: Mutant lines, EMS mutagenesis, genetic variability, heritability, genetic advance

Introduction

Rice (*Oryza sativa* L.) is one of the world's most important cereal crops and serves as the primary staple food for more than half of the global population. Belonging to the family *Poaceae* and subfamily *Oryzoideae* (Khush, 1997). As a self-pollinated, short-day C₃ crop, it contributes substantially to global food and nutritional security, providing over half of the daily caloric intake for nearly one-third of the world's population (Maclean *et al.*, 2002) [12]. In India, rice occupied an area of about 477.30 lakh hectares, with a production of 1364.37 lakh tonnes and productivity of 2.86 t ha⁻¹ during 2024-25 (Anon., 2025a) [4]. In Gujarat, rice cultivation covered an area of 10.13 lakh hectares, producing 26.01 lakh tonnes with a productivity of 2567 kg ha⁻¹ in 2024-25 (Anon., 2025b) [5]. The major rice-growing districts of Gujarat include Ahmedabad, Kheda, Mahisagar, Anand, Vadodara, Dahod, Panchmahals, Surat, Valsad, Tapi, The Dangs and Navsari.

Despite remarkable advances achieved through conventional breeding, further improvement in rice productivity has become increasingly challenging due to the narrowing genetic base of elite cultivars, continuous selection pressure and the adverse effects of climate change. The limited availability of genetic variation restricts the development of high-yielding, climate-resilient cultivars. Consequently, the creation and utilization of new genetic variability have become important priorities in modern rice improvement programmes (Anon., 2023; Anon., 2024) [2, 3].

Induced mutagenesis has proven to be an effective complementary breeding approach for generating novel allelic variation without substantially altering the desirable genetic

background of well-adapted cultivars. Among chemical mutagens, Ethyl Methane Sulphonate (EMS) is one of the most widely used owing to its high mutagenic efficiency, ease of application and ability to induce predominantly point mutations with minimal chromosomal aberrations. EMS-derived mutant populations have successfully generated useful variability for several agronomic traits, including plant architecture, maturity, grain yield and stress tolerance, thereby expanding the genetic resources available for rice improvement (Naik *et al.*, 2022; Chendake *et al.*, 2023) [15, 9].

Grain yield is a complex quantitative trait governed by the interaction of several agro-morphological components such as flowering time, maturity, plant height, productive tillers, panicle length, grains per panicle, grain weight, and harvest index. Since these traits are influenced by both genetic and environmental factors, an understanding of the magnitude of genetic variability and the nature of gene action controlling them is essential for effective selection. Estimation of genotypic and phenotypic coefficients of variation, heritability, and genetic advance provides valuable information for identifying traits with greater breeding potential. High heritability coupled with high genetic advance generally indicates the predominance of additive gene action and suggests that direct phenotypic selection is likely to be effective in achieving genetic improvement.

Although several studies have reported the effectiveness of EMS mutagenesis in rice, information on the genetic variability and inheritance of agro-morphological traits in advanced-generation EMS-derived mutant populations of the popular Gujarat rice cultivar Gurjari remains limited. Evaluation of stabilized M₆ mutant lines offers an excellent opportunity to identify heritable and agronomically valuable mutations with potential use in breeding programmes.

Therefore, the present investigation was undertaken to assess the extent of genetic variability, heritability and genetic advance among EMS-derived M₆ mutant lines of the rice cultivar Gurjari using thirteen agro-morphological traits. The study aims to identify key traits governed predominantly by additive gene action and to generate valuable genetic resources that can be effectively utilized for the development of high-yielding rice cultivars through mutation breeding.

Materials and Methods

Experimental site and study area

The present investigation was carried out at Regional Rice Research Station, Navsari Agricultural University, Vyara, Gujarat, India, during *Kharif* - 2024. The experimental site is located in the south Gujarat agro-climatic zone and is characterized by a tropical monsoon climate with high humidity and well distributed rainfall throughout the cropping season.

The soil of the experimental field is medium black to alluvial in nature with good fertility status and water-holding capacity, making it highly suitable for rice cultivation. Standard agronomic practices recommended for the region were followed throughout the experiment to ensure optimum crop growth and development.

Experimental material and development of mutant population

The experimental material comprised 101 EMS-induced M₆ mutant lines derived from the rice cultivar Gurjari, including the parental variety Gurjari as a control. The mutant

population was advanced from M₁ to M₅ generations through selection based on phenotypic performance from summer 2022 to summer 2024. 100 mutants selected in M₅. The 101 M₆ mutant lines along with the parent cultivar were evaluated in a Randomized Block Design (RBD) with three replications during *Kharif* - 2024. Each genotype was grown in a plot with spacing of 20 x 15 cm. All recommended agronomic practices, including irrigation, fertilizer application and plant protection measures, were uniformly followed throughout the experimental period. The experimental design was structured to minimize environmental variation and ensure accuracy and reliability of experimental results.

