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INDUCED GENETIC VARIABILITY, HERITABILITY AND GENETIC ADVANCE IN SESAME (*Sesamum indicum* L.)

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SUMMARY

Three widely adapted sesame genotypes - Rama, SI 1666, and IC 21706 - were induced by 200 Gy, 400 Gy, and 600 Gy doses of γ rays as well as by 0.5%, 1.0%, 1.5%, and 2.0% concentrations of ethyl methane sulfonate (EMS) separately. Mutant generations from M_1 to M_2 were raised to assess the extent of variability, heritability, and genetic advance for yield and important yield components in mutant populations. Mutations surpassed the magnitude of variability over the control population in both generations. Mutagenic treatments caused a shift in the mean values of quantitative traits in both positive and negative directions, albeit the magnitude of the shift varying with mutagen, its dose, parental genotype, and character under consideration. Lower doses of mutagens were more proficient for induction of mutations. The chemical mutagen (EMS) was much more effective than the physical mutagen (γ rays) in producing polygenic variability. The genotype IC 21706 and the treatment using 0.5% concentration of EMS appeared to be the best for engendering variability, highlighting their potentiality for selecting higher yielding plants in early generations. In the M_2 generation, there was considerable increase in genetic estimates for all the metric traits, as compared with that in the M_1. In general, estimates of genetic variability and heritability dwindled with increasing doses of γ rays and EMS. All genotypes showed a promising increase in genotypic variability, heritability and genetic advance for all traits, implying that these characters can be transmitted to future generations. This means that a significant gain could be achieved through selection in early generations.

Keywords: Genetic advance, genotypic coefficient of variability, heritability, induced mutation, phenotypic coefficient of variability, sesame

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INTRODUCTION

Sesame (*Sesamum indicum* L.; family - Pedaliaceae; chromosome number 2n = 26), the fifth important edible oil crop in India after groundnut, rapeseed-mustard, sunflower and soybean, evinces good promise in the state of West Bengal because its productivity is superior to that of the national average. Nevertheless, the productivity of this crop stands alarmingly poor *vis-a-vis* those of other oil-yielding crops. Sesame, as a quality oilseed crop, can help tide over the problem of edible oil shortage in the country if production and productivity were enhanced. In this context, West Bengal, can play a major role as it ranks highest in productivity among the other states of India, even though, the figures are far from satisfactory. With appropriate breeding strategies, production can likely be revolutionized as the prevailing agro-climatic and soil edaphic conditions in this state are favorable.

The area under sesame is unlikely to be extended further due to the planting of other competitive crops. Hence, to augment sesame production, the only recourse is to boost up productivity. There is a wide scope for increasing crop productivity through the use of high-yielding varieties. But the development of improved sesame cultivars is restricted by limited genetic variability. The narrow genetic base hinders the thorough restructuring of the crop. In other words, the narrow gene pool diminishes the need for crop restructuring to attain higher productivity. The creation of variation constitutes a primary step to get desirable plant types. Mutation breeding has been perceived as an important tool to foster additional variability in qualitatively and quantitatively inherited traits in a number of crop plants. The variability thus created enhances opportunities for selection of new genotypes with the desired characteristics. Induced mutation can play a momentous role in the restructuring of the plant, leading to yield improvement. It could create additional genetic variability to supplement conventional crop breeding. The induced variability can be exploited to develop new varieties of sesame with improved agronomic traits. Induced mutation has been employed successfully in sesame by many workers (Das and Haque, 1997; Govindarasu and Ramamoorthi, 2000; Sheeba *et al*., 2003, 2005; Chowdhury *et al*., 2009; Diouf *et al*., 2010; Begum and Dasgupta, 2010, 2011).

The extent of variability is detected by genotypic and phenotypic coefficients of variability (GCV and PCV), providing information about the relative amount of variation in different characters. Several researchers (Labana *et al*., 1980; Ali, 1985, Naazar *et al*., 2003, Larik *et al*., 2009; Siddiqui *et al*., 2009) have discussed the importance of genetic components of variance in predicting responses in selection. Since yield and its component characters are controlled by polygenes, information on the extent of the heritable portion of variability induced by mutation is meaningful for developing improved varieties. Therefore, genetic variability in terms of coefficients of variability is not sufficient to determine the amount of heritable variability. The estimate of heritability acts as a predictive mechanism in expressing the reliability of phenotypic values. Hence, it helps plant breeders to make a selection for a particular character when heritability is high (Arulbalachandran *et al*., 2010). Because heritability is also influenced by the environment, the information on heritability alone may not suffice in pinpointing characters enforcing selection. Therefore, an estimation of heritability, coupled with genetic advance, is also needed to assess the heritable portion of total variation and the genetic gain expected for effective selection. Heritability estimates provide information on the extent to which a particular genetic character can be transmitted to successive generations, whereas genetic advance helps in formulating suitable selection indices. Such estimates facilitate the evaluation of genetic and environmental effects, thereby aiding in selection. Estimates of heritability can be used to predict genetic advance under selection, so that breeders can anticipate improvement from different types and intensities of selection. It is interesting to know the upshot of mutations on genetic variability, heritability, and genetic advance of characters. Such a study is not common in sesame. The estimation of the extent of induced variability in M_1 and M_2 generations will be of great importance for carrying out further selection.

