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Induced genetic variability for yield and yield traits in aromatic rice (*Oryza sativa* L.)

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The nature of induced mutation for polygenic variability was studied in two traditional aromatic rice genotypes, viz., *Kalanamak* and *Badshah Bhog.* Induced variability was observed in both the M_2 and M_3 generations indicated the possible selection for quantitative characters. The shift in mean was not found to be unidirectional nor equally in both directions in all the treatments. Most of the mutagenic families in different treatments showed shift in mean toward negative side coupled with high range and CV as compared to their respective control. In general, combination treatments of 30kR gamma-ray+ 0.2% EMS and 40 kR gamma-ray+ 0.2% EMS induced maximum variability for most of the traits. The use of physical and chemical mutagens or a combination of both has been an important tool for the increase of variability in agronomic traits. In general, there was reduction in variability, as judged from range and CV, in M_3 as compared to M_2 in all the treatments and traits in both the genotypes. The present investigation had clearly demonstrated the high potentials of 40 kR gamma-ray +0.2% EMS followed by 40 kR gamma-ray and 30 kR gamma-ray +0.2% EMS were found to be more useful in releasing desirable variability for yield and component traits in desired directions for most of the characters in both the genotypes in both the generations.

Key words: Kalanamak, Badshah Bhog, polygenic variability, micro-mutations.

INTRODUCTION

India has largest area under paddy in the world and ranks second in the production after China (Anonymous, 2007). The primary objective of the mutation breeding is to enhance the frequency and spectrum of mutations and also to increase the incidence of viable mutations. Since genetic variability is a pre-requisite for any successful breeding programme, the creation and management of genetic variability becomes central base for crop improvement programme. Rice is a diploid and self-pollinated crop and it possess enormous possibilities of improvement through mutation breeding; significant achievements have been made in developing new rice varieties with desirable characters through mutation breeding (Baloch et al., 2002). The present investigation has been taken up with two genotypes of rice which included *Kalanamak* (Medium Slender Grain) and

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Badshah Bhog (Short and flattened grain).

MATERIALS AND METHODS

Two thousand pure, healthy and dry seeds (moisture, 12%) of the two rice varieties, namely, *Kalanamak* and *Badshah Bhog* were irradiated with 10, 20, 30 and 40 kR doses of ^{60}Co. gamma rays at National Botanical Research Institute, Lucknow, Uttar Pradesh. Irradiated and unirradiated seed lots of each variety were divided into two equal parts (one thousand each). First lot was used as gamma rays treatment alone and other for combined treatment of gamma rays + Ethyl methane sulphonate (0.2%) and EMS (0.2%) alone. For chemical mutagen treatment, seeds were submerged for six hours in distilled water to insure complete hydration of the seeds at 30°C in incubator. Soaked seeds were blotted for removing surface water before transferring them into Ethyl methane sulphonate (0.2%) prepared with phosphate buffer solution having the pH 7.0 for a period of 6 h. in incubator (25°C) and were given intermittent shaking throughout the period of treatment to maintain uniform concentration. After EMS treatment, the seeds were thoroughly washed in running tap water for one hr to remove residual chemicals.

For micro mutational studies, all the M_1 plants having 60% pollen fertility or more (minimum being twenty plants per treatment) were advanced to raise M_2 generation following the procedure adapted by Gaul (1964). Seeds of twenty M_1 plants, selected on the basis of pollen fertility as described above, were sown separately in the nursery during rainy season of 2006. Twenty one days old seedlings of all the twenty M_1 plants selected from each treatment were transplanted in the well puddle field in Randomized Block Design with three replications. Agronomic practices were the same to that of M_1 generation. Data on five competitive normal looking plants from each M_2 families were taken randomly to record the observations on nine quantitative characters, namely, days to 50% flowering, days to maturity, plant height (cm), panicle length (cm), number of panicle bearing tillers/plant, number of grains/panicle, 100-seed weight (g) and grain yield/plant (g). Since the minimum number of promising micro-mutants in M_2 families for any one of the treatments was twenty, 5 normal looking plants were selected at random from each of these 20 families. Promising micro-mutants exhibiting higher grain yield from the family coupled with higher coefficient variation compared to their respective control were selected to grow M_3 generation treatment-wise. Since numbers of micro- mutations were variable in each treatment, only top twenty micro mutants were sown on raised nursery beds during the rainy (Kharif) season 2007. The 21 days old seedling of all the twenty M_2 plant progenies were transplanted in well puddle field at the distance of 20 × 10 cm from row to row and plant to plant, respectively as has been done in M_2 generation. Randomized Block Design with three replications was followed for transplanting. Each micro mutant was transplanted in three rows of 4 m in length. Recommended agronomic practices were followed to raise good crop. The quantitative and quality traits studied in the M_2 were also studied in the M_3 on five normal looking plants selected at random from each mutant families in each treatment in both the varieties.

RESULTS AND DISCUSSION

The primary objective of the mutation breeding is to enhance the frequency and spectrum of mutations and also to increase the incidence of viable mutations. Many physical and chemical mutagens have been used for inducing viable mutants in rice. In mutation breeding the choice of the mutagen is most important, and various methods have been developed to ascertain the efficiency of mutagen(s) and mutagenic treatments for the induction of desirable characters in a cultivated crop. Since genetic variability is a pre-requisite for any successful breeding programme, the creation and management of genetic variability becomes central base for crop improvement programme. Selection and hybridization are conventional methods for improvement of qualitative and quantitative traits. In this context, it is quite desirable to opt for induced mutagenesis which is recognized as a quick and successful method in creating genetic variability and bringing about desirable improvement. Mutations may be artificially induced by a treatment with certain physical or chemical agents; such mutations are known as induced mutations.