Data collection and traits recorded

Observations were recorded from five randomly selected competitive plants per genotype in each replication except days to 50% flowering and days to maturity taken on plot basis. Thirteen quantitative agro-morphological traits were evaluated according to the Standard Evaluation System (SES) for Rice (Anon., 2013) [1]. The traits included days to 50% flowering (DFF), days to maturity (DM), plant height (PH, cm), productive tillers per plant (PTP), panicle length (PL, cm), grains per panicle (GP), 100-grain weight (100-GW, g), grain length (GL, mm), grain breadth (GB, mm), length-to-breadth ratio (L/B), grain yield per plant (GYP, g), straw yield per plant (SYP, g) and harvest index (HI,%). Grain length and grain breadth were measured using a digital image analyzer and the mean values were calculated from ten randomly selected grains for each genotype.

Statistical Analysis

The experimental data were analyzed at the Department of Genetics and Plant Breeding, N. M. College of Agriculture, Navsari Agricultural University, Navsari. Analysis of variance (ANOVA) was performed under a RBD as per Panse and Sukhatme (1978) [17] to test the significance of differences among genotypes.

Genotypic and phenotypic coefficients of variation (GCV and PCV) were computed following Burton and Devane (1953) [6]. Broad-sense heritability was estimated as the ratio of genotypic variance to phenotypic variance. Genetic advance and genetic advance as percent of mean were calculated following Johnson *et al.* (1955) [11]. All statistical analyses including ANOVA and variability parameters analysis were performed using Agri Analyze software (Popat *et al.*, 2024) [18].

Results and Discussion

Variability Analysis among EMS-Induced M₆ Mutant Progenies

The analysis of variance revealed highly significant differences among the 101 EMS-induced M₆ mutant progenies of Gurjari rice for all the thirteen quantitative traits studied (Table 2). The treatment mean squares were highly significant for all studied agro- morphological traits indicating the existence of substantial genetic variability among the mutant progenies. The observed variability confirmed the effectiveness of EMS mutagenesis in inducing genetic alterations and generating variation for economically important traits. Similar findings of significant variability among rice mutants have been reported by Harish Chandar *et al.* (2022) [7] in EMS-induced BPT-5204 rice mutants and by Sandeep *et al.* (2018) [19] in diverse rice genotypes.

Mean Performance and Range of Variation

The mean performance, range of variation, standard error, critical difference, and coefficient of variation for the thirteen quantitative traits studied are presented in Table 1. The wide range of variation observed for all traits indicated the effectiveness of EMS mutagenesis in generating useful variability among the M₆ mutant progenies.

Days to 50% flowering varied from 77.33 days in mutant 24KM₆-28 to 104.33 days in mutant 24KM₆-93 with a population mean of 87.54 days (Table 1). Similarly, days to maturity ranged from 103.33 to 129.33 days with a mean of 114.13 days. The occurrence of early flowering and early maturing mutants is beneficial for developing short-duration rice cultivars suitable for multiple cropping systems and stress-prone environments. Similar variability for phenological traits has been reported by Sandeep *et al.* (2018) [19].

Plant height exhibited considerable variation with a mean value of 114.83 cm (Table 1). The shortest plant height was recorded in mutant 24KM₆-59 (42.93 cm), while mutant 24KM₆-52 (180.00 cm) exhibited the maximum plant height. The occurrence of dwarf and semi-dwarf mutants is particularly valuable because reduced plant stature contributes to lodging resistance and improved harvest index. Similar observations were reported by Chandar *et al.* (2022) [7].

Panicle length ranged from 11.80 cm to 35.93 cm, with a mean of 24.73 cm (Table 1). The longest panicle was

recorded in mutant 24KM₆-93, whereas mutant 24KM₆-59 exhibited the shortest panicle length. Productive tillers per plant varied from 4.40 to 12.07 with a mean value of 7.49. Mutant 24KM₆-03 recorded the highest number of productive tillers. Grains per panicle exhibited extensive variation ranging from 13.20 to 263.13 grains with a mean value of 123.90 grains, with mutant 24KM₆-47 recording the maximum number. Similar observations regarding variability in panicle and yield component traits were reported by Divya *et al.* (2018) [10].

The 100- grain weight varied from 1.46 g to 3.34 g, with a mean value of 2.56 g (Table 1). Grain yield per plant ranged from 3.98 g to 31.45 g with a mean value of 19.80 g, where mutant 24KM₆-65 recorded the highest grain yield. Straw yield per plant ranged from 7.05 g to 46.03 g, with mutant 24KM₆-93 producing the maximum straw yield. Harvest index ranged from 28.86% to 62.72%, with mutant 24KM₆-82 recording the highest harvest index. These results indicate the effectiveness of EMS mutagenesis in generating variability for yield and its component traits. Similar findings have been reported by Harish Chandar *et al.* (2022) [7]. Grain quality traits also exhibited considerable variability (Table 1). Grain length ranged from 7.14 mm to 11.04 mm, grain breadth from 1.91 mm to 3.18 mm, and grain L/B ratio from 2.90 to 5.02. The substantial variation observed in grain dimensions provides opportunities for improving grain quality and consumer preference.