The present investigation was formulated to assess the nature and magnitude of genetic variability of sesame mutants in the M_1 and M_2 generations, along with non-treated control populations, with particular reference to yield and its important components.

MATERIALS AND METHODS

Plant materials

Three diverse genotypes of sesame (*Sesamum indicum* L.) - Rama, SI 1666, and IC 21706 (Table 1) - were used in the experiment.

Mutagenic treatments

Homogeneous seeds of each of the 3 genotypes were treated with 3 doses (200 Gy, 400 Gy, and 600 Gy) of γ rays and 4 concentrations (0.5%, 1.0%, 1.5% and 2.0%) of ethyl methane sulfonate (EMS) individually. Genetically pure uniform dry seeds (10-12% moisture content) of each genotype were irradiated at the rate of 30 Gy/min with a ^{60}Co source in the gamma garden of the Central Research Institute for Jute and Allied Fibres (Indian Council of Agricultural Research), Barrackpore, Kolkata, West Bengal, India. For each irradiation dose, 300 seeds were treated. In contrast, for each concentration of EMS (prepared in sodium phosphate buffer with pH 7.0), 150 healthy seeds were treated for 6 h with constant intermittent shaking. The treated seeds were then rinsed thoroughly under running tap water and surface-dried with filter paper for immediate sowing in the field. Altogether, 8 treatments (control; 200 Gy, 400 Gy, and 600 Gy doses of γ rays; 0.5%, 1.0%, 1.5%, and 2.0% concentrations of EMS) were used for each genotype.

Raising the M_1 and M_2 generations

Treated seeds, along with control (untreated seeds), were sown separately for each genotype at a spacing of 35 × 10 cm during 2004-05 at the Agricultural Experimental Farm, University of Calcutta, Baruipur, West Bengal, India, representing the alluvial part of coastal South Bengal (22° 21′ 56′′ N, 88° 26′ 14′′ E) to raise the M_1 generation. Subsequently, M_2 generation was raised during 2005-06. A randomized block design was followed with 3 replications. Normal recommended agronomic practices were used to grow the crop.

Data collection and analysis

In both generations, observations were made on 11 morphological characters: days to 1st flowering, flower duration (d), plant height (cm), number of branches per plant, number of capsules per plant, capsule length (cm), number of seeds per capsule, 1000-seed weight (g), days to maturity and seed yield per plant (g). For precision, seed yield and its 3 most important components, as reported by Begum and Dasgupta (2011), were taken into consideration. In both M_1 and M_2 generations, the range, mean, and genetic parameters such as coefficients of variation (PCV and GCV), heritability and genetic advance as a percentage of the mean for each treatment were estimated and compared with those of the control for each character separately. Genetic parameters were computed following the methods suggested by Singh and Chaudhary (1979) using the statistical software MSTAT-C, version 2.1 (Michigan State University).

Table 1. Description of parental materials.

Genotype	Characteristic features	Source
Rama	Plant erect, height medium; lower leaves broad, furcated and serrated, less hairy; flowers pinkish white; early maturing; medium sized capsule, dry capsule color brown; seed surface rough and glossy, seed coat color brown, seed medium sized	Pulse and Oilseed Research Station, Berhampore, West Bengal, India
SI 1666	Plant erect, taller; leaves long, not serrated, medium hairy; dry capsule color brownish black; seed surface smooth and glossy, seed coat color black, seed size bold	Jawaharlal Nehru Krishi Viswavidyalaya (Oilseed Project Directorate), Jabalpur, Madhya Pradesh, India
IC 21706	Plant erect, large height; leaves long, narrow, non-serrated, pigmentation dark green; flowers dark pinkish white, more hairy; late maturing; capsules more hairy, dry capsule color brown; seed surface rough and dull, seed coat color white, seed size medium	National Bureau of Plant Genetic Resources, New Delhi, India

RESULTS

The ramification of mutations on genetic variability in sesame was conspicuous. Genotypes showed variable responses to different mutagenic treatments for all traits, which indicated that the treatments induced mutation to a great extent. An inconsistent treatment effect was noted for plant height in the mutagen-treated populations of the 3 genotypes (Table 2). In the M_1 generation, the treated Rama population exhibited an increase in plant height over the control only at 200 Gy, while all other γ ray doses reduced the plant height of IC 21706. Interestingly, no treatment caused taller SI 1666 plants compared with the control. In M_2, mean plant height was reduced using all doses of γ rays, irrespective of genotype, except in the irradiated population of SI 1666. On the other hand, all EMS doses induced taller plants in IC 21706, barring the 2.0% dose. The tallest plant was recorded in the 0.5% EMS-induced population of IC 21706. In the M_1 generation, the greatest variation in plant height was seen in the 200 Gy-irradiated population of IC 21706, whereas in the induced population of SI 1666 in M_2, the effect was more pronounced at the 1.0% EMS dose. The highest GCV (16.45%), heritability (75.62%), and genetic advance (29.48%) for plant height in M_1 were estimated from the 0.5% EMS-treated population of Rama; in M_2, the mutant population of IC 21706 induced by the same dose demonstrated the highest GCV (18.64%), heritability (85.13%) and genetic advance (35.44%).

