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Studies on Gamma Ray Induced Mutations in Mungbean [*Vigna radiata* (L.) Wilczek]

Priya Ranjan Tah
Department of Plant Breeding, Faculty of Agriculture,
Bidhan Chandra Krishi Viswavidyalaya, Nadia, Westbengal, 74152, India

Abstract: Dry seeds (10% moisture content) of K851 and Sona of mungbean [*Vigna radiata* (L.) wilczek] were treated with 10, 20, 30 and 40 kR γ-irradiation to evaluate the extent of macro and micro mutations appearing in the M_2 generation and to estimate the potentiality of micro mutations for future use in plant improvement programme. Some important macro mutation like bushy, trailing, multifoliate, cluster pods, synchronous maturity and some sterile mutants were isolated in the M_2 generation. Irradiation with gamma ray also provided the scope for selecting the short statured plants as mutants with short height. Significant changes ($p>0.05$) with wide range of variations had been identified in yield and its contributing characters like number of pods/plant, 100 seed weight and seed yield per plant, cluster of pods/plant, number of leaves/plant, primary and secondary branches/plant, internode length and plant height. Pollen fertility was highest in control than the treatments in both the varieties. Highest seed yield/plant, 100-seed weight, protein content, pod width were noted in 40 kR γ-irradiation. Similarly, highest plant height at 20 kR, internode length at 30 kR and primary branches/plant at 30 kR were observed. The selection of individual plants in the M_2 generation can be studied to observe the spectrum of variation for quantitative characters. Observation of mutants like synchronously maturing and multifoliate may be progressed in the M_2 generation through directed selection and these stable mutants can be used as donors for restructuring mungbean genotypes.

Key words: Induced mutations, γ-irradiation, mungbean

INTRODUCTION

Induced mutagenesis has been employed to create desired genetic variability, the base of crop improvement. Mutation induction with radiation was most frequently used method to develop direct mutant varieties, as improvement by acclimatization, selection and hybridisation have proven to be time consuming, laborious with limited genetic variation[1,2]. Thus mutation breeding has been recognized since the beginning of this century as one of the driving force of evolution, besides selection and evolution.

Physical mutagens namely X-rays, gamma rays, fast neutrons, thermal neutrons, ultraviolet and beta radiations have been frequently used for induced mutagenesis[1]. Except ultraviolet rays, all radiation types were found to ionise atoms in a tissue by detaching electrons from the atoms[3]. Apart from physical mutagens, several chemical mutagens were also frequently used for induced mutagenesis in crops, respectively, Ethyl Methane Sulphonate (EMS), Ethylene amine (EI), Methyl Nitroso Urea (MNU), N-nitroso-N-methyl Urea (NMU) and Ethyl Nitroso Urea (ENU).

Previous researchers have reported hereditary changes in the desirable characters in crop plant by using gamma rays as a physical mutagen, which has been used to develop 64% of the radiation-induced mutant varieties followed by X-rays (22%)[4]. Consequently, the high yielding varieties rice (RD6, RD15, PNR-102, PNR-381), bread wheat (Jauwar 78, Soghat 90, kiran 95), barley (diamant, golden promise), chickpea (CM-88, CM-98), mungbean (NIAB Mung 92, NIAB Mung 98) and cotton (NIAB-78) have been developed through γ-irradiation. Jamil and Khan[5] reported promising fluctuation in the germination %, plant height, number of grains per plant, grain yield in the wheat through γ-irradiation. Gamma irradiation as a mutagen can induce useful and harmful mutation in plants. Hence it is important to predict the most beneficial doses of gamma rays for improvement of specific traits of crop plants. Khalil *et al.*[6] and Singh and Chaturvedi[7] reported late flowering mutants in mungbean and soyabean, respectively. Linear reduction in plant height with increase in gamma ray dosage has also been obtained in the mungbean variety Pusa Baisakhi treated with 10, 20, 30 and 40 kR gamma rays[8,9]. Tickoo[10] observed mutants of dwarf habit in advanced generation of gamma ray mutagen treated populations in Mungbean. But Khan *et al.*[11] and Singh *et al.*[12] observed an increase in the mean values of plant height in M_2 generation.