Table 1: Mean performance and range for various M₆ EMS induced Gurjari derived rice traits

M ₆ Progenies	Traits												
	DF	DM	PH	PL	PTP	GP	100 GW	GYP	SYP	HI	GL	GB	L/B
24KM ₆ -1	91.00	118.00	107.60	23.93	7.67	122.20	2.96	23.94	15.40	54.89	9.40	2.90	3.24
24KM ₆ -2	92.00	117.33	130.93	26.00	7.27	225.27	1.94	22.46	22.62	53.28	8.93	2.55	3.55
24KM ₆ -3	88.67	115.67	83.80	18.20	12.07	34.73	2.56	16.19	16.10	41.35	9.29	2.51	3.70
24KM ₆ -4	90.33	116.00	97.20	21.93	8.13	96.33	2.49	16.85	15.89	52.00	9.20	2.69	3.46
24KM ₆ -5	92.00	120.00	84.93	17.87	11.53	39.27	2.54	10.05	12.69	43.56	9.25	2.60	3.56
24KM ₆ -6	87.67	113.67	117.93	24.87	6.47	152.20	3.34	28.97	18.52	60.75	9.47	2.78	3.42
24KM ₆ -7	90.00	117.33	123.73	23.20	8.40	109.60	3.17	24.98	24.09	47.23	9.84	2.85	3.46
24KM ₆ -8	89.67	117.33	78.27	20.47	8.53	67.73	2.82	14.10	14.45	41.69	9.49	2.50	3.81
24KM ₆ -9	99.33	125.33	129.27	30.27	7.20	155.80	2.94	26.63	29.26	47.41	9.54	2.71	3.53
24KM ₆ -10	89.33	118.33	109.07	28.60	5.73	142.60	1.46	11.26	15.47	41.06	8.41	2.52	3.36
24KM ₆ -11	93.33	119.33	120.27	27.07	5.87	134.40	2.20	14.47	19.77	42.62	9.70	2.34	4.15
24KM ₆ -12	84.00	114.00	111.00	24.53	6.00	117.20	2.84	16.43	17.39	48.85	7.14	2.74	3.44
24KM ₆ -13	87.00	113.00	109.93	23.40	9.60	123.00	2.35	24.87	25.38	48.35	8.21	2.60	3.18
24KM ₆ -14	90.67	119.67	112.07	23.60	9.73	127.07	2.08	19.65	31.95	38.57	7.76	2.47	3.16
24KM ₆ -15	88.33	115.33	137.00	28.47	6.87	176.60	2.52	27.42	26.42	49.22	9.68	2.55	3.88
24KM ₆ -16	90.67	119.00	142.47	28.53	6.73	175.47	2.98	27.84	30.29	48.63	9.94	2.72	3.67
24KM ₆ -17	86.67	112.67	69.33	18.47	8.27	35.93	1.88	7.13	13.12	36.57	9.02	2.51	3.60
24KM ₆ -18	90.33	117.33	134.67	25.73	7.60	169.80	3.16	24.54	29.41	42.82	9.41	2.95	3.23
24KM ₆ -19	84.00	109.00	112.80	25.60	5.80	138.33	2.74	17.74	17.21	49.65	8.53	2.82	3.04
24KM ₆ -20	89.67	119.67	136.93	25.47	5.87	178.13	2.97	23.20	20.61	52.68	9.51	3.10	3.10
24KM ₆ -21	87.33	114.33	112.33	23.53	6.53	104.33	2.86	17.95	14.72	53.74	9.71	2.88	3.40
24KM ₆ -22	81.00	110.00	135.07	26.33	7.80	142.93	3.10	26.92	18.75	57.38	9.77	2.76	3.55
24KM ₆ -23	82.33	109.33	130.13	26.07	7.13	152.53	2.14	20.59	23.22	46.88	8.83	2.48	3.57
24KM ₆ -24	93.33	122.33	129.27	25.20	8.20	135.20	2.41	19.33	25.46	42.10	9.15	2.81	3.28
24KM ₆ -25	90.00	118.00	109.73	25.67	7.67	144.40	2.16	20.85	19.74	51.26	8.50	2.70	3.17
24KM ₆ -26	98.33	127.33	135.47	27.93	7.80	163.93	2.14	24.27	31.68	42.83	9.40	2.46	3.87
24KM ₆ -27	86.67	112.67	108.53	23.93	7.80	95.47	2.90	16.71	17.19	48.43	11.04	2.29	4.86
24KM ₆ -28	77.33	103.33	130.13	20.60	9.13	98.40	1.71	11.78	27.95	30.35	8.25	2.31	3.60
24KM ₆ -29	86.67	112.67	107.13	24.67	7.67	115.60	2.31	18.38	17.48	51.33	8.74	2.72	3.27
24KM ₆ -30	85.00	110.00	111.47	23.67	10.33	107.00	3.09	26.48	21.10	55.44	9.54	2.79	3.44
24KM ₆ -31	81.33	108.33	85.33	21.27	7.93	72.67	1.66	8.10	7.05	51.67	8.44	2.26	3.74
24KM ₆ -32	87.33	113.33	107.00	28.47	8.20	156.73	1.52	13.41	14.98	45.48	8.40	2.15	3.91
24KM ₆ -33	88.00	115.00	106.87	26.20	7.60	111.87	2.89	19.33	21.45	46.15	9.41	2.64	3.58
24KM ₆ -34	84.67	110.67	116.20	27.07	8.67	141.33	1.89	17.83	21.68	45.21	8.49	2.19	3.91
24KM ₆ -35	83.33	109.33	86.87	21.80	7.27	66.80	1.67	8.63	11.75	41.00	7.70	2.31	3.33
24KM ₆ -36	86.67	112.67	102.87	24.33	8.07	85.53	2.82	24.53	22.11	49.68	9.53	2.70	3.55
24KM ₆ -37	84.33	109.33	99.40	26.27	8.20	161.73	2.51	26.92	17.34	61.11	8.89	2.32	3.83