In most cases, the mutagens consistently increased the number of branches per plant in the mutant populations of the 3 genotypes in the M_1 generation (Table 3). The maximum number of branches was found in the 0.5% EMS treatment in IC 21706, followed by 400 Gy dose of γ rays in the irradiated population of SI 1666. Conversely, in the M_2 population of Rama, the mean number of branches per plant was reduced with all doses of physical and chemical mutagens, except at 0.5% EMS (Table 3). Interestingly, the number of branches per plant improved significantly when variety SI 1666 was induced by either of the mutagens, irrespective of dose. Likewise, the number of branches per plant was found to increase with all doses of EMS, but reduction was greater with a higher dose of γ rays in the treated population of IC 21706. The highest mean branch number was observed in the 0.5% EMS-induced population of SI 1666, followed by the 2.0% EMS-treated population of IC 21706. The highest range of variation for this trait in both generations was recorded in the 0.5% EMS-treated populations of Rama and IC 21706, respectively. In the M_1 generation, 0.5% dose of EMS induced the highest GCV (16.51%) and genetic advance (29.71%) in the treated population of IC 21706, while the same treatment with similar dose produced maximum heritability (78.46%) in the mutant population of SI 1666. On the other hand, in M_2, for the same trait, the highest GCV (20.79%) with maximum heritability (81.70%) and genetic advance (38.71%) were noted at 0.5% dose of EMS in SI 1666.

The mutagenic treatments caused a shift in the mean values of number of capsules per plant in both positive and negative directions in both generations (Table 4). Of the different doses of γ rays, 600 Gy induced the lowest number of capsules per plant in SI 1666 in M_1, while 200 Gy gave the lowest capsule number in irradiated populations of Rama and IC 21706 (Table 4). A considerable reduction in capsule number was also found with different doses of EMS. The maximum reduction was recorded in the 1.0% EMS-induced population of Rama. In the M_2 generation, irrespective of genotype, almost all doses of EMS, on average, induced significant improvement in number of capsules per plant (Table 4). The mutant population of Rama irradiated by 200 Gy of γ rays and that of IC 21706 induced by 0.5% EMS showed the maximum range of variation in M_1 and M_2 generations, respectively. Interestingly, in both generations, 0.5% EMS induced the highest coefficient of variation (20.98% and 26.72%, respectively) and genetic advance (38.07% and 49.05%, respectively) in the treated population of IC 21706, whereas the highest heritability estimates (82.48% and 87.72%, respectively) were exhibited by the mutant populations of SI 1666 treated with 0.5% and 1.0% EMS, respectively.

Out of all genotypes and treatments, the higher seed yield per plant in the M_1 generation was more explicit at 400 Gy in Rama;

Table 2. Estimates of range, mean and genetic parameters for plant height (cm) in M_1 and M_2 generations.