Corresponding Author: Priya Ranjan Tah, Department of Biological and Physical Sciences, Faculty of Sciences, University of Southern Queensland, Toowoomba 4350, Australia
Tel: 617 4631 1491 Fax: 617 4631 1530

There is considerable evidence that mutations are induced in polygenic traits and that there is a genetic gain under selection. In the M_2 generation, macro mutations may be observed particularly following radiation treatment. The macro mutants are usually undesirable due to accompanying genetic instability. Micro mutations that alter quantitatively inherited characters are more useful to the breeders since they are least deleterious although they are more difficult to detect. The micro mutations increase variability in yield, protein content, plant height, flowering, pod production, seed weight, or other yield related traits that are quantitatively inherited. Through mutation breeding attempts may be made to broaden the variation spectrum to facilitate selection of lines with improved nutritional qualities, especially with respect to protein associated with high yield.

While the cereals compensate for mungbean's low levels of sulphur amino acids, the mungbeans compensate for cereals' shortage of lysine. Due to the insufficiency of variability present in the existing germ plasm, enormous efforts have been made to improve this crop through exhaustive collection of germplasms from natural resources and segregants produced in their hybridized materials. As such for conventional breeding approaches will take much time for gaining reasonable improvement in such crop and there is an urge to meet the immediate need for the farmers, the breeders are trying to increase the variability in the existing germplasms through induction of mutation.

The present study was conducted to evaluate the effect of gamma rays on quantitative characters in Mungbean (*Vigna radiata* (L.) Wilczek). Mungbean being a self-pollinated has a very limited genetic variability and induced mutations can provide additional source of variability in an ongoing breeding programme. Hence and experiment was conducted to evaluate the extent of genetic variability in the quantitative characters in M_2 generation following mutagenesis with gamma rays.

MATERIALS AND METHODS

Plant materials and mutagen treatment: Two mungbean cultivars K-851 and Sona adapted in the northern and the eastern part of India were chosen. The former was selected from the cross of Amrit x Pusa Baisakhi for its early maturing property of 55-60 days after sowing, while the later is a dwarf, semi spreading and early maturing variety with duration of 60-65 days after sowing. Uniform, healthy dry seeds of (10% of moisture) of mungbean K851 and Sona were exposed to 10, 20, 30 and 40 kR doses of gamma rays with a dose rate of 9.13 rad sec^{-1} from cobalt-60 at the Central Research Institute of Jute and Allied Fibres (CRIJAF) Barrack pore, West Bengal, India. The seeds were shown during February, 2001 for M_1 generation and February 2002 for M_2 generation. A spacing of 30 cm row to row and 15 cm plant to plant were maintained. A total of 6000 seeds were used for sowing in the M_1 generation (2001), of which plants 2468 for K851 and 2890 plants for Sona were survived to produce seeds. Seeds from all the M_1 generation plants of each treatment were harvested separately and were bulked to grow a representative bulk M_2 generation. Observations were taken for characters like plant height, internode length, number of leaves in the M_1 and M_2 generation. In the next year (2002), seeds were sown in March. The M_2 generation consisted of 10000 plants consisting 80 rows of 10 m in length for K851 and 11500 plants consisting of 90 rows of 10 m in length for Sona, respectively. Data recorded to study quantitative traits like number of pods/plant, 100 seed weight and seed yield in the M_2 generation. Induced variability was assessed by basic statistics procedures such as mean, range, Critical Difference (CD) and Standard Error (SE). Data were also recorded on days to flowering, nitrogen percentage and protein content.

Plants showing visible symptoms of sterility with shading of young buds, late maturing and short height were selected to measure of the range of pollen fertility in the M_2 generation. The floral buds were then stored at 70% ethanol at room temperature. The pollen fertility recorded was carried out using the 1% acetocarmine solution by rupturing the undesirable and matured anthers on the microscopic slide, covered with glass cover slip and then pollens were observed under microscope for pollen fertility. The stained and non stained pollen were counted. The stained pollen was considered viable while non stained pollen were considered sterile.

Among the other visible macro mutation identified is synchronous matured plant, where all the pods matured at a time. It has a significant difference from the normal control lines.

Determination of LD_{50} (Probit analysis) for germination count: The observed mortality percentage corrected for control mortality by Abbott's formula:

$$PT = (P_o\text{-}P_c)/100\text{-}P_c \times 100$$

Where, P_o is observed mortality percentage, P_c is the control mortality percentage and PT is the corrected mortality percentage. Then the computation of LD_{50} value for K851 and Sona were produced.