24KM ₆ -38	87.33	114.33	109.87	23.27	6.40	130.67	3.15	20.87	13.65	60.10	9.27	2.56	3.65
24KM ₆ -39	84.67	110.67	96.33	22.13	7.40	92.27	3.02	20.28	13.75	58.61	9.69	2.73	3.57
24KM ₆ -40	85.33	112.33	91.67	22.00	7.60	90.73	3.21	21.20	13.95	59.72	9.98	2.88	3.48
24KM ₆ -41	87.67	113.67	81.40	20.73	4.40	53.60	2.25	6.60	8.11	42.11	8.54	2.39	3.57
24KM ₆ -42	88.33	114.33	113.00	23.40	6.53	124.67	2.94	22.19	13.85	61.10	9.49	2.74	3.50
24KM ₆ -43	94.33	120.33	125.13	26.33	7.33	132.20	3.04	25.58	23.02	52.44	9.61	2.56	3.77
24KM ₆ -44	81.00	106.00	105.60	26.13	8.40	113.53	2.24	15.64	13.05	55.06	9.41	2.38	3.96
24KM ₆ -45	86.67	113.67	101.33	26.27	8.33	95.33	2.35	16.52	17.27	49.03	10.30	2.29	4.56
24KM ₆ -46	90.00	116.00	118.00	27.13	7.47	127.60	2.34	20.00	19.25	51.02	10.64	2.28	4.71
24KM ₆ -47	90.67	117.67	138.40	26.80	5.93	263.13	1.85	26.96	21.73	54.72	7.69	2.39	3.22
24KM ₆ -48	85.33	111.33	112.27	21.93	7.00	119.13	2.97	23.83	17.28	58.13	9.13	2.94	3.15
24KM ₆ -49	89.67	115.67	111.93	27.67	6.47	132.27	2.53	24.09	19.20	55.25	9.56	2.61	3.68
24KM ₆ -50	82.00	108.00	88.67	24.00	10.13	89.20	2.49	19.26	16.12	53.10	9.50	2.32	4.13
24KM ₆ -51	89.00	114.00	89.67	24.60	7.60	100.00	2.35	16.81	20.34	46.15	10.20	2.40	4.27
24KM ₆ -52	88.67	115.67	180.00	26.27	8.47	194.87	2.40	28.44	34.04	44.47	9.63	2.38	4.05
24KM ₆ -53	86.00	112.00	166.73	27.20	7.13	170.00	2.70	25.59	28.29	47.31	9.31	2.61	3.57
24KM ₆ -54	87.33	114.33	115.67	24.07	6.60	118.93	3.12	21.42	16.49	56.23	9.64	2.77	3.48
24KM ₆ -55	99.00	125.00	122.13	25.07	9.93	115.00	1.73	19.13	34.46	36.76	9.49	2.08	4.57
24KM ₆ -56	88.00	114.00	100.73	23.13	7.27	103.07	2.85	19.59	15.72	55.63	9.48	2.63	3.61
24KM ₆ -57	97.67	123.67	112.87	25.40	6.47	223.60	2.53	30.16	24.21	55.92	8.45	2.58	3.28
24KM ₆ -58	81.67	106.67	98.07	21.80	7.47	112.87	2.24	22.58	16.83	57.47	8.82	2.46	3.60
24KM ₆ -59	92.00	119.00	42.93	11.80	8.93	13.20	2.13	3.98	8.45	28.86	8.46	2.19	3.86
24KM ₆ -60	82.00	108.00	81.60	18.87	9.93	57.53	2.60	13.84	15.13	46.69	9.51	2.65	3.60
24KM ₆ -61	81.33	108.33	98.93	22.67	5.87	107.67	2.75	18.04	15.03	54.62	9.01	2.61	3.47
24KM ₆ -62	81.33	107.33	102.60	24.80	7.73	88.80	2.72	17.90	23.12	44.09	9.55	2.28	4.20
24KM ₆ -63	81.33	107.33	100.00	26.07	8.87	89.53	2.55	19.39	14.36	57.59	9.36	2.27	4.12
24KM ₆ -64	85.00	111.00	126.13	25.07	6.47	130.47	2.71	20.84	15.67	56.46	9.49	2.33	4.08
24KM ₆ -65	83.33	108.33	138.20	30.93	8.00	223.80	1.83	31.45	28.39	52.68	9.24	1.91	4.86
24KM ₆ -66	84.00	111.00	85.27	25.27	8.93	131.40	2.08	15.73	15.52	49.58	9.18	2.02	4.66
24KM ₆ -67	84.00	110.00	99.07	23.27	8.60	103.60	2.22	15.20	18.24	43.63	9.15	2.07	4.54
24KM ₆ -68	90.00	117.00	113.93	28.20	5.40	135.53	2.56	21.08	18.41	51.37	10.07	2.66	3.81
24KM ₆ -69	100.0	126.00	133.40	24.20	6.07	126.73	2.93	18.85	30.78	38.91	9.38	2.82	3.37
24KM ₆ -70	86.33	112.33	171.93	27.73	5.20	197.20	2.55	24.44	37.48	38.99	9.67	2.26	4.30
24KM ₆ -71	90.33	116.33	113.67	24.20	5.80	139.40	2.32	16.93	20.41	43.65	8.75	2.60	3.40
24KM ₆ -72	84.00	109.00	155.07	28.53	5.73	68.47	3.09	13.55	24.20	35.31	9.27	2.88	3.22