Treatments	Range		Mean		PCV%		GCV%		H%		GA % of mean	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
Rama												
Control	62.00-67.00	61.50-65.00	64.83	63.49	6.11	6.48	-	-	-	-	-	-
200 Gy	37.00-100.00	17.00-98.50	66.47	56.45	15.38	19.03	12.92	16.37	70.57	73.96	22.36	29.01
400 Gy	38.50-99.10	32.00-131.50	54.66	58.81	14.75	18.52	11.66	15.37	62.50	68.85	18.99	26.27
600 Gy	21.50-95.00	33.00-96.20	60.59	54.37	14.65	18.24	11.58	15.00	62.43	67.69	18.84	25.43
0.5% EMS	24.00-88.00	39.00-135.00	63.62	80.06	18.92	20.11	16.45	17.41	75.62	74.96	29.48	31.05
1.0% EMS	23.00-82.00	39.00-115.00	59.21	63.35	12.97	18.75	10.79	15.33	59.17	66.83	18.49	25.82
1.5% EMS	30.20-81.00	32.00-117.00	57.70	72.12	13.80	15.19	11.34	12.76	67.50	70.57	19.19	22.09
2.0% EMS	26.50-84.00	45.00-103.00	60.97	62.98	11.30	13.94	8.78	11.28	60.37	65.43	14.05	18.79
SI 1666												
Control	90.00-97.00	115.00-129.00	94.40	125.18	6.07	7.66	-	-	-	-	-	-
200 Gy	39.50-126.00	62.00-218.00	84.71	144.33	12.18	15.32	10.17	13.39	69.74	76.41	17.49	24.12
400 Gy	40.50-109.40	43.00-203.00	74.32	128.78	11.37	14.29	8.87	12.29	60.91	74.03	14.27	21.79
600 Gy	46.20-51.33	66.50-146.50	48.05	130.06	10.77	12.24	8.39	10.05	60.67	67.44	13.47	17.00
0.5% EMS	36.00-100.50	26.00-171.00	73.71	128.46	15.72	16.19	13.48	14.20	73.54	76.96	23.82	25.67
1.0% EMS	25.00-118.00	35.00-200.00	84.15	94.31	14.80	15.07	11.78	12.42	63.31	67.90	19.30	21.08
1.5% EMS	54.90-100.20	35.00-142.00	77.78	75.39	13.84	14.65	10.77	11.72	60.49	63.97	17.25	19.31
2.0% EMS	50.20-95.10	50.00-78.00	75.12	59.50	11.93	13.17	9.33	10.33	61.17	61.55	15.03	16.69
IC 21706												
Control	88.00-93.00	105.00-113.30	90.50	108.75	6.142	7.586	-	-	-	-	-	-
200 Gy	53.00-145.00	39.00-105.00	86.31	87.90	11.75	15.89	9.09	12.48	59.92	61.64	14.50	20.18
400 Gy	60.50-107.40	35.00-99.00	77.79	66.32	11.37	14.50	8.90	12.00	61.26	68.48	14.35	20.45
600 Gy	51.40-77.60	29.00-88.00	59.75	59.49	10.37	10.20	7.90	7.87	58.02	59.54	12.39	12.52
0.5% EMS	74.20-130.20	126.00-236.00	104.80	171.31	14.50	20.21	12.32	18.64	72.21	85.13	21.56	35.44
1.0% EMS	89.50-100.20	137.00-188.00	93.03	155.42	12.84	15.99	10.64	13.14	68.69	72.09	18.17	23.74
1.5% EMS	55.50-122.40	83.40-195.00	80.62	154.01	12.93	14.74	10.40	12.48	64.72	71.76	17.24	21.78
2.0% EMS	66.10-102.10	86.0 0-119.00	78.97	106.40	10.51	11.79	8.06	9.32	58.85	62.53	12.66	15.18

Table 3. Estimates of range, mean and genetic parameters for number of branches per plant in M_1 and M_2 generations.

Treatments	Range		Mean		PCV%		GCV%		H%		GA % of mean	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
Rama												
Control	3.00-5.00	4.00-5.00	4.37	4.40	7.74	8.14	-		-	-	-	-
200 Gy	0.00-13.00	0.00-16.00	3.58	3.61	11.97	12.874	9.86	10.80	67.85	70.37	17.10	18.66
400 Gy	0.00-16.00	0.00-14.00	5.57	3.67	10.66	11.846	9.00	9.82	71.35	68.78	15.67	16.79
600 Gy	0.00-15.00	0.00-9.00	6.26	3.32	10.33	11.270	8.67	9.62	70.37	72.86	14.98	16.92
0.5% EMS	2.00-26.00	2.00-19.00	5.07	5.46	13.06	13.663	11.17	12.16	73.09	79.16	19.67	22.28
1.0% EMS	0.00-14.00	0.00-14.00	4.47	3.17	12.45	12.833	10.51	10.81	71.24	71.00	18.27	18.77
1.5% EMS	0.00-9.00	2.00-6.00	3.40	3.52	9.35	11.522	7.08	9.86	57.43	73.25	11.06	17.39
2.0% EMS	0.00-14.00	2.00-13.00	4.37	3.51	8.03	8.641	6.18	7.15	59.35	68.48	9.81	12.19
SI 1666												
Control	2.00-3.00	2.00-3.00	2.37	2.40	7.37	7.54	-	-	-	-	-	-
200 Gy	0.00-10.00	0.00-20.00	2.90	2.96	12.79	14.09	10.26	12.13	64.36	74.14	16.95	21.52
400 Gy	0.00-15.00	0.00-11.00	8.03	3.03	12.08	13.30	9.82	11.17	66.10	70.46	16.45	19.31
600 Gy	1.00-5.00	0.00-12.00	2.67	5.50	8.99	9.14	6.94	7.87	59.68	74.26	11.05	13.98
0.5% EMS	0.00-11.00	0.00-19.00	5.27	10.46	13.31	23.00	11.79	20.79	78.46	81.70	27.51	38.71
1.0% EMS	2.00-13.00	0.00-18.00	7.60	5.98	11.26	17.28	9.39	14.78	69.54	71.21	16.13	24.99
1.5% EMS	1.00-13.00	2.00-10.00	7.73	4.83	10.26	11.39	8.48	9.77	68.36	73.55	14.45	17.25
2.0% EMS	1.00-10.00	0.00-4.00	4.60	3.04	10.05	8.42	8.03	7.17	63.93	72.52	13.23	12.58
IC 21706												
Control	2.00-3.00	4.00-6.00	2.33	4.95	7.67	8.85	-	-	-	-	-	-
200 Gy	2.00-8.00	0.00-8.00	3.37	2.21	14.48	20.24	11.80	17.87	66.39	78.00	19.80	32.52
400 Gy	1.00-6.00	0.00-6.00	2.33	2.20	14.17	18.74	11.52	14.94	66.06	63.53	19.28	24.53
600 Gy	2.00-7.00	0.00-3.00	3.67	1.55	12.13	18.92	9.60	15.27	62.63	65.12	15.64	25.38
0.5% EMS	0.00-11.00	0.00-24.00	8.33	8.55	18.90	23.07	16.51	20.43	76.32	78.43	29.71	37.26
1.0% EMS	2.00-7.00	0.00-22.00	4.27	5.50	14.46	20.93	12.35	17.28	72.97	68.16	21.73	29.38
1.5% EMS	1.00-12.00	3.00-18.00	4.63	5.35	11.78	19.70	9.62	14.68	66.72	55.54	16.19	22.54
2.0% EMS	4.00-15.00	4.00-16.00	6.33	10.45	10.58	16.62	7.99	13.27	56.97	63.73	12.42	21.82