Plant height

In *Kalanamak* and *Badshah Bhog* (Table 1 and Figure 1), all but 10 kR, EMS, and 10 kR gamma-ray+ EMS treatments showed significant reduction in mean values coupled with high variability, as evident from range and CV in both the M_2 and M_3 generations. Remarkably, treatment with 30 kR gamma-ray caused shift in mean towards positive side in both the generations as compared to the control. The magnitude of variability, as judged from range towards desirable side (negative shift in mean values), was very high at 40 kR gamma-ray and 40 kR gamma-ray+ EMS in both the generations. Induction of mutants with short plant height in the treatments with 40 kR gamma-ray and 40 kR gamma-ray +EMS were very remarkable in both the generations. In *Badshah Bhog*, all the treatments except 10 and 20 kR gamma-ray alone and their combination treatments with EMS caused significant reduction in plant height in both M_2 and M_3 generations. The shift in mean towards negative direction that is, towards short stature was more evident in the treatments 30 kR gamma-ray+ EMS and 40 kR gamma-ray, as judged from the lower values of range in both the generations. EMS treatment significantly increased the mean values (shift towards positive side) for plant height in both the generations.

Days to 50% flowering

In *Kalanamak* and *Badshah Bhog* (Table 2 and Figure 2), all but 10, 20 and 10 kR gamma-ray + EMS treatments showed significant decline in mean values coupled with high variability, as evident form range and CV, in both M_2 and M_3 generations. The combination treatments produced more variability as compared to single treatments. The magnitude of variability, as judged from range, towards desirable side (negative shift in mean) was very high in treatments 20 kR gamma-ray +EMS

Table 1. Range, mean and coefficient of variation (CV) for Plant height (cm) in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV
Control	162-184	170.25	6.24	156-174	167.56	4.21	160-185	170.46	6.50	157-173	167.64	4.51
Gamma rays												
10kR	151-186	168.18	8.10	154-179	166.20	7.98	150-184	169.17	7.23	155-180	166.31	7.04
20kR	150-188	167.78*	14.15	150-180	165.19	10.45	152-188	167.98*	11.98	153-185	165.82	8.91
30kR	148-189	172.78*	11.69	149-188	164.41*	13.66	150-185	173.20*	9.19	154-187	164.53*	11.19
40kR	89-188	164.87*	18.69	100-189	163.73*	17.10	104-189	165.23*	15.11	109-188	163.88*	15.01
EMS												
0.2%	150-184	168.34	10.19	148-183	170.67*	9.12	151-185	168.88	9.52	150-184	170.82*	7.13
Gamma-ray +EMS												
10kR+0.2%	153-185	167.90	12.78	145-185	165.47	11.53	155-186	169.09	10.68	149-186	166.01	10.03
20kR+0.2%	150-186	166.31*	14.21	140-185	165.37	12.35	157-186	166.67*	12.24	145-188	165.45	11.13
30KR+0.2%	148-188	165.19*	16.27	90-187	163.69*	14.19	150-187	166.35*	14.67	96-187	164.17*	12.16
40kR+0.2%	92-189	164.02*	20.54	133-189	162.32*	18.98	102-189	165.16*	16.98	136-186	163.74*	16.76
S.Em±	1.21			1.35			1.18			1.37		
CD at 5%	2.54			2.83			2.47			2.87		

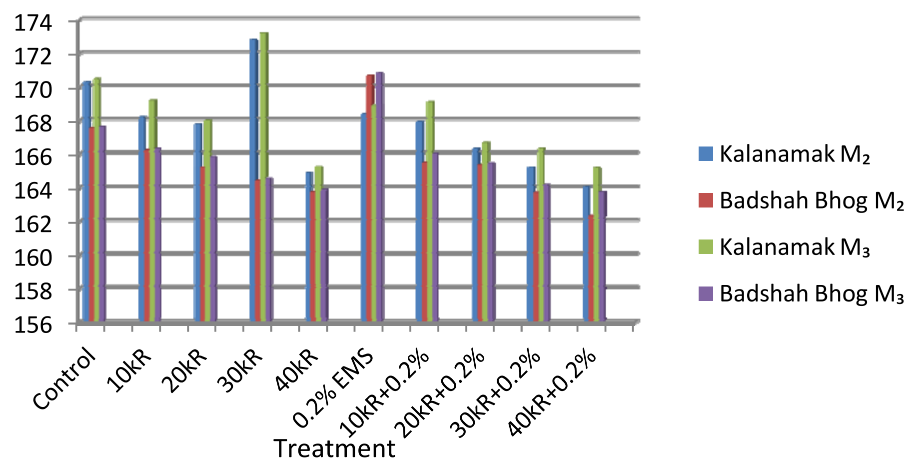

Figure 1. Plant height.