Estimation of nitrogen and protein content: Estimation of protein content was done in through Nitrogen analysis of Micro-Kjeldahl method in the M_2 generation. The nitrogen content of the sample can be calculated by

N (g) = [(mL HCl-mL Blank) x Normality x 14.01)]/weight (g)

Multiplication of total nitrogen value with 6.25 (for pulses) will give the true protein content.

Statistical analysis: Statistical analysis for 2 varieties with 5 treatments, having (2x5) treatments is done by Factorial randomised block design in the M_1 generation. Factorial experiments are applicable where there is an effect of more than one factor (ex, Variety and treatment) and each at two or more levels are considered together. Once the test for any factor becomes significant, next objective is to find out the treatment means which is significantly different from each other with the help of corresponding Standard error and critical difference. The calculation in the M_2 generation was done by simple randomised block design.

RESULTS AND DISCUSSION

M_1 generation (2001)

Percentage of mortality in M_1 generation (corrected mortality percentage in parenthesis): From the Table 1, it revealed that the mortality rate increased linearly with the increase of treatment doses, though the rate of mortality in K851 was higher than Sona in all the treatments. Higher corrected mortality was exhibited in 40 kR γ-irradiation in both the varieties and each were 52 and 50%, respectively. The Lethal Dose (LD_{50}) of both the varieties was very close to each other, which were 54.06 and 53.20 kR, respectively.

Decrease in germination% with the increase of treatment doses as observed in this present observation was also reported by Borah[13]. LD_{50} is of great importance to know the sensitivity of different genotypes to the critical dose of mutagens causing 50% mortality. As the present varieties considered in this experiment showed LD_{50} almost in the similar range and where by it may be concluded that both genotypes were equally sensitive to gamma irradiation. The germination of the treated seeds had shown a sharp dose rate relationship, which decreased with the increase in the doses of treatments. However, the effect was not much drastic in the M_2 generation. Sarkar *et al.*[9] treated dry seeds (10% moisture content) of Pusa Baisakhi, a standard variety of mungbean with 10, 20, 30 and 40 kR gamma rays and showed linear reduction in germination percentage with increase in doses of gamma rays. Singh *et al.*[14] studied in the M_1 generation, the effects on seed germination and seedling survival by treating the dry seeds of mungbean cv. PS-16 with various doses of gamma rays (20, 30 and 40 kR) and observed a linear relationship between doses of these mutagens and decrease in seed germination.

Plant height and internode length: Analysis of variance revealed the presence of significant varietal and treatment effect and absence of interaction effects (Table 2). Height in both the varieties reduced due to treatment effect, where maximum reduction took place at 40 kR γ-irradiation. Treatment effects in case of K851 were not significantly different except the 40 kR, having a lowest mean plant height of 36.6 cm within the two cultivars. But in case of Sona the effect due to 30 and 40 kR was in the same group and 10 and 20 kR in different groups. In this case a negative effect of γ-irradiation on the average mean performance between the two genotypes with 10, 20, 30 and 40 kR showing 12.42, 13.84, 20.02 and 29.29% reduction in plant height over control.

Like the present investigation, Shakoor *et al.*[15] observed adversely affected plant height in the M_1 generation. In the present investigation, Sona has given a comparatively linear relationship with respect to reduction in plant height with different doses of gamma irradiation whilst in case of K851 the treatments from 10 to 30 kR were not significantly different. But in both the cases 40 kR treatment can be considered for obtaining extremely dwarf plants. The deviation in the results may be due to environmental effect and different genetic materials used for the experimental work.

The variations due to internode length for the varieties and their interactions with the treatments were found to be non-significant given in Table 2. Significant reduction in internode length as compared to control was found to persist in the different irradiation doses and maximum reduction in both the varieties was observed at 40 kR γ-irradiation in both the genotypes. Negative effect of γ-irradiation was observed in the mean performance of internodal length between the cultivars with 10, 20, 30 and 40 kR showing a 7.27, 18.63, 24.68 and 43.41% reduction in internode length compared to control.

Number of leaves and secondary branches per plant: Significant variations for number of leaves due to variety and different treatments were noticed (Table 3). However, their interaction within the treatment has been found non significant. The treatments consistently brought improvement for this character over control. The maximum stimulating effect for mean performance of number of leaves has been observed in 30 kR with an increase of 30.30% over control. Marginal reduction in mean performance has been observed in 40 kR of 3.63% over 30 kR, making it most effective dose.

