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Gamma rays and ethyl methane sulfonate induced polygenic variability in *Cicer arietinum* L. var. Pusa-212

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ABSTRACT

The present study revealed the induced polygenic variability in chickpea var. Pusa-212 following treatments with gamma rays (150, 200, 300, and 400 Gy), ethyl methane sulfonate (EMS) (0.1, 0.2, 0.3, and 0.4%), and their combinations (200 Gy + 0.2%, 300 Gy + 0.2%, 200 Gy + 0.3%, and 300 Gy + 0.3% EMS). A significant amount of genetic variability was induced for various quantitative traits in the treated populations as compared to control in the M2 generation. In an M3 generation, the amount of genetic variability was low compared to M2. Mean values for various polygenic traits showed positive and negative shifts in M2, whereas significant positive shifts were noticed for yield and yield contributing traits in the M3 generation. For days to flowering, plant height and days to maturity, heritability (h2) increased, whereas genetic advance (GA) decreased from M2 to M3 generation in most of the selected treatments indicating non-additive gene effects. However, in case of number of fertile branches per plant, pods per plant, seeds per pod, 100 seed weight, and total plant yield, all the genetic parameters (genotypic coefficient of variation, h2 and GA) increased from M2 to M3 generation in the selected treatments with a few exceptions indicating additive gene effects and chances for further improvement of these traits in the advanced generations. The selection was effective in M2 as significant gains in mean values coupled with high heritability, and GA were achieved for yield and yield contributing traits in the M3 generation.

KEY WORDS: Chickpea, ethyl methane sulfonate, gamma rays, polygenic variability, quantitative traits

INTRODUCTION

Cicer arietinum L. (2*n* = 16) is an important food legume crop of the world grown over an area of about 11.2 million hectares, with a production of 9.2 million tons and an average yield of 818 kg/h [1]. For past several years, the average yield of chickpea has remained stagnant due to its limited natural variability that in turn is attributed to its monophyletic descendence from *Cicer reticulatum* [2,3]. Studies on isozyme and restriction fragment length polymorphisms analysis have also revealed a low level of genetic variability in chickpea [4]. Lack of sufficient variability for major quantitative traits has, therefore, become a limiting factor for its improvement. Mutagenesis has proved to be a handy tool to enhance the natural mutational rate, thereby enlarging the genetic variability and increasing the scope for obtaining desired selections [5,6]. The role of mutation breeding in increasing the genetic variability, and its practical value for plant improvement programs has been proved beyond doubt in several crop plants [7-15]. The inheritance of quantitative traits is controlled by the interaction of many genes or polygenes, with each gene contributing having an additive effect on the total phenotypic variability. In crop improvement programs, it is the quantitative variation for yield and its component traits that are important to a plant breeder. Since most of the economically important characters are influenced by environment, estimates of genetic parameters such as phenotypic and genotypic coefficient of variation (PCV and GCV), heritability (h2) and genetic advance (GA) in segregating generations of mutagen-treated populations gives an indication about the scope of improvement in the trait concerned, through selection [16]. In the present investigation, an attempt has been made to ascertain the magnitude of induced genetic variability in M2 and M3 generations for various quantitative traits in chickpea var. Pusa-212.