Table 2. Range, mean and coefficient of variation (CV) for Days to 50% flowering in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV
Control	138-150	141.60	4.48	136-149	141.15	3.34	140-151	141.89	4.57	135-148	141.23	3.30
Gamma-ray												
10kR	136-152	140.84	7.04	133-152	139.77	5.89	135-155	141.14	6.80	133-151	139.93	5.16
20kR	133-155	139.66	8.66	129-153	138.64*	6.48	134-156	140.22	7.65	130-152	138.80*	6.01
30kR	129-156	138.79*	9.78	126-153	140.68	8.79	129-155	139.74*	8.44	126-153	140.76	7.71
40kR	128-157	137.97*	12.51	119-155	138.02*	10.16	124-155	138.45*	9.19	120-155	138.10*	9.18
EMS												
0.2%	137-159	143.61*	6.90	132-151	143.55*	6.13	138-156	143.98*	6.02	131-152	143.59*	5.01
Gamma ray+ EMS												
10kR+0.2%	129-153	139.68	7.08	126-153	139.86	7.49	130-154	141.09	6.91	128-152	140.06	6.11
20kR+0.2%	108-156	138.45*	9.39	122-154	137.57*	8.81	110-154	139.85*	8.86	124-153	137.93*	7.17
30kR+0.2%	128-155	136.96*	10.55	120-155	138.16*	9.71	127-153	138.90*	8.94	121-155	138.26*	8.61
40kR+0.2%	98-150	134.78*	14.55	115-156	136.31*	11.26	110-154	135.33*	8.94	117-156	136.58*	10.02
S.Em±		0.95			0.79			0.92			0.82	
CD at 5%		1.99			1.67			1.94			1.73	

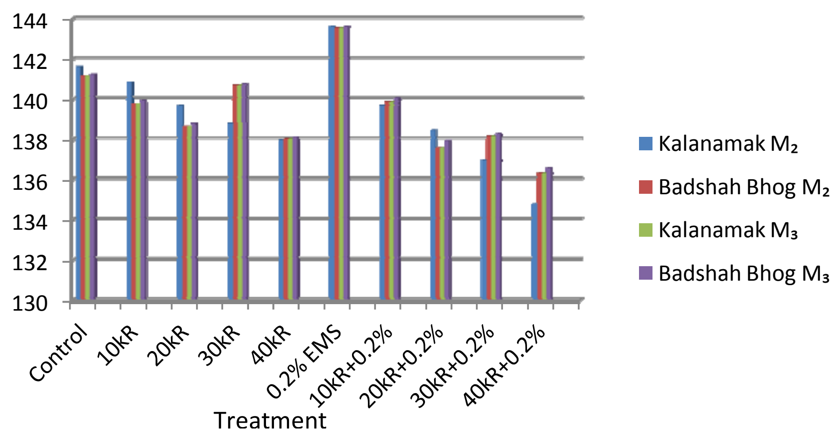

Figure 2. Days to 50% flowering.

and 40 kR gamma-ray+EMS in both the generations. Induction of mutants with as early in the treatments 20 kR gamma-ray + EMS and 40 kR gamma-ray + EMS were very remarkable in both the generations in the genotype *Kalanamak*. In the genotype *Badshah Bhog,* all the treatments except 10, 30 and 10 kR gamma-ray + EMS caused significant reduction in days to flowering in both M_2 and M_3 generations. The shift in mean towards negative direction (early flowering) was more evident in the treatments 30 kR gamma-ray + EMS, 40 kR gamma-ray + EMS and 40 kR gamma-ray, in both the generations. In this genotype, also, combined treatments (30 kR gamma-ray + EMS and 40 kR+ EMS) were found to be more promising as compared to single treatments with gamma-ray and EMS alone in both the generations. Single treatment with EMS alone significantly increased the mean days to flowering in both the genotypes and generations.

Days to maturity

In *Kalanamak* and *Badshah Bhog* (Table 3 and Figure 3), all but treatments `10, 20 and 10 kR gamma-ray + EMS showed significant reduction in days to maturity in both the generations in the genotype *Kalanamak*. The shifts toward negative side that is, early maturing were more pronounced in the treatment 40 kR gamma-ray + EMS as evident from the lower value of the range. While in other genotype, *Badshah Bhog* all the treatments except 10 kR gamma-ray, 30 kR gamma-ray and 10kR gamma-ray + EMS caused significant reduction in mean days to maturity in both the generations. Early maturing mutants were noted in the treatments 40kR gamma-ray + EMS, 30 kR gamma-ray + EMS and 40 kR gamma-ray. It was remarkable to note the induction of very early maturing (130-138) mutants in *Kalanamak* as compared to *Badshah Bhog* (induction of early mutants with 140-145 days). Single treatment with EMS alone caused significant positive shift in mean days to maturity in both genotypes and generations.

Panicle length

All but treatments 10 kR gamma-ray, 20 kR gamma-ray, EMS and 10 kR gamma-ray + EMS showed significant reduction in panicle length in both the generations in the genotype *Kalanamak* (Table 4 and Figure 4). The significant shift in the mean values towards positive side for panicle length was noted in treatment 30 kR gamma-ray in both the generations. From the upper values of range, treatments 40 kR gamma-ray, 30 kR gamma-ray + EMS and 40 kR gamma-ray + EMS were important in the M_2, while in the M_3 only treatment 40 kR gamma-ray + EMS was remarkable. In *Badshah Bhog,* all the treatments except 10, 20 and 10 kR gamma-ray +EMS caused significant reduction in mean values for panicle length in both the generations. The significant shift in mean in positive side in panicle length was noted in the treatment with EMS in both M_2 and M_3 generations, while 30kR gamma-ray caused significant increase in mean values in M_2 generation only.