24KM ₆ -73	84.33	111.33	122.33	27.20	7.13	161.40	1.86	17.86	17.81	49.03	9.09	2.22	4.11
24KM ₆ -74	90.00	116.00	118.07	28.87	10.53	86.33	1.69	14.48	31.95	31.65	10.41	2.10	5.02
24KM ₆ -75	88.67	115.67	127.47	28.40	5.67	216.47	2.50	27.35	23.72	53.72	8.30	2.86	2.90
24KM ₆ -76	82.33	108.33	122.73	23.60	7.47	88.07	2.74	17.22	15.63	52.22	8.95	2.57	3.49
24KM ₆ -77	81.33	107.33	104.80	25.80	8.20	94.47	2.88	18.06	17.25	49.93	10.15	3.18	3.20
24KM ₆ -78	88.00	114.00	115.27	22.53	6.13	105.47	2.87	10.71	15.39	40.87	7.40	2.39	2.94
24KM ₆ -79	82.00	107.00	151.87	23.60	10.13	173.67	2.27	19.89	27.18	42.15	7.69	2.38	3.25
24KM ₆ -80	94.00	121.00	122.07	25.67	8.13	110.87	1.72	12.82	20.80	38.32	8.38	2.45	3.59
24KM ₆ -81	99.33	125.33	124.60	24.93	8.60	128.60	3.17	24.77	28.28	48.01	9.47	2.71	3.53
24KM ₆ -82	87.00	114.00	116.53	24.33	6.47	128.53	3.13	26.20	16.43	62.72	9.52	2.65	3.55
24KM ₆ -83	80.67	106.67	79.13	23.27	6.53	70.73	2.69	14.44	9.67	46.48	9.49	2.61	3.66
24KM ₆ -84	87.00	113.00	72.47	18.60	7.13	45.00	1.71	4.96	9.53	41.22	9.29	2.37	3.81
24KM ₆ -85	82.67	108.67	111.93	23.87	7.00	114.00	2.92	21.98	19.57	57.19	9.28	2.78	3.52
24KM ₆ -86	86.33	111.33	114.60	23.87	5.67	144.60	3.29	23.22	13.90	62.02	9.35	2.61	3.59
24KM ₆ -87	82.00	109.00	101.40	24.33	8.13	86.93	2.79	18.83	14.53	56.52	10.37	2.31	4.53
24KM ₆ -88	85.33	111.33	111.00	24.00	6.07	121.07	3.14	22.27	15.24	58.49	9.50	2.89	3.29
24KM ₆ -89	80.00	107.00	124.53	25.40	9.40	83.93	2.68	17.22	18.89	47.46	9.12	2.53	3.60
24KM ₆ -90	86.33	112.33	118.60	27.07	5.87	132.73	2.43	18.72	18.03	50.43	8.82	2.44	3.63
24KM ₆ -91	87.33	113.33	131.27	24.80	6.00	148.33	2.86	25.04	19.66	53.44	9.07	2.68	3.43
24KM ₆ -92	87.00	113.00	117.20	22.00	5.93	118.67	2.98	18.12	13.99	55.79	9.28	2.95	3.17
24KM ₆ -93	104.3	129.33	179.67	35.93	6.47	134.13	2.65	25.74	46.03	36.94	7.91	2.66	2.99
24KM ₆ -94	86.67	113.67	140.93	25.53	6.07	166.40	2.52	22.25	19.64	51.32	9.00	2.64	3.42
24KM ₆ -95	85.33	111.33	117.07	23.33	6.80	112.33	3.14	19.73	14.73	56.84	9.44	2.83	3.35
24KM ₆ -96	88.33	115.33	117.73	23.67	6.47	120.60	2.85	22.61	14.63	59.57	9.63	2.99	3.26
24KM ₆ -97	97.00	123.00	130.47	27.53	7.07	162.40	2.43	23.57	22.80	51.65	9.57	2.35	4.12
24KM ₆ -98	85.33	111.33	124.20	24.20	6.60	135.87	3.13	23.53	16.47	58.98	9.33	3.07	3.05
24KM ₆ -99	84.00	110.00	121.67	25.40	8.87	125.27	2.80	23.04	17.01	56.80	9.33	3.17	2.95
24KM ₆ -100 (WT) Gurjari	95.00	125.00	118.87	24.40	6.67	145.73	2.89	23.32	22.03	51.42	9.02	2.90	3.14
24KM ₆ -101	88.33	115.33	134.33	29.13	8.33	157.67	2.42	25.10	27.22	47.16	8.61	2.59	3.33
General mean	87.54	114.13	114.83	24.73	7.49	123.90	2.56	19.82	19.80	49.37	9.19	2.57	3.64
Range	Max.	104.33	129.33	180.00	35.93	12.07	263.13	3.34	31.45	46.03	62.72	11.04	5.02
	Min.	77.33	103.33	42.93	11.80	4.40	13.20	1.46	3.98	7.05	28.86	7.14	1.91
S.Em±	1.20	1.17	3.45	0.83	0.84	16.52	0.13	2.95	2.54	3.83	0.28	0.10	0.18
CD at 5%	3.35	3.25	9.61	2.32	2.34	46.08	0.36	8.24	7.10	10.67	0.79	0.27	0.50
CV%	2.38	1.77	5.20	5.82	19.42	23.10	8.84	25.81	22.27	13.42	5.35	6.47	8.48