MATERIALS AND METHODS

Certified seeds of chickpea (*C. arietinum* L.) var. Pusa-212 were treated with different doses of gamma rays (150, 200, 300, and 400 Gy) and various concentrations of ethyl methane sulfonate (EMS) (0.1, 0.2, 0.3, and 0.4%) prepared in phosphate buffer (pH = 7) for 6 h with intermittent shaking. A portion of irradiated seeds was also subjected to combination treatments with EMS (200 Gy + 0.2%, 300 Gy + 0.2%, 200 Gy + 0.3%, and 300 Gy + 0.3% EMS) for 6 h. For EMS treatments, seeds were pre-soaked in distilled water for 12 h, and the treated seeds were washed thoroughly in running tape water to remove any residual effect of the mutagen. Each treatment including control comprised of 300 seeds. Thereafter, the treated and control seeds were sown in the field in three replicates in a complete randomized block design with seed to seed and row to row distance maintained at 20 cm and 30 cm, respectively. Seeds harvested from individual M1 plants in each dose/treatment were sown as M2 families in three replicates in the field. Observations on various quantitative traits were recorded on 10-15 normal looking plants of each progeny from treated as well as control populations. The progenies segregating for macromutations were not used for such analysis. Based on mutagenic effectiveness and efficiency recorded in M1 and M2 [17] and the performance of yield and other desirable traits, the following treatments were selected in M2 for raising M3 generation *viz*. gamma rays (200 and 300 Gy), EMS (0.2 and 0.3%), and combination treatments (200 Gy +0.2% EMS and 300 Gy+0.2% EMS). In each of these selected treatments, for raising the M3 generation, such 10-15 M2 progenies were selected which showed significant deviation in mean values in the desired direction particularly for the yield and its contributing traits from the mean values of control. Seeds from each selected progeny in M2 were bulked by taking an equal amount of seeds from all M2 plants of a single progeny. A random sample of this bulk was then sown in the field to raise the M3 generation. To assess the extent of induced variability in M2 and M3 generations and the effectiveness of selection, data on various quantitative traits were subjected to statistical analysis (ANOVA) for determination of the PCV and GCV, heritability in broad sense (h2), and expected GA as a percentage of mean [18-20]. The significant differences (least significant difference) between treated and control population means were computed by the method given by Snedecor and Cochran [21] with some suitable modifications [1].

RESULTS AND DISCUSSION

In the present investigation, data on eight quantitative traits *viz*. days to flowering, days to maturity, plant height, number of fertile branches per plant, number of pods per plant, number of seeds per pod, 100 seed weight, and total yield per plant were analyzed to assess the extent of induced variability in M2 and M3 generations (Tables 1 and 2). The mean shifted in a positive and negative direction in the treated populations for all the quantitative traits in M2 generation, the positive shift was observed in lower or intermediate dose treatments where as the negative shift was observed at higher dose treatments except for days to flowering and maturity where reverse was true. Moreover, there was a further increase in mean values toward positive direction for yield and yield contributing traits in the M3 generation as compared to M2. There are different opinions regarding the direction of mutations. By using physical and chemical mutagens, many workers have found mean values for various quantitative traits decreasing significantly in M2 generation [7,22-25]. They attributed the decline to either physiological damage caused chiefly by chemical mutagens or chromosomal aberrations caused mainly by irradiations. These disturbances get eliminated progressively in the subsequent generations. Another group of workers believes that mean remains unchanged although there is an increase in variance due to mutagenic treatments indicating bidirectional mutations [26,27]. These workers believe that the mean performance of a population having an equal proportion of favorable and unfavorable genes would remain unchanged since mutations in plus and minus direction will be equally likely. The shift in mean values in both positive and negative direction after mutagenic treatments has been reported by many workers [8,13,28-31]. Since quantitative traits have a complex genetic constitution involving a large number of genes interacting with one another, consequently variations in both directions are expected. Present results indicate that induced mutations are random, polydirectional, and quantitative in nature and cause heritable changes in polygenic systems. Besides, the direction of a mutation depends on the character under study and the dose applied.

Flowering and maturity time decreased significantlly in some mutagenic treatments where as a significant increase for these traits was observed in higher treatments. This decrease in flowering and maturity time coupled with increase in variability offer the possibility of selecting early flowering and maturity mutants in chickpea. Similar results have been reported by other workers [8,30]. A significant decrease in flowering and maturity time

Table 1: Estimates of genetic parameters for various quantitative traits in M_2 generation of chickpea (*C. arietinum* L.) var. Pusa-212