Panicle bearing tillers per plant

In *Kalanamak* (Table 5 and Figure 5), all but 10 kR gamma-ray, 20 kR gamma-ray, EMS and 10 kR gamma-ray + EMS treatments showed significant decline in mean values from the control coupled with high variability, as evident from the range and CV, in both M_2 and M_3 generations. The magnitude of variability, as judged from the range towards desirable side (positive shift in mean), was very high in 40 kR gamma-ray +EMS in both the generations. Induction of mutants in the treatment with 40 kR gamma-ray +EMS was remarkable in M_2 generation in the genotype *Kalanamak*. In *Badshah Bhog* (Table 5 and Figure 5), all the treatments except 10 kR gamma-ray, EMS, 10 kR gamma-ray + EMS and 30 kR gamma-ray + EMS caused significant reduction in panicle bearing tillers per plant in both M_2 and M_3 generations. The shift in mean toward positive direction that is, higher panicle bearing tillers per plant was noted in treatment with 30 kR gamma-ray in the both M_2 and M_3. The mutants with increased panicle bearing tillers per plant were noted in most of the treatments in both the generations.

Number of grains per panicle

In *Kalanamak* (Table 6 and Figure 6), all but 10 kR gamma-ray, EMS and 10 kR gamma-ray + EMS treatments showed significant shift in mean values of number of grains per panicle as compared to control coupled with high variability, as evident from the range and CV, in both M_2 and M_3 generations. The treatments 20 kR gamma-ray and 30 kR gamma-ray + EMS induced significant shift in mean toward positive side in both the M_2 and M_3. Looking at higher values of range, combined treatments 30 kR gamma-ray + EMS and 40 kR gamma-ray + EMS were most promising, in both the generations as compared to control (113-199). Drastic effects of the treatments as judged from lower values of range, were very high in all the treatment as compared to control in both the generations. In *Badshah Bhog* (Table 6 and Figure 6), all the treatments except 10 kR gamma-ray, EMS and 20 kR gamma-ray + EMS in M_2 and 10 kR gamma-ray, EMS, 10 kR gamma-ray + EMS and 20 kR gamma-ray + EMS in M_3 showed significant shift in mean. The positive shift in mean was noted only in treatment 30kR gamma-ray in both M_2 and M_3 generations. Combined treatments (30 kR gamma-ray + EMS and 40 kR gamma-ray +EMS) were most promising,

Table 3. Range, mean and coefficient of variation (CV) for Days to maturity in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV
Control	161-179	168.85	4.33	163-178	170.88	3.61	160-179	168.93	4.39	164-177	170.90	3.63
Gamma ray												
10kR	160-181	168.28	5.83	154-182	169.38	4.76	158-182	168.37	5.19	155-180	169.42	4.12
20kR	154-183	167.15	6.09	153-184	167.51*	6.31	149-182	167.59	5.99	152-183	167.58*	5.18
30kR	152-185	166.48*	9.66	148-186	169.31	7.66	147-186	166.81*	8.89	149-185	169.38	6.99
40kR	149-188	165.95*	11.14	144-188	166.83*	8.31	150-189	166.55*	10.81	146-187	166.85*	7.82
EMS												
0.2%	158-185	170.94*	6.18	155-181	173.65*	5.17	156-186	171.87*	5.91	154-182	173.82*	4.61
Gamma ray+ EMS												
10kR+0.2%	156-186	168.82	8.41	151-183	170.96	6.87	155-187	168.95	7.89	152-182	171.07	5.66
20kR+0.2%	145-188	166.72*	10.15	149-184	166.43*	7.91	146-189	166.83*	9.75	150-185	166.64*	6.84
30KR+0.2%	150-189	166.45*	12.42	145-186	168.65*	9.89	151-188	166.78*	11.06	147-187	168.87*	8.71
40kR+0.2%	130-189	163.04*	16.69	140-189	165.30*	10.42	138-189	164.08*	14.81	144-188	165.38*	9.82
S.Em±		0.97			0.71			0.96			0.72	
CD at 5%		2.03			1.66			2.01			1.69	

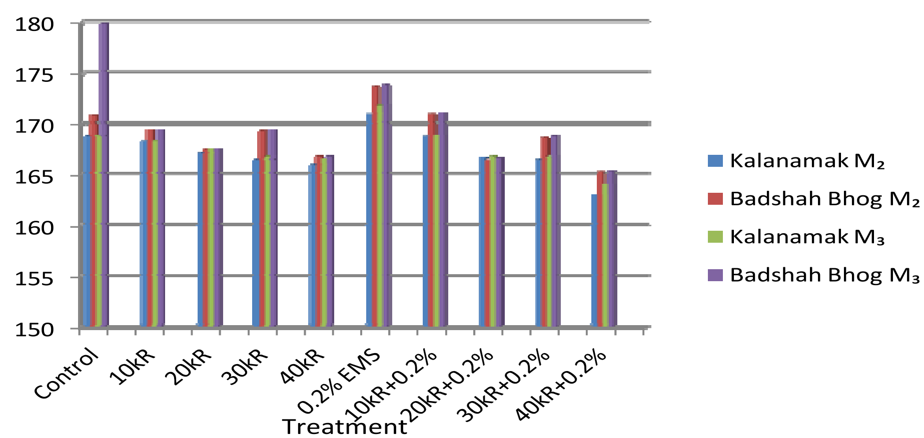

Figure 3. Days to maturity.