Table 3 also shows the presence of significant variation among treatments and varieties with the non-significant varietal response to different treatments of γ-irradiation. The number of secondary branches per plant was more in Sona (14.453), compared to K851 (12.320), respectively. The maximum stimulating effect on the number of branches was observed with 30 kR γ-irradiation showing 33.9 and 26.24% increase over control in Sona and K851, respectively. While the maximum stimulating effect within the same treatments between two cultivars was also observed in 30 kR γ-irradiation showing 30.55% increase over control. Previous investigation by Seth and Chaudhary[18] in this respect has revealed 20 kR being the most effective dose. Though Ganguli and Bhaduri[19] had reported a reduction in the number of branches as a result of irradiation, the number of primary branches was significantly more than the control in the treatments. So by increasing the number effective branches, the number of pods per plant would be increased with a concomitant increase in plant yield.

M_2 generation (2002)

Visible macromutations: Different macromutations were isolated from M_2 generation were identified. For K851, 26 bushy plants isolated of which 2 from 20 kR, 10 from 30 and 14 from 40 kR treatments. But only 5 bushy plants were identified from Sona of which 2 and 3 plants were from 30 kR and 40 kR, respectively. These plants have numerous lateral branches and were erect. Flowering and fruiting were normal in these plants. Only 3 plants from 30 kR treatments from K851 were isolated and the main shoot along with its lateral branches was found to creep along the grounds. Yield of these plants were not satisfactory. Flowering and maturity were normal. Twelve multifoliate plants were identified from 30 and 40 kR treated K851 variety. Of these 12 plants, 4 were isolated from 30 kR treated population and the rest were 40 kR treated ones. Nineteen plants from Sona and 7 plants from K851 were isolated from M_2 population, which beared clustered pods. The frequency of clustered pods varied between the treatments among the varieties and from 10, 20 and 30 kR treated M_2 populations of K851, only 2, 1 and 4 plants were isolated, respectively and similarly the number of plants were identified in Sona were 1, 4, 6 and 8 plants from 10, 20, 30 and 40 kR treatments.

Eleven synchronously maturing plants from the treated population of K851 and 7 such plants from Sona had been isolated. The plants from each of the variety were isolated from 20 and 40 kR treatments. The 10 kR treatment of both the variety had developed one such plant. Maximum synchronous plants appeared in K851 from 30 kR treatments. Five plants in K851 and 4 plants in Sona were appeared to be sterile which were isolated from 40 kR treated population. These plants had thick, leathery, dark green leaves and uneven lamina surface. Flower buds dropped before blooming. These plants were very short in height with small leaves.

Previous study by Chaturvedi and Singh[20], Yadav and Singh[21] and Tickoo[10] observed that mutations for synchronous maturity in mungbean through mutagen treatment. Grafia *et al.*[22] observed a large seeded multifoliate *Vigna radiata* mutant. Satyanarayana *et al.*[23] also observed leaves with 9 or more leaflets per leaf. Detection of mutation in quantitative traits included leaf mutants was done by crossing F_2 seeds of *Vigna radiata* x *Vigna radiata* (wild) and *Vigna mungo* x *Vigna mungo* (wild) has been done by irradiating them with 10-70 kR gamma rays[24]. Out of the different micro mutants isolated from M_2 generation in the present experiment, some of the macro mutants bearing clustered pods with synchronous maturity can be considered of practical use. Such type of macro mutants appeared in maximum proportion in the higher doses of gamma ray treatment. So it may be concluded that for the development of such important variants, the Mungbean varieties should be exposed to higher doses of physical irradiation.

Pollen fertility: Pollen fertility was higher in control (95.23% for K851 and 91.42% for Sona) than the treatments in both the varieties (Table 4). Fertility percentage tended to reduce to every increase in the treatment dose and pollen fertility levels becomes lowest at 40 kR (56.12 and 58.15%) γ-irradiation in K851 and Sona, respectively. The difference in the range of fertility level becomes wider at the higher level of treatments in both the varieties. Awasthi and Dubey[25] reported that viable pollens were fully turgid and were stained uniformly by acetocarmine or iodine solution, while sterile pollens, having no cytoplasm content, fail to pick up the stain.