Treatment	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h^2	GA (percentage of mean)	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h^2	GA (percentage of mean)
			Days to flowering						Days to maturity			
Control	95.36±0.62	0.00	6.15	3.75	37.12	6.02	150.46±0.78	0.00	4.84	2.88	35.34	4.52
γ-rays												
150 Gy	94.83±0.87	−0.53	7.74	5.13	43.86	8.96	150.60±1.00	+0.14	5.24	3.19	37.18	5.14
200 Gy	96.46±0.96	+1.10	8.75	6.41	53.61	12.39	152.86±1.02	+2.40	5.61	4.10	53.60	7.93
300 Gy	93.60±1.17	−1.76	7.05	5.79	67.23	12.53	147.70±1.28	−2.76	8.05	5.38	44.71	14.03
400 Gy	98.13±1.06	+2.77	9.32	7.50	64.87	15.95	152.90±0.98	+2.44	4.51	3.54	61.63	7.34
LSD 5%=0.86, 1%=1.25, 5%=0.86, 1%=1.25												
EMS												
0.1%	95.30±0.86	−0.06	9.16	5.03	30.17	7.29	150.06±0.91	−0.40	5.45	3.38	38.51	5.54
0.2%	94.06±1.04	−1.30	10.88	8.13	55.86	16.05	148.20±1.00	−2.26	8.62	6.32	53.83	12.25
0.3%	93.26±1.17	−2.10	11.47	10.63	85.84	25.99	145.33±1.28	−5.13	7.80	6.72	74.16	15.27
0.4%	98.63±0.96	+3.27	9.25	5.89	40.64	9.92	158.33±0.99	+8.07	6.15	4.49	32.27	5.23
LSD 5%=0.81, 1%=1.18, 5%=2.12, 1%=3.08												
γ-rays+EMS												
200 Gy+0.2%	91.80±0.91	−3.56	9.41	7.10	57.03	14.16	150.73±1.02	+0.27	5.48	4.79	76.33	11.05
300 Gy+0.2%	96.36±1.27	+1.00	12.39	10.85	76.72	24.95	145.50±1.32	−4.96	7.29	5.64	59.84	11.51
200 Gy+0.3%	96.53±1.14	+1.17	9.45	7.47	62.48	15.58	148.36±1.04	−2.10	5.80	3.92	45.57	6.98
300 Gy+0.3%	98.70±0.92	+3.34	8.04	4.85	36.30	7.71	156.40±0.91	+5.94	4.38	3.22	54.27	6.27
LSD 5%=1.01, 1%=1.48, 5%=2.79, 1%=4.06												
			Plant height (cm)						Number of fertile branches per plant			
Control	60.65±0.54	0.00	6.50	3.21	24.37	4.18	5.80±0.21	0.00	19.29	10.06	27.21	13.86
γ-rays												
150 Gy	61.85±0.75	+1.20	10.62	4.64	19.09	5.35	6.06±0.23	+0.26	20.88	10.29	24.29	13.39
200 Gy	63.72±0.80	+3.07	11.97	7.63	40.58	12.83	6.73±0.34	+0.93	33.29	18.62	31.27	27.48
300 Gy	60.33±0.88	−0.32	12.33	7.42	36.21	11.79	5.96±0.27	+0.16	27.87	17.21	38.12	28.05
400 Gy	56.12±0.88	−4.53	6.52	5.37	67.89	11.68	5.13±0.27	−0.67	36.35	28.00	59.32	56.93
LSD 5%=1.12, 1%=1.63, 5%=0.37, 1%=0.55												
EMS												
0.1%	60.95±0.68	+0.30	8.83	4.83	30.01	6.70	5.86±0.24	+0.06	22.32	12.33	30.52	17.98
0.2%	62.50±0.84	+1.85	14.05	10.08	51.57	19.12	6.96±0.38	+1.16	48.10	29.03	36.41	46.24
0.3%	58.16±1.03	−2.49	13.14	8.94	46.29	16.05	6.20±0.28	+0.40	29.08	19.53	45.12	34.64