Table 4. Range, mean and coefficient of variation (CV) for panicle length in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV
Control	24-30	26.62	6.23	24-29	25.93	6.49	25-31	26.69	6.31	25-29	25.95	6.39
Gamma ray												
10kR	23-31	26.34	7.05	22-29	25.40	7.96	24-30	26.50	6.84	23-28	25.82	7.16
20kR	21-31	25.92	10.80	21-30	25.17	8.87	20-31	26.15	9.04	23-29	25.26	8.19
30kR	22-30	27.63*	8.53	21-31	24.89*	11.50	23-29	27.69*	8.14	22-30	24.95*	10.51
40kR	20-32	24.46*	14.99	19-31	24.37*	12.84	19-31	24.53*	11.61	20-31	24.79*	11.78
EMS												
0.2%	24-29	26.59	8.61	23-29	26.72*	9.72	24-30	26.69	7.19	22-30	26.68*	8.42
Gamma ray+ EMS												
10kR+0.2%	22-30	25.97	9.81	22-31	25.35	8.91	21-31	26.04	8.21	22-31	25.39	7.61
20kR+0.2%	20-31	25.82*	10.98	21-30	24.83*	10.13	22-30	25.97*	8.99	21-31	24.93*	9.10
30KR+0.2%	20-32	25.13*	13.49	20-30	24.75*	11.15	21-31	25.37*	11.84	19-31	24.96*	10.06
40kR+0.2%	19-32	23.91*	15.94	19-31	23.78*	11.68	20-30	24.11*	12.94	20-30	23.96*	10.81
S.Em±		0.34			0.37			0.32		0.33		
CD at 5%		0.72			0.77			0.68		0.70		

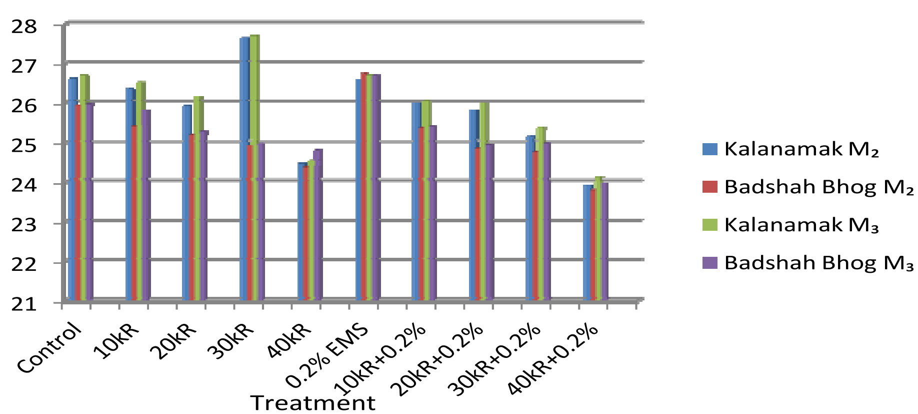

Figure 4. Panicle length.

Table 5. Range, mean and coefficient of variation (CV) for panicle bearing tillers per plant in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range†	Mean	CV	Range†	Mean	CV	Range†	Mean	CV	Range†	Mean	CV
Control	5-10	6.86	15.16	4-9	6.84	15.14	4-10	6.94	15.29	4-9	6.86	14-91
Gamma-ray												
10kR	3-11	6.77	23.04	4-12	6.86	23.32	3-12	6.83	22.16	4-11	6.95	22.98
20kR	3-14	6.64	28.15	3-13	6.32*	27.61	2-14	6.72	27.91	4-12	6.39*	26.15
30kR	2-15	6.33*	30.80	2-13	7.31*	31.14	2-15	6.44*	30.02	3-13	7.34*	30.12
40kR	1-15	5.87*	33.99	2-15	5.84*	35.02	1-15	5.93*	32.36	2-14	6.04*	34.02
EMS												
0.2%	3-12	6.57	27.12	4-11	6.89	26.19	4-12	6.73	26.19	4-11	6.91	25.14
Gamma-ray +EMS												
10kR+EMS	2-14	6.59	25.81	3-12	6.85	23.38	3-11	6.66	24.49	3-10	7.06	22.31
20kR+EMS	2-15	7.76*	28.04	3-14	6.65	29.41	3-14	7.84*	27.31	3-13	6.75	28.18
30KR+EMS	2-13	6.35*	32.89	2-15	6.34*	33.27	2-14	6.40*	31.46	2-13	6.40*	32.14
40kR+EMS	2-16	5.72*	35.66	1-15	5.55*	37.43	2-15	5.88*	34.29	1-14	5.77*	35.21
S.Em±		0.22			0.22			0.22			0.21	
CD at 5%		0.45			0.46			0.44			0.44	

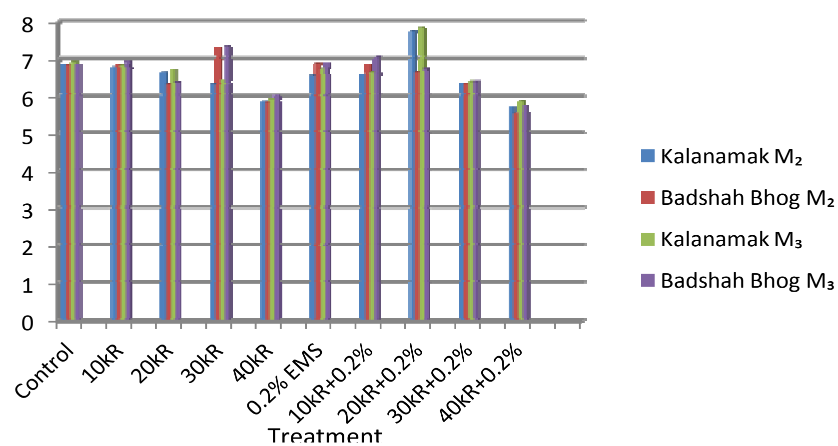

Figure 5. Panicle bearing tillers per plant.