Analysis of variance

The analysis of variance revealed highly significant differences among the mutants for all the studied traits

(Table 2), indicating the existence of substantial genetic variability. Mean squares due to treatments were highly significant for all agro-morphological traits.

Table 2: Analysis of variance (mean sum of a square) of experimental design for grain yield and its component traits in rice

Sources of Variation	d.f.	DFF	DM	PH (cm)	PL (cm)	PTP	GP	100 GW (g)
Replications	2	0.5644	0.3663	1185.249	20.703	10.857	760.7061	0.133
Treatments	100	72.304**	83.259**	1475.538**	28.721**	6.008**	5610.17**	0.639**
Error	200	4.3277	4.0863	35.620	2.069	2.11	819.11	0.051

Sources of Variation	d.f.	GYP (g)	SYP (g)	HI (%)	GL (mm)	GB (mm)	L/B ratio
Replications	2	875.671	29.847	2223.187	0.376	0.064	0.299
Treatments	100	96.197**	135.173**	168.272**	1.382**	0.205**	0.619**
Error	200	26.163	19.431	43.916	0.241	0.027	0.095

* and ** indicate significance at 5% and 1% levels of probability, respectively.

Genetic Variability, Heritability and Genetic Advance

The effectiveness of selection in any breeding programme largely depends on the magnitude of genetic variability present in the breeding material. Therefore, the estimation of genetic parameters such as genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability and genetic advance provides valuable information regarding the nature and extent of variability and the expected response to selection. The estimates of genotypic variance, phenotypic variance, environmental variance, GCV, PCV, broad-sense heritability, genetic advance and genetic advance as percentage of mean (GAM) for the thirteen quantitative traits studied in the EMS-induced M₆ mutant progenies of Gurjari rice are presented in Table 3.

Phenotypic and genotypic coefficient of variation

The estimates of PCV were higher than the corresponding GCV values for all the characters studied, indicating the influence of environmental factors on the expression of these traits. However, the magnitude of difference between PCV and GCV varied among traits. Relatively narrow differences between PCV and GCV were observed for PH, DFF, DM, PL and 100-GW, suggesting that these traits were less influenced by environmental factors and that the observed phenotypic variation was largely attributable to genetic factors. Similar observations have been reported by Sandeep *et al.* (2018) ^[19], Chandar *et al.* (2022) ^[7] and Mamun *et al.* (2022) ^[13]. They also observed small differences between PCV and GCV for several agronomic traits in rice.