Days to 50% flowering, days to maturity and leaf orientation: The result for of Table 5 reveals the decrease in mean value for days to flowering in the treatments with various doses of gamma rays in both the varieties. Mean value for flowering was least in 20 kR γ-irradiation in both the varieties, though flowering period extended longer for 1 to 2 days than control, K851, Sona. Though flowering starts one week late in 30 or 40 kR treatments in K851, but it take a week less to complete the 50% flowering and

within twelve days these treatments have 50% flowering while control took 18 days. Mutagen treatment can induce eduction in mean values for days to flowering as observed by Khan[26] in the M_2 and M_3 generations generated through both chemical and physical mutagens in mungbean. In this respect, Singh *et al.*[27] and Yadav and Singh[27] reported lateness in flowering in their mutagens treated populations. Reduction in flowering period is a useful characteristic, which may help to isolate early mutants.

In M_2 generation, none of the treatments showed effective decrease in maturity period except 20 kR treatment in K851 when marginal decreased was noticed. On contrary at higher doses, lateness for 4 to 8 days was observed in K851 and Sona, respectively. Previous work by Malik[29] and Yadav and Singh[21] obtained early maturing mutants in M_2 or later generations. On the contrary, Kwon and Oh[30] obtained late maturing mutants in M_3 generations. Marginal increase in 50% flowering period in the present experiment have failed to influence the maturity period of the mutants which may be due to longer period of maturity, taken by early set pods of mutants to come to the harvesting stage.

Protein content: Protein content in M_2 generation was found to increase from control for irradiation treatment in both the varieties (Table 6) and it showed linear relationship with doses with maximum increase noticed in 40 kR γ-irradiation of 4.18 and 4.05% with the percentage of yield increase 14.99 and 12.37% for K851 and Sona over control. Positive correlation with increase in protein content and 100 seed weight (maximum increase of 16.95 and 22.49% over control at 40 kR for K851 and Sona), pod width (maximum increase of 23.78 and 8.53% over control at 40 kR for K851 and Sona was observed), petiole length (maximum increase of 5.07 and 9.49% over control at 40 kR for K851 and Sona. A direct relationship between protein content and pod length was also noticed with increase of 0.56% over control at 40 kR for K 851. Increase in cluster of pods per plant of 16.57% was also noticed over control at 40 kR for Sona. However a negative relation have also been observed between number of clusters per pod and protein content showing a 8.63% at 40 kR over control for K851, whilst, a reduction in pod length of 9.65% was also noticed at 40 kR over control for Sona. Positive correlation between seed protein content and seed yield was previously reported by Naidu and Rosaiah[31] from the association analysis in segregating and non-segregating populations of mungbean.

Genotype and dose interaction for pods/plant and 100 seed weight: Significant variation for number of pods/plant among the population raised from different treatments was evident in both the varieties except among the population raised from 20 kR treatments. Increase for this character have been maximum at 30 and 40 kR treatments in both the varieties and the range of variation in case of K851 was in between 73 to 130% and in case of Sona, it was between 40 to 86%, respectively. Non-significant variation was predominant for 100 seed weight in most of the M_2 populations raised from different treatments in both the varieties except 10 kR of Sona. Some of the families created from treated population at 30 and 40 kR γ-irradiation, had shown satisfactory improvement over control with a range in between 15% to 23% in K851 and 24 to 30% in Sona (Table 7).

Increase in number of pods in M_2 generation was also observed by Chaturvedi and Singh[20], Thakre *et al.*[35]. However, Khan *et al.*[36] have given the opposite results of reduction in pods/plant with the increase in the dose of gamma rays. The contradiction could be due to environmental effect and genotypic divergence. High coefficient of genetic variability with respect to 100 seed weight was reported by Khan[37] and Singh *et al.*[38] with an increase for 100 seed weight after γ-irradiation.

Genotype and dose interaction for seed yield/plant: Families grown from all the treatments of both the varieties exhibited significant variation for seed yield within the families except those from 20 kR treatments of both the varieties. The families which showed yield improvement over control at higher range were within higher doses of treatments in both the varieties. The maximum stimulating effect for increase in the seed yield/plant was noticed in 40 kR (12.37 and 14.99%), followed by 30 kR (10.43 and 12.53%) and 10 kR (3.78 and 2.62%) over control (Table 7).

Like the present investigation similar results in mungbean with an increase of 25 to 30% seed yield/plant in gamma ray treated plants than control were given by Thakre *et al.*[35]. Isolation of mutants of mungbean from 40 kR treatment were higher yielding in M_2 generation were also detected by Chaturvedi and Singh[20]. Whilst, Khan[39] observed a better heritability estimates and genetic advance for seed yield/plant at 40 than 20 kR γ-irradiation in mungbean Isolation of high yielding mutants in mungbean were also done by Sharma and Singh[40], after exposure to 10 kR γ-irradiation. Hence for bringing direct improvement in yield in the mutants, selection may be practiced among the families at higher range of treatments.