Table 6. Range, mean and coefficient of variation (CV) for Number of grains per panicle in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range]	Mean	CV
Control	119-193	130.48	17.25	132-219	136.55	16.21	122-199	131.65	16.69	139-218	137.16	16.01
Gamma-ray												
10kR	81-218	128.67	25.71	89-226	134.66	25.62	89-220	130.77	24.91	75-228	136.45	25.04
20kR	72-224	135.25*	29.03	52-230	131.87*	26.94	76-220	138.93*	27.78	59-230	133.17*	25.82
30kR	65-231	124.07*	33.65	49-236	141.45*	34.39	62-237	127.42*	30.15	57-239	142.21*	31.15
40kR	56-238	126.41*	35.94	41-245	127.97*	38.15	60-240	128.11	32.34	59-251	130.98*	30.06
EMS												
0.2%	69-221	127.62	26.12	60-230	135.78	27.88	56-218	128.45	25.14	71-231	136.82	26.02
Gamma-ray +EMS												
10kR+EMS	67-226	128.05	28.10	56-225	131.17*	30.43	61-226	130.94	27.29	68-223	135.64	28.09
20kR+EMS	58-237	125.25*	35.68	54-236	138.09	33.19	50-234	126.88*	29.98	51-234	139.79	30.12
30KR+EMS	50-247	142.36*	36.02	45-249	129.57*	35.02	61-250	145.16*	30.25	49-246	132.29*	33.31
40kR+EMS	47-251	115.03*	38.73	41-261	125.73*	41.42	55-249	119.39*	35.10	51-260	127.77*	36.13
S.Em±		1.86			1.72			1.85			1.80	
CD at 5%		3.90			3.67			3.88			3.64	

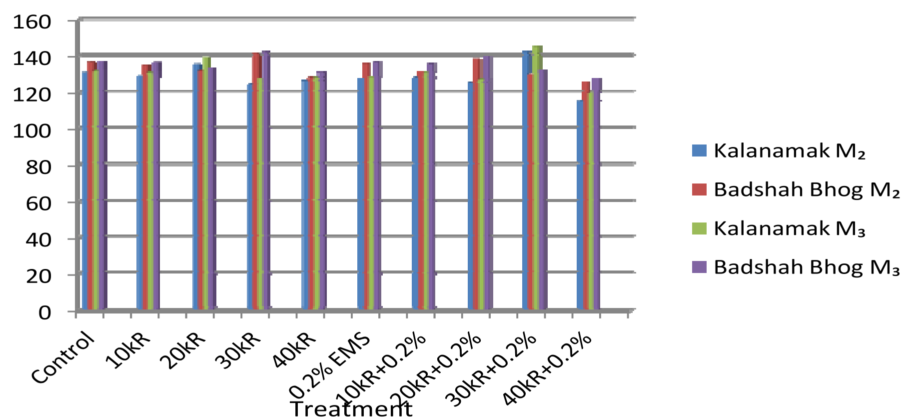

Figure 6. Number of grains per panicle.

as judged from high CV and isolation of mutants with increased number of grains per panicle as compared to control in both M_2 and M_3 generations.

100-seed weight

The significant shift in mean values as compared to control coupled with high variability, as evident from the range and CV, in both M_2 and M_3 generations were noted in *Kalanamak* (Table 7 and Figure 7), all the treatments except 10 kR gamma-ray, 20 kR gamma-ray, EMS and 10kR gamma-ray + EMS. While positive shift in mean was noted only in treatment 20 kR gamma-ray + EMS in both the M_2 and M_3. Mutants with high seed weight as compared to control were noted in all the treatments except 10 kR gamma-ray, 20 kR gamma-ray, EMS, and 10 kR gamma-ray + EMS in both the generations. In *Badshah Bhog* (Table 7 and Figure 7), all the treatments except 10kR gamma-ray, EMS, 10 kR gamma-ray + EMS and 20 kR gamma-ray +EMS caused significant shift in mean 100-seed weight in M_2 and M_3 generations. The shift in mean toward positive direction i.e., higher 100-seed weight was noted in treatment with 30 kR gamma-ray in both M_2 and M_3 and 20 kR gamma-ray + EMS in only M_3. The mutants with increased 100-seed weight were noted in treatments 40 kR gamma-ray and 40 kR gamma-ray + EMS in both the M_2 and M_3, while in treatment 30 kR gamma-ray + EMS in M_3 only.

Grain yield per plant

In *Kalanamak* (Table 8 and Figure 8), all the treatments except 10 kR gamma-ray, 20 kR gamma-ray, EMS and 10 kR gamma-ray + EMS caused significant shift in mean values as compared to control in both M_2 and M_3 generations; positive shift in mean was noted in the treatments 20 kR gamma-ray in M_3 only and 20 kR gamma-ray + EMS in both M_2 and M_3. It was remarkable to note mutants with increased grain yield per plant as judged from upper values of range, in most of the treatments in both M_2 and M_3 generations. While in *Badshah Bhog* (Table 8 and Figure 8), all treatments except 10 kR gamma-ray, EMS, 10 kR gamma-ray + EMS and 20 kR gamma-ray +EMS caused significant shift in mean grain yield per plant as compared to control in both the generations; positive shift in mean was noted only in treatment 30 kR gamma-ray. Combined treatments with 30kR gamma-ray and 40 kR gamma-ray were more drastic in reducing grain yield per plant in both the generations in both the genotype, *Kalanamak* and *Badshah Bhog*. Mutants with high grain yield as compared to the control, in most the treatments were remarkable to note.