0.4%	54.22±0.89	−6.43	9.63	7.77	65.17	16.56	4.60±0.29	−1.20	43.76	31.42	51.54	59.55
LSD 5%=1.25, 1%=1.82, 5%=0.24, 1%=0.36												
γ-rays+EMS												
200 Gy+0.2%	62.85±0.90	+2.20	12.15	9.21	57.43	18.42	7.50±0.34	+1.70	37.45	24.45	42.63	42.14
300 Gy+0.2%	59.75±0.98	−0.90	13.53	9.01	44.39	15.85	6.43±0.31	+0.63	39.00	26.36	45.70	47.05
200 Gy+0.3%	56.47±0.98	−4.18	11.13	8.66	60.63	17.81	6.03±0.27	+0.23	23.95	17.91	55.92	35.36
300 Gy+0.3%	57.34±0.87	−3.31	11.33	7.02	38.30	11.46	5.20±0.24	−0.60	36.30	21.77	35.96	34.46
LSD 5%=1.41, 1%=2.06, 5%=0.45, 1%=0.65												
			Number of pods per plant						Number of seeds per pod			
Control	141.51±1.56	0.00	8.32	5.10	37.60	8.26	1.58±0.02	0.00	4.20	2.68	40.90	4.53
γ-rays												
150 Gy	143.30±1.97	+1.74	7.40	5.93	64.23	12.55	1.65±0.02	+0.07	6.00	3.97	43.88	6.95
200 Gy	150.86±2.82	+9.30	11.25	7.52	44.68	13.27	1.70±0.03	+0.12	5.73	3.95	47.37	7.17
300 Gy	146.13±2.99	+4.57	10.23	7.13	46.61	13.13	1.75±0.03	+0.17	7.62	6.26	67.41	13.57
400 Gy	134.73±2.30	−6.83	14.45	9.09	39.63	15.12	1.47±0.02	−0.11	10.65	7.42	48.57	13.65
LSD 5%=3.59, 1%=5.23, 5%=0.09, 1%=0.13												
EMS												
0.1%	142.36±2.27	+0.80	9.46	8.32	77.28	19.31	1.60±0.02	+0.02	6.12	4.80	61.46	9.93
0.2%	146.20±2.98	+4.64	10.61	7.73	53.08	14.86	1.78±0.03	+0.20	8.86	6.53	54.22	12.69
0.3%	144.63±2.92	+3.07	14.59	9.53	42.68	16.44	1.65±0.03	+0.07	6.96	5.45	61.36	11.28
0.4%	129.50±2.39	−12.06	19.20	11.33	34.81	17.64	1.43±0.02	− 0.15	9.54	6.85	51.61	12.99
LSD 5%=3.01, 1%=4.38, 5%=0.09, 1%=0.13												
γ-rays+EMS												
200 Gy+0.2%	152.43±2.85	+10.87	13.23	8.21	38.49	13.44	1.68±0.03	+0.10	10.39	7.64	54.09	14.84
300 Gy+0.2%	148.50±2.84	+6.94	15.54	10.39	44.75	18.36	1.66±0.03	+0.08	7.47	5.78	59.74	11.79
200 Gy+0.3%	130.60±2.57	−10.96	15.76	12.15	59.41	24.72	1.40±0.02	−0.18	11.38	7.18	39.76	11.95
300 Gy+0.3%	133.33±2.56	−9.23	12.95	7.63	34.72	11.87	1.49±0.02	−0.09	6.37	4.79	56.66	9.52
LSD 5%=4.60, 1%=6.49, 5%=0.08, 1%=0.12												
			100 seed weight (g)						Total yield per plant (g)			
Control	12.85±0.11	0.00	5.19	2.73	27.71	3.80	29.64±0.42	0.00	14.44	5.56	14.81	5.64
γ-rays												
150 Gy	13.16±0.15	+0.31	7.30	4.28	34.39	6.73	31.05±0.50	+1.41	17.25	7.65	19.64	8.94
200 Gy	14.60±0.18	+1.75	5.49	4.71	73.66	10.67	33.96±0.59	+4.32	13.23	8.71	43.39	15.16

