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Research Article

IDENTIFICATION OF SEMI-DWARF AND HIGH YIELDING MUTANTS IN DUBRAJ RICE VARIETY OF CHHATTISGARH THROUGH GAMMA RAY BASED INDUCED MUTAGENESIS

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Abstract- Ideal plant architecture is the basis of super high-yielding rice. Plant height is one of the most important agronomic traits for producing high yields. Excessive plant height results in lodging and reduced yield. Dubraj, a local cultivar of rice, is also known as “miracle rice variety” due to its aromatic, medium slender(fine) grain with extra ordinary premium grain quality and excellent taste. But it is very tall and very late in maturity. Due to its tall stature, the variety is prone to lodging causing severe yield penalty. Physical mutagen (*viz.*, Gamma rays) has been used in the past to generate vast functional variability for different traits in cereals specially rice crop. In the present investigation, gamma ray induced mutagenesis have been used successfully to develop Dubraj mutants with reduced plant height, increased tiller number, earlier in maturity and higher grain yield. Seeds were irradiated with 300Gy Gamma ray dose and M1 generation was planted. Ample amount of variability presents the mutants for all the morphological and yield attributing traits. Total 18 economically useful mutants were selected in M_2 generation for further advancement and stabilization. These mutants were of different tyeps *viz.*, semi-dwarf with mid late maturity mutants, increased tillering ability with high grain yielding mutants, bushy and broad leaf mutants, grassy leaf mutant and sterile type mutant. Due to induced mutation, plant height of mutants was reduced upto 10.9% to 47% whereas days to maturity were reduced upto 4% to 14% as compare to their parent. Percent increase in tillering ability of mutants is ranged from 18% to 88% whereas total of 3% to 49.9% yield increment was seen in mutants. Identification and stabilization of few semi-dwarf mutants coupled with other yield component traits *viz.* effective tillers/plant, number of fertile spikelets/panicle, tolerance to disease and responsiveness to fertilizer has assumed great significance in improving traditional aromatic rice cultivar Dubraj. Three most desirable mutatnts *viz.*, mutant-13, mutant-14 and mutant-453 were identified for release as commercial cultivar. These mutants were further advanced for stabilization and multiplication.

Keywords- Dubraj, induced mutation, gamma rays, traditional aromatic rice, semi-dwarf.

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Introduction

Rice is the staple food crop of millions of people from the dawn of civilization. It is consumed by half of the world’s population and cultivated in more than 100 countries in all over the world. Asia alone produces over 95% of global rice with China (144MT) and India (104.83MT), are by far the largest producers of rice, ranked first and second, respectively (Source : https://apps.fas.usda.gov). In India, Chhattisgarh state is very popular for growing short slender/medium slender aromatic rices *viz.* Dubraj, Badshahbhog, Vishnubhog, Gopalbhog, Kubrimohar, Tulsi Manjari, Laxmibhog, Jawaphool etc. More than 100 traditional land races of aromatic rice with pleasant aroma are grown in different parts of the state. Dubraj, the most popular variety in the local markets of Chhattisgarh and with popular brand names “Pride of Chhattisgarh and Chhattisgarh ka Basmati”, receives a premium price in the market due to its excellent cooking quality and taste. Estimates indicate that Dubraj occupied 10% of the total rice area of Chhattisgarh. But with the expansion of acreage of high yielding non aromatic varieties, the area under Dubraj is on the decline. The major drawbacks with Dubraj are photo insensitivity, late maturity (>150 days), tall plant stature (>140cm), proneness to lodging and poor response to fertilizer application. Though Dubraj has low yield potential, but it fetches premium price and is being cultivated by marginal farmers. As the market value of Dubraj is quite substantial, there is need to improve the yield potential of such premium cultivars by reducing the plant height and enhancing fertilizer responsiveness without compromising with important quality traits including aroma [1]. Mutation breeding is a tool in the hands of breeders to create variability in crop population and to make selection in the population with the view to bring about further improvement in crop. Mutation breeding, particularly using gamma rays, took off worldwide in the 1960s and has resulted in spectacular successes, notably in seed propagated crops. The widespread exploitation of mutant varieties has generated billions of additional incomes to farmers and significantly promoted social-economic development of local communities [2]. In general, mutation breeding has been playing a key role in self-pollinated crops in which limited variability exist. Mutation breeding techniques have been used for generating wide genetic variations and developing thousands of new crop varieties during the past decades. Crop plant characteristics that have been improved by mutation breeding are generally those that have either not found favor with natural selection or were not achieved during previous plant breeding efforts [3]. Induced mutagenesis is an important tool to improve one or two characters particularly plant height in rice crop. Therefore present work is an attempt to develop economically viable reduced height and early to mid-late maturing and high yielding mutants in rice variety Dubraj using Gamma ray irradiation.