The use of physical and chemical mutagens or a combination of both has been an important tool for the increase of variability in agronomic traits (Bansal et al., 1990; Agrawal et al., 2000; Sharma et al., 2008). The potentiality of ionizing radiation and chemical mutagens is different and their ability to induce mutation varies from crop to crop and genotype to genotype. Therefore, it is desirable to have the appropriate treatment schedule before under taking the mutagenesis.

On the other hand, Gupta and Swaminathan (1967) suggested that different M_2 families should be analysed for their mean and variance and families showing superior mean and increased variance over the control should be selected. Similar selection process was applied in the present study and also advocated by various workers in rice as well as other crops (Singh, 2003; Singh and Singh, 2003). In general, mutagenic treatments had resulted in decreased mean coupled with enhanced variability in both genotypes and generations as compared to their respective control, though the magnitude of shift in mean varied with the treatment, genotype and trait. The decline in means of treated population was demonstrated in rice (Jana and Roy, 1973; Awan et al., 1980; Siddiqui and Singh, 2010).

The decrease in means of mutagen treated population might be due to greater frequency of mutations with detrimental effects or due to difference in magnitude of induced individual change. The shift in mean was not found to be unidirectional nor equally in both directions in all the treatments. For days to flowering and maturity and plant height shifts in mean toward negative direction, as also noted in the present case, were of great significance as they yielded high frequency of mutants with early flowering and maturing and short stature. The induction and isolation of short statured with early maturing mutants having other desirable traits of the parental genotypes would be quite rewarding. In rice several workers (Singh and Singh, 2003; Domigo et al., 2007; Siddiqui and Singh, 2010) also found induced variability in desired directions for earliness and short stature.

The unidirectional variability towards positive side for grain yield and its component traits, as noted in the present case, were of great significance. This had yielded large number of mutants with improved grain yield per plant as well as other component traits irrespective of genotypes. Several workers also noted similar results after mutagenic treatment in rice (Singh and Singh, 2003, Siddiqui and Singh, 2010). Auxiliary traits like, panicle bearing tillers/plant, panicle length, number of grains per panicle and 100-seed weight on an average, showed positive shift in mean coupled with enlarged variability towards both sides. These auxiliary traits, as expected because of their positive correlation with grain yield, contributed significantly towards grain yield. Similar results were also noted in several crops, such as, rice (Baloch et al., 2002; Elayaraja et al., 2005; Domingo et al., 2007; Bughio et al., 2007; Siddiqui and Singh, 2010).

Hence, in the present study, most of these auxiliary traits were studied to screen out the high yielding mutants

Table 7. Range, mean and coefficient of variation (CV) for 100 -seed weight in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV
Control	1.69-1.99	1.85	6.65	1.66-2.11	1.83	5.68	1.70-2.01	1.87	6.91	1.66-2.09	1.84	5.63
Gamma-ray												
10kR	1.65-2.01	1.80	7.07	1.63-2.13	1.79	9.09	1.66-2.03	1.82	6.87	1.66-2.10	1.82	8.96
20kR	1.64-2.09	1.91	8.98	1.56-2.14	1.71*	10.17	1.65-2.12	1.92	8.03	1.58-2.13	1.72*	9.82
30kR	1.41-2.19	1.73*	11.87	1.58-2.19	1.95*	12.07	1.49-2.21	1.74*	10.89	1.60-2.16	1.99*	11.08
40kR	1.52-2.21	1.74*	12.08	1.55-2.26	1.70*	13.50	1.55-2.24	1.75*	11.99	1.55-2.20	1.71*	12.48
EMS												
0.2%	1.64-2.09	1.79	8.16	1.65-1.99	1.74	11.19	1.61-2.02	1.80	7.69	1.65-1.98	1.76	10.12
Gamma-ray +EMS												
10kR+EMS	1.58-2.06	1.77	9.19	1.45-2.16	1.75	9.10	1.51-2.19	1.78	8.96	1.60-2.13	1.78	8.14
20kR+EMS	1.53-2.17	1.96*	11.64	1.50-2.16	1.92	11.50	1.59-2.24	1.98*	10.21	1.55-2.14	1.95*	10.16
30KR+EMS	1.50-2.17	1.74*	12.81	1.49-2.21	1.66*	12.21	1.50-2.33	1.75*	11.69	1.52-2.16	1.71*	10.09
40kR+EMS	1.43-2.29	1.73*	15.97	1.42-2.36	1.65*	13.41	1.45-2.26	1.74*	13.87	1.51-2.25	1.69*	12.01
S.Em±		0.048			0.048			0.049			0.049	
CD at 5%		0.100			0.101			0.103			0.102	

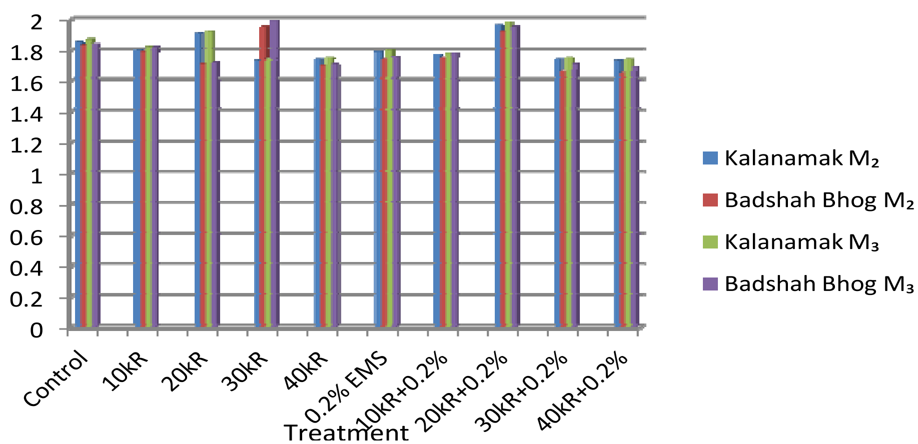

Figure 7. 100-seed weight.