(Cond...)

Table 1: ***(Continued....)***

Treatment	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h²	GA (percentage of mean)	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h²	GA (percentage of mean)
300 Gy	13.92±0.16	+1.07	13.48	7.92	34.49	12.27	32.70±0.64	+3.06	22.17	9.82	19.63	11.49
400 Gy	13.40±0.17	+0.55	5.36	3.85	51.74	7.32	25.83±0.55	−3.81	17.71	9.29	27.50	12.86
LSD 5%=0.25, 1%=0.36, 5%=1.94, 1%=2.82												
EMS												
0.1%	12.65±0.15	−0.20	11.19	5.39	23.17	6.84	30.52±0.53	+0.88	17.80	8.22	21.31	10.02
0.2%	14. 82±0.22	+1.97	13.71	8.47	38.18	13.82	33.68±0.63	+4.04	13.25	9.52	51.67	18.07
0.3%	14.06±0.24	+1.21	8.51	6.83	64.43	14.48	31.90±0.69	+2.26	21.63	10.73	24.62	14.06
0.4%	11.75±0.18	−1.10	8.40	6.30	56.32	12.49	25.46±0.54	−4.18	16.92	10.34	37.34	10.68
LSD 5%=0.30, 1%=0.43, 5%=1.99, 1%=2.89												
γ-rays+EMS												
200 Gy+0.2%	13.82±0.20	+0.97	9.36	6.61	49.86	12.32	34.74±0.59	+5.10	15.97	8.41	27.76	11.70
300 Gy+0.2%	14.48±0.21	+1.63	11.64	7.68	43.61	13.40	32.42±0.75	+2.78	28.20	14.15	25.18	18.74
200 Gy+0.3%	12.50±0.18	−0.35	8.56	5.83	46.42	10.49	27.60±0.75	−2.04	12.57	7.72	37.74	12.52
300 Gy+0.3%	12.16±0.19	−0.69	13.12	7.37	31.56	10.93	24.34±0.51	−5.30	21.45	12.24	32.56	18.44
LSD 5%=0.35, 1%=0.51, 5%=1.86, 1%=2.70												

PCV: Phenotypic coefficient of variability, GCV: Genotypic coefficient of variability, GA: Genetic advance as percent of mean, h²: Heritability in broad sense, LSD: Least significant difference, SE: Standard error, *C. arietinum: Cicer arietinum*, EMS: Ethyl methane sulfonate

Table 2: Estimates of genetic parameters per various quantitative traits in M_3 generation of chickpea (*C. arietinum* L.) var. Pusa-212

Treatment	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h²	GA (percentage of mean)	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h²	GA (percentage of mean)
	Days to flowering						Days to maturity					
Control	96.50±0.78	0.00	6.30	3.55	31.87	5.30	148.60±0.90	0.00	4.96	3.37	46.26	6.06
γ-rays												
200 Gy	94.73±0.86	−1.77	7.14	5.94	69.25	13.06	151.36±1.17	+2.76	5.43	4.35	64.38	9.23
300 Gy	92.36±0.90	−4.14	6.95	5.42	60.87	11.17	145.53±1.15	−3.07	4.75	4.43	87.08	10.92
LSD 5%=1.39, 1%=2.31, 5%=1.57, 1%=2.61												
EMS												
0.2%	90.40±0.86	−6.10	9.06	7.25	64.09	15.33	144.20±1.14	−4.40	6.64	5.83	77.10	13.53
0.3%	94.63±0.97	−1.87	10.20	8.91	76.35	20.56	144.50±1.11	−4.10	4.82	4.39	83.12	10.57
LSD 5%=1.81, 1%=3.01, 5%=1.34, 1%=2.22												
γ-rays+EMS												
200 Gy+0.2%	94.16±0.83	−2.34	8.97	8.49	89.58	21.22	148.43±1.07	−0.17	4.94	4.19	71.77	9.37
300 Gy+0.2%	96.70±1.09	+0.20	11.51	9.46	67.63	20.55	146.40±1.11	−2.20	6.40	5.10	63.41	10.72
LSD 5%=3.27, 1%=5.42, 5%=1.14, 1%=1.89												
	Plant height (cm)						Number of fertile branches per plant					
Control	60.83±0.59	0.00	4.40	2.96	45.43	5.28	5.93±0.21	0.00	14.67	8.94	37.19	14.40
γ-rays												
200 Gy	64.50±0.86	+3.67	6.62	4.63	48.95	8.56	7.20±0.30	+1.27	20.81	15.26	53.73	20.50
300 Gy	62.46±0.75	+1.63	6.60	5.99	82.33	14.35	7.36±0.32	+1.43	28.83	19.42	45.39	34.55
LSD 5%=1.09, 1%=1.81, 5%=0.63, 1%=1.05												
EMS												
0.2%	63.38±0.80	+2.55	8.53	7.34	74.06	16.67	8.23±0.38	+2.30	35.60	25.54	51.45	48.36
0.3%	56.53±0.82	−4.30	8.75	7.70	77.54	17.90	7.80±0.33	+1.87	24.04	18.36	58.31	37.01
LSD 5%=1.15, 1%=1.91, 5%=0.60, 1%=1.00												
γ-rays+EMS												
200 Gy+0.2%	63.70±0.75	+2.87	6.97	6.55	88.32	16.25	8.70±0.33	+2.77	30.46	25.60	70.68	56.83
300 Gy+0.2%	58.62±0.85	−2.21	8.20	6.48	62.55	13.53	7.56±0.35	+1.63	31.38	23.01	53.76	44.53
LSD 5%=1.27, 1%=2.11, 5%=0.25, 1%=0.41												
	Number of pods per plant						Number of seeds per pod					
Control	143.40±1.69	0.00	6.65	4.27	41.32	7.26	1.60±0.01	0.00	3.95	2.86	52.50	5.48
γ-rays												
200 Gy	153.50±2.31	+10.10	9.89	7.87	63.27	16.52	1.80±0.02	+0.20	5.80	4.71	66.05	10.11
300 Gy	151.66±2.61	+8.26	9.89	8.14	67.68	17.68	1.74±0.03	+0.14	9.68	8.52	77.46	19.80
LSD 5% = 3.88, 1% = 6.44 5% = 0.13, 1% = 0.21												
EMS												
0.2%	153.73±2.93	+10.33	13.51	9.41	48.59	17.32	1.76±0.02	+0.16	11.13	9.66	75.26	22.12
0.3%	148.46±3.35	+5.06	10.83	9.82	82.26	23.52	1.73±0.03	+0.13	6.81	6.28	84.89	15.27
LSD 5%=3.65, 1%=6.05, 5%=0.07, 1%=0.12												
γ-rays+EMS												
200 Gy+0.2%	154.80±2.32	+11.40	12.00	10.50	76.54	24.25	1.76±0.03	+0.16	10.34	8.73	71.30	19.45
300 Gy+0.2%	156.23±2.90	+12.83	11.31	8.50	56.51	16.88	1.70±0.03	+0.10	8.15	7.39	82.29	17.70
LSD 5%=4.47, 1%=7.41, 5%=0.10, 1%=0.17												