Table 1: Percentage of mortality in M_1 generation (Corrected mortality percentage in parenthesis)

	Control		10 kR		20 kR		30 kR		40 kR		
Genotype	P_c	PT	P_0	PT	P_0	PT	P_0	PT	P_0	PT	LD_{50} (kR)
K851	10	10	22	13	30	22	38	31	52	47	54.06
Sona	9	9	18	10	25	17	36	30	50	45	53.20

P_o = Observed mortality Percentage; P_c = Control mortality Percentage; PT = Corrected mortality Percentage; LD = Lethal Dose

Table 2: Mean performance for plant height and internode length in M_1 generation of mungbean variety K851 and Sona

	Plant height (cm)			Internode length (cm)		
Treatments	Sona	K851	Mean	Sona	K851	Mean
Control	51.933	51.600	51.767	3.227	3.287	3.257
10 kR	49.067	41.600	45.333	3.100	2.940	3.020
20 kR	46.667	42.533	44.600	2.453	2.847	2.650
30 kR	41.733	41.067	41.400	2.240	2.667	2.453
40 kR	38	35.200	36.600	1.773	1.913	1.843
Mean	45.480	42.400		2.559	2.731	
	T	V	T×V	T	V	T×V
CD (5%)	4.0566*	2.5656*	NS	0.3528*	NS	NS
SE ±	1.3653	0.8635	1.9308	0.1187	0.0751	0.1679

T = Treatment; V = Variety; CD = Critical Difference; SE = Standard error; NS = Non Significant

Table 3: Mean performance for number of leaves and number of secondary branches in M_1 generation of mungbean variety K851 and Sona

	Number of leaves			Number of secondary branches		
Treatments	Sona	K851	Mean	Sona	K851	Mean
Control	11.933	10.600	11.267	11.133	9.933	10.533
10 kR	15.600	13.733	14.667	14.467	13.000	13.733
20 kR	15.800	13.800	14.800	14.800	13.067	13.933
30 kR	18.267	14.067	16.167	16.867	13.467	15.167
40 kR	16.800	14.400	15.600	15.000	12.133	13.567
Mean	15.680	13.320		14.453	12.320	
	T	V	T×V	T	V	T×V
CD (5%)	1.851*	1.170*	NS	1.568*	0.991*	NS
SE ±	0.623	0.394	0.881	0.527	0.333	0.7464

T = Treatment; V = Variety; CD = Critical Difference; SE = Standard Error; NS = Non Significant

Table 4: Mean and range for pollen fertility in M_2 generation of mungbean variety K851 and Sona

	Variety			
	K851		Sona	
Treatments	Range (%)	Mean (%)	Range (%)	Mean (%)
Control	90.90-99.32	95.23	86.84-96.00	91.42
10 kR	74.00-81.25	76.75	76.47-85.71	79.70
20 kR	69.38-72.35	70.85	65.21-72.72	69.05
30 kR	54.08-72.32	61.39	56.75-60.00	58.21
40 kR	47.36-65.38	56.12	49.05-67.16	58.15

Table 5: Mean performance for days to 50% flowering and days to maturity and leaf orientation for K851 and Sona in the M_2 generation

	Days to 50% flowering		Days to maturity		Leaf orientation	
Variety with dose	Mean (days)	Range (days)	Mean (days)	Range (days)	Mean (deg)	Range (deg)
K851						
Control	43.68	32-50	60.28	56-64	66	30-125
10 kR	41.38	31-52	61.02	54-68	62	25-85
20 kR	41.09	35-54	59.86	52-64	57	20-88
30 kR	42.82	38-50	64.98	57-69	83	42-145
40 kR	43.58	39-51	65.18	59-72	101	57-160
Sona						
Control	44.98	38-50	65.36	58-70	54	35-71
10 kR	43.16	38-48	65.59	59-69	50	36-68
20 kR	42.62	36-50	66.39	58-72	63	30-85
30 kR	43.08	37-49	68.98	60-76	76	41-126
40 kR	43.87	39-51	69.18	62-79	88	46-134

Table 6: Correlation of mean performance for pod length, pod width, petiole length, pods/cluster, seed yield, 100 seed weight, nitrogen and protein content of K851 and Sona