Materials and Methods

A traditional aromatic rice variety Dubraj (Mai Dubraj) with medium slender grain was selected for this study. Approximately 1000 seeds of Dubraj were irradiated with 300Gy dose of gamma rays at Bhabha Atomic Research Centre, Trombay, Mumbai, during 2013. The irradiation dosage was chosen based on previous favorable results in mutation breeding program. The M_1 generation was raised during *Kharif* 2013 and a total of 454 surviving M1 generation panicles from each plant of Dubraj were harvested. In M2 generation, desirable mutants with short stature, earliness in maturity and other yield attributing traits were selected during *Kharif* 2014.These mutants were further grown in M3 and subsequent generations to attain homozygosity and stabilization. Data of M4 generation was used for further analysis and explanations of results.

According to Standard Evaluation System (IRRI)-2013, plant height was classified as semi-dwarf (lowland <110cm; upland<90cm), intermediate (lowland 110-130cm; upland 90-125cm) and tall (lowland >130cm; upland >125cm). Tillering ability of mutants was classified into very high (>25 tillers per plant), good (20-25 tillers per plant), medium (10-19 tillers per plant), low (5-9 tillers per plant) and very low (< 5 tillers per plant).

Analysis of variance for randomized complete block design and genetic parameters of variability were calculated by using online open access statistical software OPSTAT. These calculations were further confirmed by manual analysis in MS-Excel 2010. Method suggested by Burton (1952) [4] was followed for calculation of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV). Broad sense heritability (h^2) was calculated as per method suggested by Hanson *et al.* (1956) [5]. Similarly, method suggested by Johnson *et al.* (1955) [6] was used for the calculation of genetic advance (GA).

Results and Discussion

Mutation breeding is a rapid technique for refinement of defects in plant materials/ genotypes/ landraces/ varieties besides inducing polygenic variations and development of different ideotypes. Basic information on the type and dose of mutagens, relative effectiveness and types of mutations generated are necessary in utilizing mutation breeding techniques for the improvement of any crop including rice. Dwarf or reduced height mutations are considered as one of the most dependable indices, like chlorophyll mutations, for evaluating the effectiveness and efficiency of mutability of a cultivar.

Total of 18 different viable morphological mutants were identified in M2 generation of rice variety Dubraj and advanced to M3 and M4. These mutants involve traits affecting plant height (dwarf), growth habit (bushy), leaf morphology (broad leaf, narrow leaf), tiller number (high tillering), floral morphology (floret sterility) and maturity duration (early, mid-late or late). Various morphological and yield attributing traits (M4 generation) of 18 Dubraj mutants and parent are given in [Table-1]. The differences observed in the spectra of morphological mutations were more of quantitative nature rather than qualitative; high frequency of semi-dwarf and dwarf viable mutants were observed in the present study. Shadakshari *et al.* (2001) [3], Singh and Singh, (2003) [8] and Sharma *et al.* (2008) [9] also reported the higher frequency of mutants for plant height in rice.