Table 4. Estimates of range, mean and genetic parameters for number of capsules per plant in M_1 and M_2 generations.

Treatments	Range		Mean		PCV		GCV		H%		GA % of mean	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
Rama												
Control	33.00-38.00	24.00-32.00	36.87	27.10	12.47	13.69	-	-	-	20.00	-	-
200 Gy	3.00-176.00	3.00-175.00	24.83	26.07	19.28	22.60	16.83	20.01	76.20	78.74	30.27	36.65
400 Gy	4.00-152.00	3.00-156.00	39.13	31.08	18.16	20.86	16.13	18.68	78.93	80.21	29.52	34.47
600 Gy	4.00-161.00	5.00-128.00	36.90	18.81	17.54	19.27	15.42	16.16	77.28	70.30	27.93	27.90
0.5% EMS	2.00-94.00	5.00-195.00	23.47	55.97	21.24	24.23	18.86	21.85	78.84	81.31	34.49	40.59
1.0% EMS	2.00-101.00	4.00-100.00	20.13	25.23	19.47	22.13	17.18	19.78	77.27	79.87	30.99	36.41
1.5% EMS	4.00-76.00	4.00-97.00	22.50	37.34	16.04	18.00	13.71	15.31	73.02	72.38	24.13	26.84
2.0% EMS	6.00-136.00	9.00-78.00	36.77	30.59	14.23	16.30	12.80	13.23	80.92	65.94	23.73	22.14
SI 1666												
Control	28.00-36.00	28.00-35.00	31.80	31.80	12.55	13.45	-	-	-	-	-	-
200 Gy	0.00-85.00	5.00-200.00	27.50	49.73	20.78	23.35	18.29	21.16	77.47	82.12	33.16	39.50
400 Gy	0.00-95.00	4.00-167.00	38.70	68.47	17.62	21.05	15.29	18.48	75.29	77.02	27.33	33.40
600 Gy	0.00-24.00	8.00-133.00	9.00	77.00	17.03	18.35	13.96	16.33	67.21	79.15	23.57	29.92
0.5% EMS	5.00-97.00	1.00-434.00	35.73	172.25	22.24	25.93	20.19	23.08	82.48	79.21	37.78	42.31
1.0% EMS	3.00-130.00	4.00-198.00	53.00	53.64	19.27	24.50	17.33	22.94	80.88	87.72	32.11	44.26
1.5% EMS	13.00-68.00	5.00-76.00	40.40	47.82	16.40	22.89	14.03	20.20	73.18	77.83	24.73	36.70
2.0% EMS	11.00-65.00	4.00-55.00	36.83	33.55	15.67	17.30	13.50	14.40	74.25	69.25	23.96	24.68
IC 21706												
Control	25.00-32.00	98.00-105.00	28.46	101.40	13.03	13.70	-	-	-	-	-	-
200 Gy	10.00-60.00	5.00-104.00	16.67	26.25	17.76	18.35	14.94	15.93	70.75	75.37	25.88	28.49
400 Gy	17.00-55.00	4.00-92.00	23.57	21.65	16.14	24.48	13.36	21.18	68.53	74.90	22.78	37.77
600 Gy	10.00-43.00	3.00-56.00	25.53	17.20	15.27	20.43	12.39	17.24	68.53	71.19	22.78	29.96
0.5% EMS	17.00-77.00	47.00-581.00	45.50	282.40	23.82	29.99	20.98	26.72	77.59	79.40	38.07	49.05
1.0% EMS	9.00-39.00	42.00-575.00	27.67	223.65	22.43	25.89	19.28	22.89	73.85	78.21	34.12	41.70
1.5% EMS	7.00-54.00	95.00-517.00	22.70	171.35	18.96	22.09	15.92	19.31	70.49	76.40	27.54	34.77
2.0% EMS	31.00-59.00	50.00-177.00	41.10	121.70	17.29	17.96	14.34	15.02	68.78	69.88	24.50	25.86

Table 5. Estimates of range, mean and genetic parameters for seed yield (g) in M_1 and M_2 generations.