Table 8. Range, mean and coefficient of variation (CV) for Grain yield per plant in M_2 and M_3 generations.

Treatment	M_2 generation						M_3 generation					
	Kalanamak			Badshah Bhog			Kalanamak			Badshah Bhog		
	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV	Range	Mean	CV
Control	11.98-16.41	12.76	15.77	11.21-17.99	13.06	17.51	12.02-16.52	12.81	16.14	11.32-18.12	13.12	16.96
Gamma ray												
10kR	5.66-18.61	12.66	28.80	4.78-19.86	12.78	26.41	6.18-18.66	12.76	26.74	4.96-19.99	13.20	25.37
20kR	4.41-19.98	13.02	30.89	4.53-20.13	11.82*	31.36	5.44-19.69	13.84*	29.14	4.86-20.06	12.07*	26.81
30kR	4.12-20.16	9.69*	35.85	2.98-21.62	14.23*	37.87	4.61-20.46	9.98*	32.97	3.66-21.14	14.59*	35.42
40kR	3.55-21.18	10.98*	43.44	2.36-22.37	10.37*	46.81	3.98-21.88	11.59*	41.15	2.99-22.81	10.92*	44.72
EMS												
0.2%	6.13-17.99	11.95	29.13	4.36+19.61	12.08	28.57	5.84-18.74	12.16	28.95	5.91-20.40	12.65	25.33
Gamma ray+ EMS												
10kR+0.2%	5.10-18.61	12.34	30.28	4.68-20.61	12.23	35.77	6.14-19.79	12.67	30.11	5.86-20.15	12.47	31.81
20kR+0.2%	4.99-19.80	14.13*	37.39	3.98-21.65	13.66	40.33	5.32-20.84	14.47*	35.29	4.03-21.33	13.90	35.56
30KR+0.2%	3.09-21.42	11.62*	42.49	3.64-22.14	11.14*	43.33	4.32-21.97	11.76*	40.97	4.86-22.01	11.64*	40.16
40kR+0.2%	2.17-22.14	8.82*	48.56	2.84-23.19	9.12*	48.69	3.92-32.12	9.14*	44.26	3.66-22.89	9.74*	45.89
S.Em±		0.49			0.496			0.481			0.476	
CD at 5%		1.03			1.04			1.01			1.00	

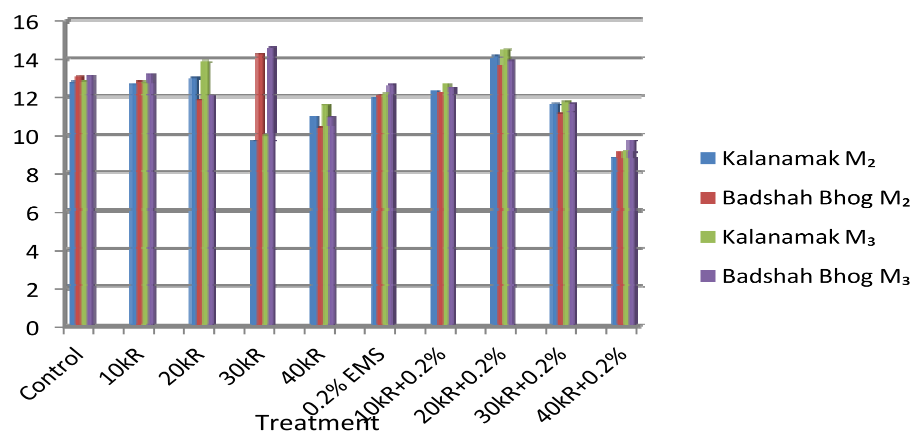

Figure 8. Grain yield per plant.

in the mutagen treated population. As such, sharp decline in grain yield per plant might be attributed to decrease in mean performance of these auxiliary traits affecting induced polygenic variability. The present investigation had clearly demonstrated the high potentials of combined treatments (gamma-ray + EMS) in releasing desirable variability for yield and component traits; treatments 40 kR gamma-ray +EMS followed by 40 kR gamma-ray and 30 kR gamma-ray +EMS were found to be most useful in releasing variability in desired directions in most of the characters in both the genotypes and generations. In few treatments, mean values higher than control were observed; 30 kR gamma-ray in *Badshah Bhog* and 20 kR gamma-ray + EMS in *Kalanamak* resulted increased mean values for most of the productive traits in both the generations. Similar results of increased mean than the control were also noted in rice (Gupta and Sharma, 1994; Siddiqui and Singh, 2010).

In general, there was reduction in variability, as judged from range and CV, in M_3 as compared to M_2 in all the treatments and traits in both the genotypes. Similar observations were also found by several workers (Singh, 2000; Siddiqui and Singh, 2010). This reduction in CV might be due to increase in the frequency of genetic death because of the homogygosity of harmful genes in M_3 generation. The differential genotypic response to different treatments was noted in present case; the genotype *Kalanamak* showed more variability than those recorded in *Badshah Bhog* for days to flowering, maturity and plant height, while more or less similar or low of variability was noted in both the genotypes for other traits (Singh, 2000; Siddiqui and Singh, 2010).

Conflict of Interests

The author(s) have not declared any conflict of interests.

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