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Table-1 *Mean performance Dubraj mutants and parent for various morphological and yield attributing traits*

Sl. no.	Genotypes	Plant height (cm)	Days to maturity	Total tillers per plant	Productive tillers per plant	Panicle length (cm)	Fertile spikelet/ panicle	Sterile spikelet/panicle	Total spikelet/ panicle	Spkelet Fertility Percentage	Grain Yield/ plant	Special Feature	Plant height category (SES 2013)	Tillering ability (SES 2013)	Leaf color	Stem thickness	Bacterial Leaf Blight scoring*
1	Dubraj	155	150	9	8	24	220	22	242	90.91	12.85	Parent	Tall	Low	Light Green	Moderate	5
2	Mutant-1	98	140	12	12	25	235	12	247	95.14	20.65		Semi-dwarf	Medium	Dark Green	Thick	5
3	Mutant-3	95	142	14	12	24	240	18	258	93.02	18.85		Semi-dwarf	Medium	Dark Green	Thick	5
4	Mutant-9	98	140	12	12	23	232	14	246	94.31	15.65		Semi-dwarf	Medium	Dark Green	Thick	5
5	Mutant-13	82	144	15	14	25	243	16	259	93.82	24.54	Most desirable mutant	Semi-dwarf	Medium	Dark Green	Thick	3
6	Mutant-14	83	142	14	14	26	248	18	266	93.23	25.65	Most desirable mutant	Semi-dwarf	Medium	Dark Green	Thick	4
7	Mutant-192	87	128	11	10	21	151	45	196	77.04	13.25		Semi-dwarf	Medium	Green	Thin	7
8	Mutant-453	99	140	14	13	25	252	13	265	95.09	23.25	Most desirable mutant	Semi-dwarf	Medium	Dark Green	Thick	5
9	Mutant-2	128	138	12	11	20	192	20	212	90.57	16.8		Tall	Medium	Light Green	Moderate	4
10	Mutant-42	122	132	14	14	21	168	39	207	81.16	16.2		Intermediate	Medium	Light Green	Moderate	4
11	Mutant-43	132	132	16	15	24	244	35	279	87.46	18.54		Tall	Medium	Light Green	Moderate	6
12	Mutant-45	138	138	18	16	22	210	29	239	87.87	17.85		Tall	Medium	Light Green	Moderate	5
13	Mutant-51	134	130	18	16	24	243	12	255	95.29	17.58		Tall	Medium	Light Green	Moderate	5
14	Mutant-73	122	128	11	11	22	175	54	229	76.42	18.68		Intermediate	Medium	Light Green	Moderate	6
15	Mutant-173	125	130	14	14	19	155	44	199	77.89	18.2		Intermediate	Medium	Light Green	Moderate	5
16	Mutant-295	86	128	16	14	25	105	109	214	49.07	19.2	Bushy Mutant	Semi-dwarf	Medium	Light Green	Moderate	6
17	Mutant-433	88	134	20	20	26	170	22	192	88.54	15.98	Bushy Mutant	Semi-dwarf	Good	Dark Green	Thick	5
18	Mutant-380	98	130	78	72	15	72	18	90	80.00	10.25	Grassy Mutant	Semi-dwarf	Very High	Green	Thin	4
19	Mutant-47	136	131	17	17	24	0	110	110	0.00	0.00	Sterile Mutant	Tall	Medium	Light Green	Moderate	3

*BLB Scale 1-3: Resistance (R); 3-5: Moderately Resistance (MR); 5-7: Susceptible (S); 7-9: Highly susceptible (HS) Location Severity Index (LSI) is ≥4.0 (IIRR)

According to Standard Evaluation System, 2013 (IRRI) for plant height, all the mutants were classified into semi-dwarf, intermediate and tall categories. Total 10 mutants were of semi-dwarf type, five mutants were of tall type and 3 mutants were of intermediate type [Table-1]. Dubraj parent was comes under tall category as per this classification. As compare to Dubraj parent, plant height in some mutants was reduced significantly and mutants become semi-dwarf stature. A total 7 semi-dwarf mutants out of 10 mutants had desirable plant type with 10.9% to 47% reduction in plant height [Table-2]. Remaining three semi-dwarf mutants had bushy type and grassy type plant stature [Table-1]. Highest percent reduction in plant height was observed in desirable mutant-13 (47.1%) followed by mutant-14 (46.4%) and mutant-295 (44.5). The percentage reduction in plant height of different mutant over traditional Dubraj is illustrated in [Fig-2]. 300Gy dose of gamma rays presumably was desirable because most of viable semi-dwarf mutants were observed. In many countries, particularly in India the native land races that are much appreciated for their premium grain quality are not being fully exploited commercially due to their low productivity. In this context, the present study is significant as it deals with the genetic enhancement of Dubraj for traits like semi dwarf plant stature through incorporation of IR 8 allele of *sd1* gene from Pusa-44 [10].