Treatments	Range		Mean		PCV		GCV		H%		GA % of mean	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
Rama												
Control	6.00-6.80	5.00-5.25	6.44	5.19	13.22	14.05	-	-	-	-	-	-
200 Gy	3.35-6.29	2.45-6.44	4.37	4.22	16.88	19.38	13.62	17.55	65.07	82.05	22.63	32.75
400 Gy	2.16-10.50	2.23-7.39	5.63	4.60	15.90	18.35	12.80	15.05	64.79	67.30	21.22	25.44
600 Gy	2.93-6.25	1.45-2.87	4.02	2.34	15.49	17.04	12.70	14.17	67.23	69.18	21.44	24.29
0.5% EMS	3.82-7.24	1.88-27.44	4.28	11.47	22.04	26.64	19.25	23.60	76.28	78.44	34.63	43.05
1.0% EMS	2.36-6.21	0.75-6.11	3.53	4.39	20.63	24.77	17.38	22.56	70.97	82.92	30.17	42.31
1.5% EMS	2.71-4.33	1.33-15.62	3.85	6.27	20.88	23.75	17.19	20.48	67.80	74.37	29.16	36.38
2.0% EMS	3.79-6.80	2.05-7.33	5.20	4.59	16.05	18.69	13.51	14.14	70.85	57.20	23.43	22.02
SI 1666												
Control	5.10-5.80	5.25-5.65	5.55	5.40	14.07	15.42	-	-	-	-	-	-
200 Gy	3.23-4.28	1.75-13.24	4.19	9.75	17.51	21.06	14.76	17.94	71.03	72.57	25.63	31.48
400 Gy	4.75-6.29	1.66-9.31	5.18	7.20	16.51	20.93	13.65	17.71	68.40	71.59	23.26	30.86
600 Gy	0.75-1.62	2.24-18.39	0.99	12.81	15.15	19.88	11.74	16.27	60.00	66.98	18.73	27.42
0.5% EMS	5.52-7.54	2.39-54.11	6.58	31.37	23.33	29.16	20.42	26.57	76.62	83.01	36.83	49.87
1.0% EMS	8.59-10.25	3.18-23.64	9.58	8.77	22.04	27.10	19.46	23.56	78.01	75.62	35.42	42.21
1.5% EMS	5.47-7.14	1.59-14.27	6.20	6.90	21.78	22.33	18.03	18.95	68.51	72.06	30.74	33.14
2.0% EMS	4.85-5.79	0.98-5.51	5.30	4.64	17.81	19.76	13.88	16.58	60.81	70.38	22.30	28.64
IC 21706												
Control	3.96-4.28	18.54-21.47	4.14	19.52	13.46	14.97	-	-	-	-	-	-
200 Gy	1.00-2.50	1.60-6.69	1.84	3.53	20.05	22.97	17.01	20.04	72.06	76.12	29.75	36.02
400 Gy	1.95-3.23	1.39-3.57	3.05	2.62	19.87	21.98	17.44	18.56	77.11	71.34	31.55	32.30
600 Gy	2.05-5.09	0.88-4.19	3.51	1.46	19.51	21.71	17.27	19.31	78.44	79.10	31.51	35.38
0.5% EMS	4.52-10.29	15.69-68.28	8.31	55.64	24.11	31.54	21.04	28.31	76.17	80.53	37.83	52.33
1.0% EMS	1.98-7.11	13.46-62.51	4.15	42.06	22.78	27.58	19.32	24.45	71.91	78.58	33.74	44.64
1.5% EMS	2.05-4.17	5.42-55.37	3.15	30.55	20.32	22.35	18.17	19.68	79.98	77.56	33.47	35.70
2.0% EMS	5.24-8.29	2.33-25.64	6.53	18.92	18.27	20.86	15.77	17.78	74.55	72.69	28.05	31.23

Table 6. Estimates of range, mean and genetic parameters for different quantitative traits as affected by mutagens (average of all the mutagens) in M_1 and M_2 generations.