(Cond...)

Table 2: ***(Continued....)***

Treatment	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h^2	GA (percentage of mean)	Mean±SE	Shift in mean	PCV (%)	GCV (%)	h^2	GA (percentage of mean)
	100 seed weight (g)						Total yield per plant (g)					
Control	12.96±0.08	0.00	4.36	2.99	46.83	5.40	29.72±0.42	0.00	9.32	5.33	32.75	8.06
γ-rays												
200 Gy	14.53±0.11	+1.57	7.55	6.24	68.28	13.62	35.17±0.56	+5.45	13.14	9.19	48.91	16.96
300 Gy	14.34±0.10	+1.38	6.18	5.93	91.89	15.00	34.60±0.58	+4.88	12.94	10.48	65.59	22.41
LSD 5%=0.33, 1%=0.54, 5%=1.63, 1%=2.71												
EMS												
0.2%	14.90±0.12	+1.94	8.87	7.64	74.28	17.39	35.24±0.49	+5.52	23.51	17.31	54.22	33.65
0.3%	14.62±0.11	+1.66	12.71	9.59	56.85	19.08	34.43±0.58	+4.71	17.79	13.44	57.06	26.80
LSD 5%=0.32, 1%=0.53, 5%=1.87, 3%=3.11												
γ-rays+EMS												
200 Gy+0.2%	14.44±0.11	+1.48	7.69	7.18	87.36	17.73	36.50±0.62	+6.78	14.38	9.61	44.61	16.94
300 Gy+0.2%	15.75±0.13	+1.79	10.85	9.66	79.26	22.70	34.51±0.53	+4.79	19.48	12.74	42.72	21.98
LSD 5%=0.30, 1%=0.50, 5%=2.55, 1%=4.23												

PCV: Phenotypic coefficient of variability, GCV: Genotypic coefficient of variability, GA: Genetic advance as percent of mean, h^2: Heritability in broad sense, LSD: Least significant difference, SE: Standard error, EMS: Ethyl methane sulfonatel, *C. arietinum: Cicer arietinum*

coupled with high heritability and GA in M3 could be attributed to the fixation of favorable alleles in the desired direction for these traits. Larik *et al*. [25] have reported induced earliness in Sorghum bicolor due to gamma ray treatments. A significant decrease and increase in plant height were observed in selected treatments from M2 to M3 generation. The occurrence of mutations in positive and negative direction may be considered as an important reason to justify the tendency of positive and negative shifts [32]. Similar results have been reported by several workers following treatments with physical and chemical mutagens [8,13,31]. Reduction in plant height coupled with a decrease in the variance in M3 might be attributed to the fixation of genes controlling less plant height [33].