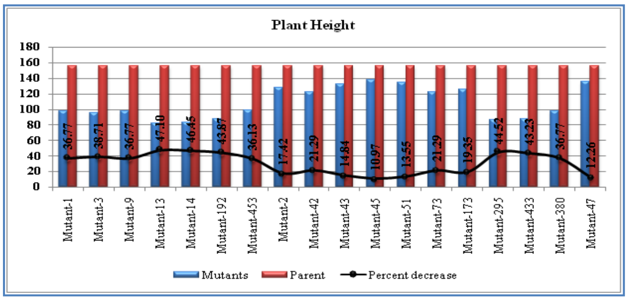

Fig-2 Percent decrease in plant height of mutants over parent Dubraj

Table-2 *Percent change in plant height, days to 50% flowering, tillering ability and grain yield per plant of mutants as compare to their parent.*

S.No.	Genotypes	Percent reduction in height (%)	Percent reduction in maturity duration (%)	Percent increase in tillering ability (%)	Percent increase in grain yield per plant (%)
1	Dubraj	0	0	0	0
2	Mutant-1	36.77	6.67	25.00	37.77
3	Mutant-3	38.71	5.33	35.71	31.83
4	Mutant-9	36.77	6.67	25.00	17.89
5	Mutant-13	47.10	4.00	40.00	47.64
6	Mutant-14	46.45	5.33	35.71	49.90
7	Mutant-192	43.87	14.67	18.18	3.02
8	Mutant-453	36.13	6.67	35.71	44.73
9	Mutant-2	17.42	8.00	25.00	23.51
10	Mutant-42	21.29	12.00	35.71	20.68
11	Mutant-43	14.84	12.00	43.75	30.69
12	Mutant-45	10.97	8.00	50.00	28.01
13	Mutant-51	13.55	13.33	50.00	26.91
14	Mutant-73	21.29	14.67	18.18	31.21
15	Mutant-173	19.35	13.33	35.71	29.40
16	Mutant-295	44.52	14.67	43.75	33.07
17	Mutant-433	43.23	10.67	55.00	19.59
18	Mutant-380	36.77	13.33	88.46	-25.37
19	Mutant-47	12.26	12.67	47.06	#DIV/0!

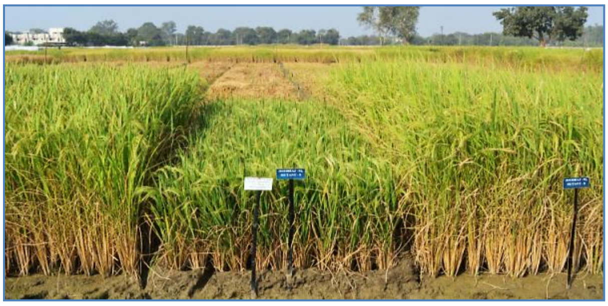

Fig-1A Dwarf mutant of Dubraj

Fig-1B Bushy Mutant

Fig-1C Grassy Mutant

Fig-1D Male sterile mutant

Fig-1E High tillering mutant

Fig-1 Different morphological mutants of rice variety Dubraj; A: dwarf mutant with parent, B: bushy mutant, C: grassy mutant, D: male sterile mutant, E: high tillering mutants

Premium grain quality of rice variety Dubraj has been marginalized over several years due to its tall stature (155cm) with weak straw and late maturity (145-155 days). Both these attributes make the cultivar incapable of responding to higher fertilizer doses or withstand lodging. In such situation, development of reduced height and mid-late maturity mutants has assumed great significance. All mutants ranged from 128 days to 144 days in maturity [Table-1]. Maturity duration of mutants was reduced as compare to their parent which comes under mid-late maturing to late maturing group. As per analysis of variance of days to maturity, significant difference was observed in all the genotypes. Therefore, it can be interpreted that maturity duration of mutants was significantly reduced as compare to their parent which will be rewarding in future. Percent reduction in days to maturity was ranged from 4% to 14%. Highest reduction was found in mutant-295

(14%). Most desirable mutants' *viz.*, mutant-13, mutant-14 and mutant-453 had reduction upto 4%, 5% and 6% respectively [Table-2]. The percentage reduction in days to maturity of different mutant over traditional Dubraj is presented in [Fig-3]. Shadakshari *et al.*, (2001) [3], Singh and Singh, (2003) [8] and Domigo *et al.*, (2007) [11] also reported mid late to late maturing mutants in rice after mutagen treatments.