Genetic parameters	Plant height (cm)		Number of branches		Number of capsules		Seed yield/plant (g)	
	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
				Rama				
Range	21.50-100.00	17.00-135.00	0.00-26.00	0.00-19.00	2.00-176.00	3.00-195.00	2.16-10.50	0.75-27.44
Mean	60.46	64.02	4.67	3.75	29.10	32.16	4.41	5.41
PCV%	14.54	17.68	10.84	11.81	17.99	20.48	18.27	21.23
GCV%	11.93	14.79	8.92	10.03	15.85	17.86	15.21	18.22
H%	65.45	69.76	67.24	71.99	77.49	75.54	69.00	73.07
GA % of Mean	20.20	25.49	15.22	17.57	28.72	32.14	26.10	32.32
				SI 1666				
Range	25.00-126.00	26.00-218.00	0.00-15.00	0.00-20.00	0.00-130.00	1.00-434.00	0.75-10.25	0.98-54.11
Mean	73.98	108.69	5.54	5.11	34.45	71.78	5.43	11.63
PCV%	12.94	14.42	11.25	13.80	18.43	21.91	19.16	22.49
GCV%	10.40	12.06	9.24	11.95	16.08	19.51	15.99	19.22
H%	64.26	69.75	67.20	73.98	75.82	78.90	69.05	72.33
GA % of Mean	17.23	20.81	16.54	21.19	28.95	35.82	27.56	33.88
				IC 21706				
Range	51.40-145.00	29.00-236.00	0.00-15.00	0.00-24.00	7.00-77.00	3.00-581.00	1.00-10.29	0.88-68.28
Mean	83.04	114.41	4.70	5.12	28.96	123.46	4.36	22.11
PCV%	12.04	14.76	13.79	19.75	18.81	22.74	20.70	24.14
GCV%	9.62	12.28	11.34	16.25	15.89	19.76	18.00	21.16
H%	63.38	68.74	66.87	67.50	71.22	75.05	75.75	76.56
GA % of Mean	15.84	21.33	19.25	27.63	27.95	35.37	32.27	38.23

among the EMS doses, greater improvement was seen at 1.0% EMS in SI 1666 (Table 5). In the M_2 generation, the mean seed yield due to physical mutagen exhibited more reduction as compared to chemical mutagen, as a decreasing trend in mean value was noticed in a majority of the physical mutagen-treated populations. Seed yield gradually decreased with a progressive increase of γ rays in the mutant population of IC 21706. But, in the treated populations of SI 1666 and Rama, no clear-cut trend was observed. On the other hand, seed yield gradually decreased with increasing EMS doses in the treated populations of SI 1666 and IC 21706. The highest seed yield was found in the induced population of IC 21706 at 0.5% EMS. In M_1, the maximum range of variation was observed in 400 Gy-irradiated population of Rama, whereas in M_2, the 0.5% EMS dose induced the highest range of variation in the treated population of IC 21706. The highest values of GCV (21.04% and 28.31%) and genetic advance (37.83% and 52.33%) in both generations were shown by the mutant population of IC 21706 at 0.5% EMS dose. Conversely, the treated populations of IC 21706 and SI 1666 recorded the highest heritability (79.98% and 83.01%) at 1.5% and 0.5% EMS, respectively.

Based on the overall average values, maximum GCV and genetic advance were observed for seed yield per plant (18.00%, 21.16% and 32.27%, 38.23%, respectively) in both generations in the mutant population of IC 21706, followed by number of capsules per plant (16.08%, 19.76% and 28.95%, 35.82%, respectively) (Table 6). Highest heritability values were recorded for number of capsules per plant (77.49% and 78.90%, respectively) in both the generations.

DISCUSSION

Induced mutations in polygenic traits can be best judged by the estimation of mean, range, coefficient of variation, heritability, and genetic advance in the successive generations of mutagen-treated populations. The present results, by and large, demonstrate the potential of mutagenic treatments for inducing mutation in both M_1 and M_2 generations. The mutagen treatments, in general, induced a shift in the mean value of yield and its important attributes both in the negative and positive direction. The magnitude of variation was not the same for all the characters in any of the three genotypes, professing variable genotypic responses to mutagens in both γ rays and EMS treatments.

Plant height and number of branches per plant were earlier identified as important yield components (Begum and Dasgupta, 2011). Nevertheless, short stature is construed as a desirable trait because resilience to lodging is important. Induction by γ rays leads to dwarfing of plants (Shah *et al*., 1990); at the same time, the treatment results in an increase in branch number (Shah *et al*., 1990). On the other hand, chemical mutagens (EMS and colchicines) induced a significant increase in mean branch number and remarkably higher values of GCV, heritability, and genetic advance in the M_2 population (Selvam *et al*., 2010).