Source (kR)	Pod length (cm)	Pod width (cm)	Petiole length (cm)	Pods /cluster	100 seed weight (g)	Yield (g)	Nitrogen content (g)	Protein (N x 6.25) g
K851								
Control	6.6358	0.3694	10.7557	4.9442	3.6277	10.1016	3.82	23.8750
10 kR	6.1366	0.3848	13.1653	4.1074	3.8148	10.3736	3.86	24.1250
20 kR	5.7943	0.4178	13.5358	4.6966	4.1284	11.2795	3.91	24.4375
30 kR	5.9200	0.4614	13.9299	5.9360	4.2015	11.5495	3.92	24.5000
40 kR	6.6735	0.4847	11.3312	4.5510	4.3683	11.8840	3.98	24.8750
Sona								
Control	5.9605	0.3624	11.9322	3.8080	2.4063	9.8206	4.49	28.0625
10 kR	5.9201	0.3719	13.1920	3.2741	2.4754	10.2070	4.50	28.1250
20 kR	5.8620	0.3419	13.4288	4.8849	2.7903	10.5735	4.53	28.3125
30 kR	5.9390	0.3847	13.5988	4.6616	2.9844	10.9647	4.58	28.6250
40 kR	5.4356	0.3962	13.1838	4.5646	3.1046	11.2076	4.68	29.2500

Genotype and dose interaction for plant height and internode length: Plant height was significantly reduced with increase in the irradiation doses, both in K851 and Sona. All the populations in 40 kR γ-irradiation had significantly reduced plant height of 37.85 and 64.20% for Sona and K851 over control. Minor increase in plant height (1.67%) has been observed in 10 kR over control. None of the plants of M_2 generation from different treatments of γ-irradiation in both the varieties had plants with longer internode length over control. In case of Sona and K851, shortest internode in plants was observed at 40 kR with 45.01 and 39.41% increase over control (Table 7). Significant reduction in plant height was also reported by Pande and Raghuvanshi[43] and Tickoo[10], who observed mutants of dwarf habit in advanced generation of gamma ray treated populations in mungbean. Reduction in internode length may be considered as important selection criteria, which prevent plant from unnecessary vegetative growth and maximum emphasis may be pursued to reproductive growth for augmentation of yielding ability of the selected variants. Plants with shorter internode length may be considered desirable ones because the stems would be strong, erect and non-drooping in nature, which may facilitate to increase in seed yield.

Genotype and dose interaction for number of leaves, number of primary and secondary branches: Significant variation in the genotype and dose interaction for number of leaves among the population in both the varieties have been found in all the treatments with maximum at 30 kR γ-irradiation for Sona and 20 kR K851 with an increase of 29.92 and 23.95% over control, respectively. Variation due to primary branch in M_2 population was insignificant for almost all the treatments in both the varieties, except 30 kR for K851 and 20 kR for Sona with an increase of 20.02 and 23.86% over control. All the treatments in both K851 and Sona showed significant variation in M_2 generation. Maximum increase of 27.48 and 30.92% over control was noticed at 20 kR γ-irradiation for Sona and K851, respectively (Table 7).

As the number of leaves was found to increase, by increasing the irradiation dose, the plants with maximum number of leaves can be obtained through mutation breeding. By the increase in number of leaves, there is a chance to increase the yield potentiality through the manipulation of photosynthetic process and thereby increasing the concentration of sink to the developing seeds. In the present investigation, 30 kR treatment offered maximum potentiality to increase number of leaves per plant and this treatment is useful in isolation of plants showing promising yield and yield contributing traits (Table 7).

Primary branch may have a positive correlation with yield as reported by Seth and Chaudhary[18] who found increase in mean values for branches/plant in mungbean with 20 kR γ-irradiation in the M_1 and M_2 generation. However Yaqoob and Rashid[1] found 30 kR γ-irradiation being optimum in mungbean for increase in number of branches per plant. Secondary branch is a yield contributing character because increase in number of branches would effectively increase the number of seed bearing pods. So directed selection towards more number of branches may be practiced from the different treated population in M_3 and succeeding generations.

Genotype and dose interaction for cluster of pods/plant: Significant variation for cluster of pods per plant was noticed at 30 and 40 kR γ-irradiation for K851, while 10 and 40 kR γ-irradiation for Sona, respectively. Increase of 16.13 and 19.95% over control was noticed at 30 kR and 40 kR for K851 while, maximum stimulating effect of 17.10 and 26.04% over control for 10 and 40 kR for Sona (Table 7). Like the present investigation Krishnaswamy *et al.*[34] also observed increase in cluster of pods per plant.