Tillering ability of Dubraj mutants was higher as compare to Dubraj parent. According to Standard Evaluation System, 2013 (IRRI), Dubraj parent was came under low (5-9 tillers) tillering genotype whereas 16 mutants were comes under medium (10-19 tillers) tillering genotypes. One grassy mutant had very high (>25 tillers) tillering ability and one bushy mutant had good (20-25 tillers) tillering ability. Percent increase in tillering ability of mutants is ranged from 18% to 88% as given in [Table-2]. Highest increase in tillering ability was observed in grassy mutant-380 (88%) followed by bushy mutant-433 (55%). Among the desirable type mutants, highest increase in tillering ability was found in mutant-45 and mutant-51 (50%) [Fig-1E]. Most desirable mutants' *viz.*, mutant-14, mutant-13 and mutant-453 had percent increase in tillering ability upto 35%, 40% and 35% respectively. The percentage improvement in tillering ability of different mutant over traditional Dubraj is given in [Fig-4]. Gamma ray induced increase in tillering in rice is well documented [11-13].

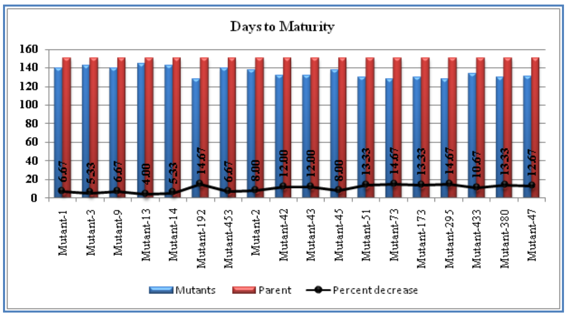

Fig-3 Percent decrease in days to maturity of mutants over parent Dubraj

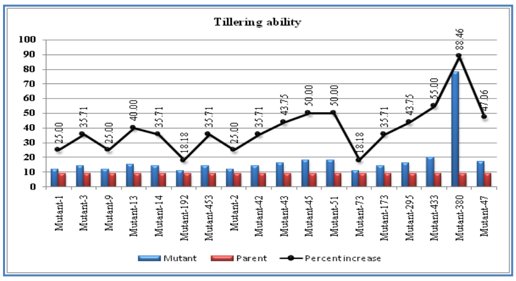

Fig-4 Percent increase in tillering ability of mutants over parent Dubraj

Grain yield per plant was also increased in mutants as compare to their parent. Total of 3% to 49.9% yield increment was seen in mutants [Table-2]. Highest increase in yield was observed in mutant-14 (49.9%) followed by mutant-13 (47.6%) and mutant-453 (44.7%). The percentage improvement in yield of different mutant over traditional Dubraj is illustrated in [Fig-5]. Many workers reported high yielding mutants in rice after mutagenic treatments [3, 8, 11, 5].