High estimates of genotypic and phenotypic coefficients of variation were recorded for GP (32.25% and 39.67%, respectively), SYP (31.38% and 38.47%, respectively) and GYP (24.38% and 35.50%, respectively) (Table 3). The high magnitude of variability observed for these traits indicates the existence of substantial genetic variability among the mutant progenies and suggests greater opportunities for effective selection and genetic improvement. The extensive variability observed for GP and GYP may be attributed to the mutagenic effect of EMS on genes controlling reproductive development and assimilate partitioning. Similar findings of high variability for these characters have been reported by Divya *et al.* (2018) ^[10], Chandar *et al.* (2022) ^[7] and Palaniyappan *et al.* (2024) ^[16]. Moderate GCV and PCV values were observed for HI, GB and L/B ratio, suggesting the presence of moderate genetic variability among the rice mutant genotypes for and

indicating limited but definite scope for genetic improvement. In contrast, relatively low GCV and PCV estimates were recorded for DFF, DM, PL and GL suggesting comparatively lower genetic variability for these traits.

Heritability (Broad sense)

Broad-sense heritability estimates ranged from 38.00% to 93.09% (Table 3), indicating considerable variation in the degree of genetic control among the studied characters. Very high heritability estimates were observed for PH (93.09%), DM (86.59%), DFF (83.96%), PL (81.11%) and 100-GW (79.33%). High heritability indicates that the observed phenotypic variation is predominantly governed by genetic factors and that the environmental influence on the expression of these traits is relatively low. Consequently, phenotypic selection for such traits may be effective even in early generations. Similar observations have been reported by Sandeep *et al.* (2018) ^[19], Sofian *et al.* (2019) ^[20] and Chandar *et al.* (2022) ^[7], who observed high heritability estimates for several agronomic and yield-related traits in rice mutant populations.

Genetic advance

However, heritability estimates alone do not provide sufficient information regarding the expected gain from selection because high heritability may result from either additive or non-additive gene action. Therefore, genetic advance as percentage of mean (GAM) was considered together with heritability estimates to understand the nature of gene action controlling these traits. In the present study, high heritability coupled with high genetic advance as percentage of mean was observed for GP (54.02%), SYP (52.71%), PH (37.92%), GYP (34.48%) and 100-GW (31.78%) (Table 3). This combination of high heritability and high GAM suggests the predominance of additive gene action and indicates that these traits are amenable to improvement through direct phenotypic selection. The high expected genetic gain for these traits implies that selection based on phenotypic performance would be effective in identifying superior mutant lines. Similar conclusions have been drawn by Johnson *et al.* (1955) ^[11], Sandeep *et al.* (2018) ^[19] and Chandar *et al.* (2022) ^[7], who reported that high heritability associated with high genetic advance is indicative of additive genetic variance and greater selection efficiency.

On the other hand, traits exhibiting high heritability coupled with moderate or low genetic advance, such as DFF and