Increase in a number of fertile branches per plant and number of pods per plant in selected treatment from M2 to M3 generation were observed in the present study. These results are in agreement with other workers [8,34,35]. It was noticed that the treatments which showed increase in a number of fertile branches also showed increase in the number of pods per plant suggesting a close correlation between these traits. Increase in mean values for these traits from M2 to M3 coupled with increased variability and heritability suggests that selection was effective in M2 generation. On the other hand, increase in mean pods per plant coupled with increased variability in M3 suggests scope for further selection for this trait. The decrease in pods per plant at higher treatments in M2 generation was probably due to high sterility observed in these treatments. Similar results have been reported earlier [7,8,36].

Seed yield is a complex character and is influenced by other quantitative traits such as branches per plant, pods per plant, seeds per pod, and seed weight. Increase in seed yield in the treated populations in the present study is probably due to an increase in other yield contributing traits. Hence, a significant increase in yield in M3 could be attributed to the effective selection adopted for various yield contributing traits in M2 and M3 generations. Increase in seed yield per plant following mutagenic treatments has also been reported earlier [7,34,35,37]. Reduction in seed yield as observed in some higher mutagenic treatments in M2 generation has been attributed to the high frequency of mutations with persistent negative effects for yield contributing traits [23,30]. In the present study, selection of mormal looking plants in M1 and selection of plants with desired shift in mean values for various yield contributing traits in M2 resulted in increase in the overall yield in the M3 generation. Several workers have proved selection of normal looking plants from non-segregating M2 families to be effective [38-40] while others believe that selection in M3 is more effective than M2 [41]. Sharma [41] concluded that efficiency of mutation breeding for polygenic traits could be increased by selecting M1 plants with maximum damage, normal looking plants from the macromutational M2 families, as well as non-segregating families with high variance and desired shift in mean followed by confirmation of these selections in M3.

The estimates of genetic parameters such as GCV, heritability, and GA are essential since they indicate the degree of stability to the environmental fluctuations and the potential transmissibility of a character from parent to offspring and from generation to generation. In the present study, a considerable amount of variability was induced in the treated populations in M2 generation (Table 2). However, lack of consistent dose-dependent response for induced variability as observed here could be due to additional uncontrolled environmental variation [30]. The variability in M3 was comparatively low for days to flowering, days to maturity, and plant height in most of the selected treatments with a few exceptions (Table 3). Heritability estimates increased while GA decreased from M2 to M3 generation for these traits indicating that these characters are under the control of non-additive gene action (dominance and epistasis) [13,35]. However, there was an increase in variability in M3 for yield and yield contributing traits in most of the selected treatments with a few exceptions (Table 3). This increase in variability was associated with an increase in heritability and GA, indicating that induced variability was genetic in nature, and further selection could be made in M3. This increase in variability in M3 has been termed as "release of additional variability" [41]. Increase in heritability estimates from M2 to M3 generation could be due to increased homozygosity of genes controlling polygenic traits [42,43]. Moreover, increase in heritability associated with increase in GA for yield, and its contributing traits in M3 suggest the effectiveness of selection in M2. According to Johnson *et al*. [44], heritability estimates along with GA is usually more helpful than heritability alone in predicting the resultant effects of selection. GA is indicative of the expected genetic progress for a particular trait under selection [45] and consequently carries much significance in self-pollinated crops. The higher values of heritability and GA suggest that mutations have mostly occurred at the loci having additive effects [46], and such traits are likely to respond effectively to phenotypic selection [16,44].

CONCLUSIONS

Intermediate treatments of gamma rays and EMS and lower combination treatments used in the present study could be effectively exploited for the genetic improvement of chickpea. Besides, increased variability coupled with increase in heritability and genetic advance for yield and contributing traits suggest the possibility of isolating high yielding genotypes in the advanced generations of mutagenized populations.

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