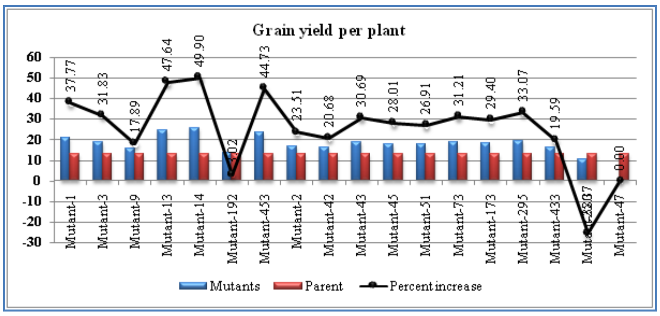

Fig-5 Percent increase in grain yield per plant of mutants over parent Dubraj

Mutants for other characters *viz.* grassy, bushy, broad leaf and sterile florets were also observed. Two bushy mutants *viz.*, mutant-295 and mutant-433 had broad leaves which are given in [Fig-1B] and one mutant (mutant-380) had very narrow or grassy leaf stature [Fig-1C] in Dubraj were observed in M2 generation and further advanced for stabilization. Bushy mutant was also reported in rice [8, 11, 14] and narrow leaf mutant was also reported in rice [8, 15]. Most of the mutants exhibited no change in the grain dimension. Dubraj grassy mutant grain size was reduced by 10 – 15%. In earlier studies reduced grain size mutant was found by Shobha rani *et al.* (2004) [16]. One mutant showed high spikelet sterility (>95%) which offers the scope for development of CMS line in back ground of Dubraj [Fig.-1D]. Complete sterile mutants in rice after mutagenic treatment were also reported by Luo and Zhang (1998) [17] and Shadakshari *et al.* (2001) [2]. Dubraj parent had tolerant capability to bacterial leaf blight. Most of the Dubraj mutant had the moderately resistance to tolerant level for bacterial leaf blight (BLB) disease. Most desirable mutants' *viz.*, mutant-13, mutant-14 and mutant-453 showed moderately resistance capacity to BLB.

Rice yields are greatly increased by the use of the semi-dwarf1 (*sd1*) gene in the initial Green Revolution [18]. Pleiotropic effect occurs when one gene influences two or more phenotypic traits. Therefore, a mutation in a pleiotropic gene might have an effect on many characters concurrently due to the gene coding for a product used by a myriad of cells or different targets that have the same signaling function. In present investigation, plant height of some mutants had been reduced with reduced maturity duration but their tillering ability, grain yield per plant, spikelet fertility and resistance to disease had been increased. This can be the result of pleotropic effect of mutated gene. This phenomenon is common in mutations of major genes such as those controlling plant height and flowering time. According to Shu and Forster (2011) [19]*Sd1* of DGWG in rice provided useful pleiotropic effects on stiff straw, lodging resistance, day-length insensitivity, seed dormancy and high yield in response to fertilizer, and was exploited in the development of the "Green Revolution" rice varieties. This particular statement is corroborated the present findings. Pleiotropic effects of mutations are a central component of theories that attempt to explain standing genetic variation in natural populations [20] and have widespread implications for human disease [21] and agriculture [22]. Although the significance of pleiotropy has long been appreciated by biologists, only recently have data become available to characterize the general nature of pleiotropy [23]. Evidence, predominantly from screens of gene knockouts, suggests most mutations affect few traits [24, 25].

Randomized complete block design based analysis of variance (ANOVA) for all the traits revealed significant differences among the all the treatments [Table-3]. This indicates the existence of ample amount of variability among Dubraj mutants for studied traits. Coefficients of variation studies indicated that the estimates of phenotypic coefficient of variation (PCV) were slightly higher than the corresponding genotypic coefficient of variation (GCV) estimates for all traits indicating the negligible influence of extraneous factors and larger effect of genotypic variation [Table-4]. Therefore, selection for these traits on the basis of phenotype only could also be rewarding [26, 27]. Phenotypic coefficient of variation and genotypic coefficient of variation was seems to be high for all the traits except for days to maturity and panicle length which showed low and intermediate classes respectively. Higher and intermediate value of GCV with PCV gives idea for direct selection of trait with significant improvement. Similar results were observed by [27-29].

Heritability in broad sense was exhibited high for all the characters among the Dubraj mutants. High heritability values indicate that the characters under study are less influenced by environment in their expression. Similarly genetic advance as percent of mean was also high for all the traits except for days to 50% flowering which showed low GA as percent of mean. Genetic advance denotes the improvement in the genotypic value of the new population over the original population. High heritability with high genetic advance as percent mean was observed for the entire trait except for days to 50% flowering. High heritability values with high genetic advance as percent of mean indicate that the characters under study are less influenced by environment in their expression. The plant breeder, therefore adopt simple selection method on the basis of the phenotype of the characters which ultimately improves the genetic background of these traits.