Interestingly, the number of capsules per plant is the most important yield attribute in the mutant population of sesame (Begum and Dasgupta, 2011). Therefore, it is likely that selection for this trait in the mutagen-treated population would improve seed yield considerably. In the present study, the mean value of capsule number shifted towards both positive and negative directions. The decrease in number of capsules per plant in the treated plants may be due to the formation of sterile capsules, a manifestation of impaired fertility, transmitted from afflicted embryos through organogenesis, with the ultimate expression in seed yield per plant (Larik *et al*., 1980). Yield is a dependent variable and is the ultimate expression of all the biological processes occurring during the growth and development of the plant (Scarascia-Mugnozza, 1964). The mean seed yield per plant of mutants deviated from the parent (control) in both positive and negative directions, albeit in most cases, reduction was conspicuous. The general trend of dwindling yield among the mutant populations could be due to pleiotropic effects (Brock, 1965) on the characters. Lower doses of both mutagens induced higher seed yield. Similar to the present findings, the results obtained by Murty (1980), Chavan and Chopde (1982), and Sheeba *et al.* (2005) showed an increase in capsule number and seed yield due to gamma irradiation.

In the present study, maximum improvement was observed at 0.5% concentration of EMS in the treated populations of all the genotypes, implying that EMS at this dose could successfully be used for engendering genetic variability and, ultimately, selection of mutants for higher seed yield. Therefore, it appears that lower doses of γ rays and EMS in general and 0.5% dose of EMS in particular can be useful from the breeding point of view. Among the three parental genotypes, utmost improvement was observed in IC 21706. IC 21706 and 0.5% EMS thus appear to be the best combination for obtaining higher yielding plants in the early generations. The present results confirm the findings of Begum and Dasgupta (2010) in sesame. In fact, the information generated through the present study constitutes preliminary findings in relation to earlier reports. It is to be mentioned here that, in the advanced generations, 19 superior M_4 lines (based on seed yield, oil content, and fatty acid composition) were selected for multi-location trials to assess the stability of desirable mutants. The newly developed elite lines were evaluated in seven locations over 4 consecutive years. Of the 19, 3 M_8 lines (CUMS-09, CUMS-11, and CUMS-17) showed stability for seed yield and yield components and possessed high oil content (relatively more PUFA content than the control). Of these, CUMS-09 and CUMS-11 were developed using the 200 Gy-irradiated mutant population of SI 1666, whereas CUMS-17 was derived from the 0.5% EMS-treated population of IC 21706. The developed mutant lines had already been included in ICAR trials for evaluation as new mutant varieties of sesame. Of the 3 mutant lines, CUSM-17 showed good performance in the 2011-12 initial evaluation trials and was promoted to the advanced varietal trials (Anonymous, 2013). Hopefully, this promising and stable mutant line with the higher seed yield, oil content, and improved oil quality would help to increase sesame production and productivity of the nation if it is identified and released as a new mutant variety.

Genetic selection parameters computed through the variance component method disclosed that a wide range of genotypic coefficients of variability exists among the traits in the mutants. Mutant populations of all the genotypes show good potential in increasing genotypic variability, heritability, and genetic advance for all the traits, indicating that these characters can be transmitted to future generations and that potential gain could be achieved through selection in early generations. The estimates of mutagen treated genotypes revealed higher values in the M_2 generation compared to the M_1. The increased heritability and genetic advance in the treated populations of the present study support the results obtained by Labana *et al*. (1980) in mustard; Chavan and Chopde (1982), Sarwar *et al*. (2008), Boranayaka *et al.* (2010) in sesame; Jagadeesan *et al*. (2008) in sunflower; Arulbalachandran *et al*. (2010) in blackgram; and Siddiqui *et al.* (2009) in rapeseed. The success of selection, however, will be greater in subsequent generations when there will be increased recombination and elimination of cytological variants (Kumar, 1972). From the practical breeding point of view, increased variation assumes greater significance. It has been reported that induced variability for quantitative traits in crop plants is heritable and that response to selection is good (Frey, 1969). The relative value of this source of variability for use in crop improvement, therefore, depends almost entirely upon the nature of phenotypic expression caused by the mutations induced at polygenic loci (Larik *et al*., 1980).

The symmetry of the induced genetic variation and the shift of the mean depend not only on the character itself but also on its previous selection history (Larik *et al*., 1980). The more highly selected or adapted character brings a greater shift in the mean and a greater asymmetry in the distribution (Brock, 1965). It would be tempting to gather from the present investigation that there has been a greater shift in the mean in all the well-adapted genotypes of sesame and that the distribution of the characters (plant height, number of branches per plant, number of capsules per plant, and seed yield per plant) are mostly symmetrical. This symmetry can thus be exploited expediently for further improvement of the genotypes.

This study clearly indicates that genetic variability induced through mutation can be exploited successfully in developing new varieties of sesame with improved agronomic traits. The traits plant height, number of branches, capsule number, and seed yield offer good scope of selection as they all exhibited high heritability along with high genetic advance. Emphasis should be given to these characters when restructuring plant type with high yield in sesame mutation breeding. In other words, it may be concluded that the nature and extent of variability generated in yield and important yield attributes through induced mutagenesis are heritable and can be used successfully to develop new mutant varieties of sesame or can be utilized as parents in hybridization program to refurbish new breeding populations.

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