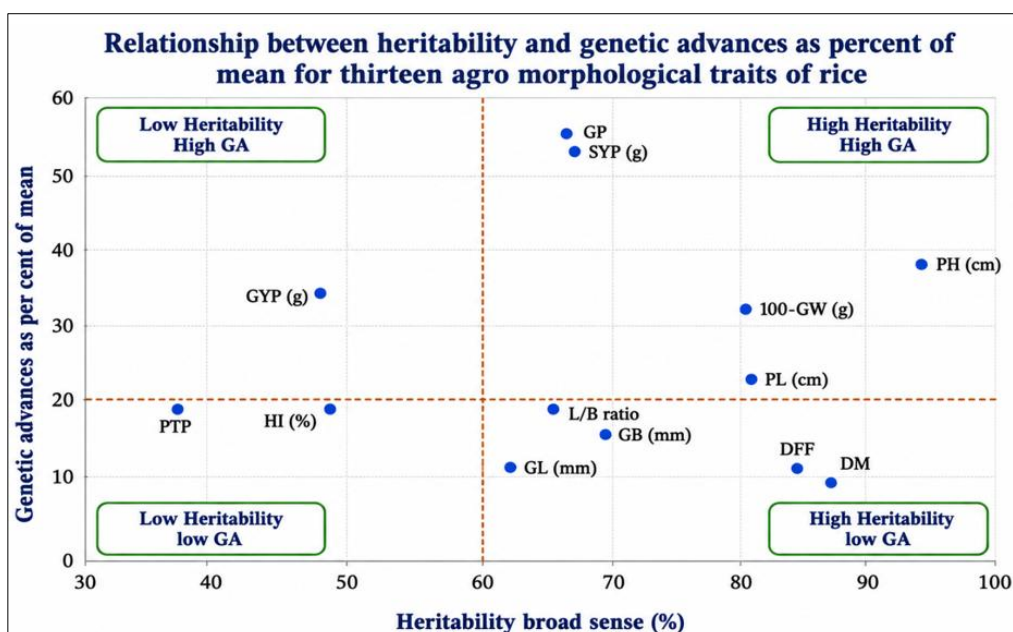
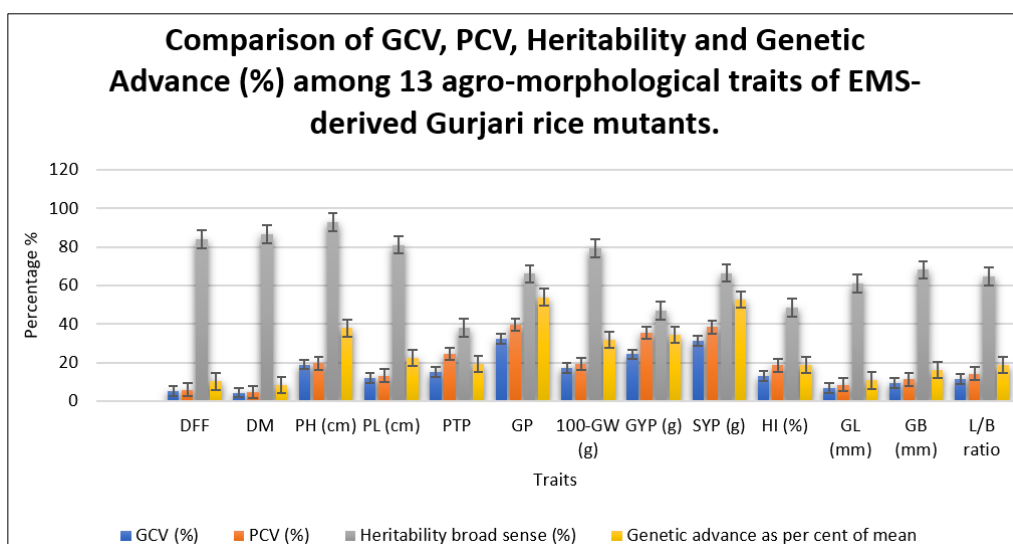
DM, suggest the involvement of both additive and non-additive gene effects, epistatic interactions, and possible environmental influences. Therefore, improvement of these traits may require recurrent selection or hybridization approaches rather than direct phenotypic selection alone.

The relatively lower heritability and genetic advance estimates observed for indicate that this trait is considerably influenced by environmental factors and complex gene interactions, making selection comparatively less efficient.

Table 3: Variability, heritability and genetic advance as per cent of mean for grain yield and its component traits in rice

Sr. No.	Traits	Components of variance			Coefficient of variation		Heritability broad sense (%)	Genetic advance as per cent of mean
		σ_g^2	σ_p^2	σ_e^2	GCV (%)	PCV (%)		
1	DFF	22.66	26.99	4.33	5.44	5.93	83.96	10.26
2	DM	26.39	30.48	4.09	4.50	4.84	86.59	8.63
3	PH (cm)	479.97	515.59	35.62	19.08	19.77	93.09	37.92
4	PL (cm)	8.88	10.95	2.07	12.05	13.38	81.11	22.36
5	PTP	1.30	3.41	2.12	15.20	24.66	38.00	19.30
6	GP	1597.02	2416.13	819.11	32.25	39.67	66.10	54.02
7	100-GW (g)	0.20	0.25	0.05	17.32	19.45	79.33	31.78
8	GYP (g)	23.34	49.51	26.16	24.38	35.50	47.15	34.48
9	SYP (g)	38.58	58.01	19.43	31.38	38.47	66.51	52.71
10	HI (%)	41.45	85.37	43.92	13.04	18.71	48.56	18.72
11	GL (mm)	0.38	0.62	0.24	6.71	8.58	61.16	10.81
12	GB (mm)	0.06	0.09	0.03	9.47	11.47	68.18	16.11
13	L/B ratio	0.17	0.27	0.10	11.48	14.28	64.71	19.03

Where, σ_g^2 , σ_p^2 and σ_e^2 are the genotypic, phenotypic and environmental variance, respectively. GCV% and PCV% are the genotypic and phenotypic coefficients of variation, respectively



Conclusion

The present study demonstrated that EMS mutagenesis successfully generated substantial genetic variability among the 101 M₆ mutant lines of the rice cultivar Gurjari, providing a valuable genetic resource for crop improvement. Significant variation observed across all thirteen agromorphological traits confirmed the effectiveness of EMS in broadening the genetic base. Plant height, panicle length, grains per panicle, straw yield per plant and 100-grain weight exhibited high heritability coupled with high genetic advance, indicating the predominance of additive gene action and their suitability for direct phenotypic selection. These findings highlight the potential of the identified EMS-derived M₆ mutant lines as valuable breeding materials for developing high-yielding rice cultivars and demonstrate the effectiveness of mutation breeding in expanding genetic variability for rice improvement.

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