Table 7: Genotype and dose interaction for quantitative characters with respective mean performance, critical difference and standard error in M_2 generation of Sona and K851

	Sona			K851		
Mutation dose	Mean	CD (5%)	SE±	Mean	CD (5%)	SE±
Pods/plant						
Control	42.9683			30.2960		
10 kR	43.1133*	10.2066	3.3646	36.6266*	8.3839	2.7638
20 kR	53.6133	NS	4.0588	49.9000	NS	3.7680
30 kR	60.4666*	12.9748	4.2772	50.5666*	15.2010	5.0111
40 kR	58.2460*	9.5217	3.1388	54.1866*	8.3489	2.7523
100-seed weight						
Control	2.4063			3.6277		
10 kR	2.4754*	0.0136	0.0045	3.8148	NS	0.0033
20 kR	2.7903	NS	0.0395	4.1284	NS	0.0012
30 kR	2.9844	NS	0.0277	4.2015	NS	0.0041
40 kR	3.1046	NS	0.0110	4.3683	NS	0.0341
Yield/plant						
Control	9.8206			10.1016		
10 kR	10.2070*	0.0327	0.0108	10.3736*	0.0541	0.0178
20 kR	10.5735	NS	1.1841	11.2795	NS	0.1391
30 kR	10.9647*	0.0934	0.0308	11.5495*	0.1269	0.0418
40 kR	11.2076	NS	0.0153	11.8840*	0.0533	0.0176
Plant height						
Control	52.6060			57.5993		
10 kR	52.6940*	5.4375	1.7925	43.0600*	3.4227	1.1282
20 kR	48.6330*	5.2547	1.7322	45.9606*	7.6194	2.5518
30 kR	42.3496*	3.6266	1.1955	42.5343*	4.8335	1.5934
40 kR	37.8490*	3.2899	1.0845	35.0783*	5.8271	1.9209
Internode length						
Control	3.2976			3.4224		
10 kR	3.0013*	0.4880	0.1609	2.9440*	0.5892	0.1876
20 kR	2.8610*	0.6420	0.2116	3.0976*	0.4324	0.1426
30 kR	2.4833*	0.5692	0.1876	2.8973*	0.4575	0.1508
40 kR	1.8133*	0.4811	0.1586	2.0736*	0.5235	0.1726
No. of leaves						
Control	12.3823			12.0010		
10 kR	15.8406*	2.0330	0.6702	14.1106*	1.8518	0.6105
20 kR	16.5586*	2.0953	0.6907	14.8753*	2.8501	0.9396
30 kR	17.6706*	3.4722	1.1453	14.6926*	2.2553	0.7435
40 kR	17.1346*	1.7452	0.5753	13.9646*	2.3334	0.7692
Primary branches/plant						
Control	2.3966			2.2766		
10 kR	2.9366	NS	0.2025	2.5600	NS	0.1450
20 kR	3.1466*	0.6860	0.2261	2.7533	NS	0.1984
30 kR	3.2966	NS	0.3262	2.8466*	0.6956	0.2293
40 kR	2.7846	NS	0.3649	2.4133	NS	0.2210
Secondary branches/plant						
Control	11.6846			10.0553		
10 kR	15.8620*	2.4822	0.8183	14.1806*	1.5539	0.5122
20 kR	14.9473*	2.4049	0.7928	14.5573*	1.7592	0.5799
30 kR	16.1140*	2.2244	0.7333	14.1396*	2.7975	0.9222
40 kR	14.1586*	2.2547	0.7433	12.4073*	2.3172	0.7639
Cluster of pods/plant						
Control	10.2253			10.0913		
10 kR	12.3353*	2.8391	0.9359	10.8600	NS	0.7627
20 kR	11.8440	NS	0.5682	10.8733	NS	1.2360
30 kR	14.0066	NS	1.7678	12.0333*	2.7462	0.9053
40 kR	13.8273*	1.3730	0.4526	12.6066*	2.2579	0.7443

* = Significant at 5% level; NS = Non Significant

Hence in the above foregoing discussion it was observed that higher doses of gamma ray irradiation in mungbean provided enough scope by developing a wide range of variation in desirable plant attributes to select high yielding mutants. Both high yielding and early genotypes have appeared in the M_2 generations and a directed selection may be practiced to isolate early maturing and high yielding types in succeeding generations.

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