Table-3 *Analysis of variance for various grain yield and attributing traits*

Source of variation	Degree of freedom	Mean Sum of Squares									
		Plant height (cm)	Days to maturity	Total tillers per plant	Productive tillers per plant	Panicle length (cm)	Fertile spkelet/ panicle	Sterils spkelet/ panicle	Total spkelet/ panicle	Spkelet Fertility Percentage	Grain Yield/plant
Replication	1	4.44	36.02	6.73	8.52	12.31	342	10.52	472.52	0.116	76.74
Treatment	18	1030.65**	80.62**	441.12**	374.95**	15.31**	9364.42**	1717.46**	5020.01**	1022.86**	63.26**
Error	18	4.11	1.02	2.29	2.3	1.18	52.88	25.86	68.08	5.39	0.237
Total	37										

Table-4 *Genetic parameters of variability for various grain yield and attributing traits*

Traits	Mean	Range		Phenotypic Coefficient of Variation (PCV)	Genotypic Component of Variation (GCV)	Heritability (broad sense)	Genetic Advance (GA)	GA as Percent of Mean
		Maximum	**Minimum**					
Plant height (cm)	110.84	155 (Dubraj Parent)	82 (Mutant-13)	20.521	20.439	99.206	46.485	41.938
Days to maturity	135.63	150 (Dubraj Parent)	128 (Mutant-73)	4.711	4.651	97.501	12.833	9.461
Total tillers per plant	17.68	78 (Mutant-380)	10 (Dubraj Parent)	84.198	83.762	98.967	30.356	171.656
Productive tillers per plant	16.58	72 (Mutant-380)	8 (Dubraj Parent)	82.840	82.334	98.781	27.947	168.571
Panicle length (cm)	22.89	26 (Mutant-433)	15 (Mutant-380)	12.542	11.610	85.688	5.069	22.139
Fertile spkelet/panicle	187.11	252 (Mutant-453)	0 (Mutant-47)	36.674	36.468	98.877	139.769	74.701
Sterils spkelet/panicle	34.21	110 (Mutant-47)	12 (Mutant-1)	86.301	85.011	97.033	59.015	172.505
Total spkelet/panicle	221.32	279 (Mutant-43)	90 (Mutant-380)	22.790	22.483	97.324	101.123	45.692
Spkelet Fertility Percentage	81.41	95.29 (Mutant-51)	0 (Mutant-47)	27.851	27.705	98.952	46.219	56.772
Grain Yield/plant	17.05	25.65 (Mutant-14)	0 (Mutant-47)	33.045	32.922	99.254	11.521	67.565

Similar results have been reported by [27-32]

Conclusion

From the present investigation, it is confirmed that Gamma ray induced mutation breeding is an effective tool for the development of semi-dwarf mutants of Dubraj with desirable yield component traits and fertilizer responsiveness. These mutants have also good yielding ability with good aroma and quality features. The identification of high yielding dwarf and semi-dwarf mutants of Dubraj rice variety with good quality parameters will help preventing extinction of local landraces/ farmer's variety of rice harboring important qualitative traits. Three most desirable mutatnts *viz.*, mutant-13, and mutant-453 were identified for multi-locational testing whereas Mutant 14 was identified as release. These mutants were further advanced for stabilization and multiplication.

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Application of research: This research is useful for further crop improvement program through induced mutagenesis. Researcher can take help about conducting mutation breeding programme in rice. Dubraj is miracle rice variety of Chhattisgarh but have tall plant stature and late maturity. Dubraj mutant developed by this work is dwarf and early maturing variety which is a good gift for farmers of Chhattisgarh state as well as for other state.

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Author Contributions: All author equally contributed

Abbreviations:

- Gy: Gray
- IRRI: International Rice Research institute
- ANOVA: Analysis of Variance
- PCV: Phenotypic coefficient of variation
- GCV: Genotypic coefficient of variation
- GA: Genetic advance
- RBD: Randomized block design
- CMS: Cytoplasmic Male Sterility
- DGWG: Dee-Gee-Woo-Gen
- Cm: Centimeter
- BLB: Bacterial leaf blight
- BARC: Bhabha Atomic Research Centre
- DAE: Department of Atomic Energy
- BRNS: Board of Research in Nuclear Sciences

Conflict of Interest: None declared

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