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Generation of Micro-mutants for Yield and Component Traits in Horse Gram [*Macrotyloma uniflorum* (Lam.) Verdc.]

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ABSTRACT

Background: Induced mutagenesis was employed in horse gram cv. CRIDA 1-18R with an objective of evolving mutants with increased yield potential.

Methods: Based on preliminary study, the variety has been irradiated with desirable doses of gamma rays (200 Gy and 300 Gy), electron beam (100 Gy and 200 Gy) and its combination (100 Gy) and the material were forwarded to M_2 generation following parent-progeny row basis. The genotypes exhibiting superior yield than control were further forwarded to M_3 generation. Multivariate analyses were performed to determine the induction of micro-mutants for 11 quantitative traits.

Result: The reduction in mean value over control was observed for most of the yield component traits at M_2 generation. Among the mutagenic treatments, combination of gamma rays with electron beam registered high mean values for pod length (5.05 cm), number of pods per plant (54.42) and single plant yield (25.68 g) at M_3 generation. Non-significant skewness and / or kurtosis at M_3 population denoted the absence of epistatic interactions for plant yield. An increase in variability pattern, H^2 and GAM at M_3 generation indicated the scope for trait (plant height, number of seeds per pod, number of clusters per plant, number of pods per plant, biological yield and single plant yield) improvement through selection.

Key words: CRIDA 1-18R, Horse gram, Irradiation, Micro-mutants.

INTRODUCTION

Horse gram [*Macrotyloma uniflorum* (Lam.) Verdc.] is an autogamous diploid legume (2n=20, 22 and 24) with massive nutrient significance. It is a climate resilient crop, widely cultivated up to an altitude range of 1800 m (Chahota *et al*. 2013) above sea level. This multipurpose legume has been domesticated during pre-historic period around 2000 BC in India (Mehra, 2000). At present, horse gram is widely grown as a grain legume in India, Sri Lanka Nepal, Malaysia, Mauritius, West Indies and Myanmar (Asha *et al*. 2006). The nutraceutical properties of horse gram were quoted in ancient Indian medicine which serves as a remedy for many diseases (Prasad and Singh, 2015). It was identified as potential food legume for future owing to its nutrient and medicinal importance coupled with drought tolerance.

Horse gram is a photosensitive crop with long maturity duration of 100-180 days (Morris, 2008). It is widely cultivated in drought prone areas in India with less input resources (Jansen and Westphal, 1989). Limited scientific efforts were made on evolving horse gram varieties suitable for modern agriculture at global level. The replacement of horse gram cultivable areas with commercial crops was a major reason for the decline in genetic diversity (Chahota *et al*. 2013). Induced beneficial mutations would circumvent bottleneck situations of self-pollinated crops including horse gram (Mehraj *et al*. 1999; Bolbhat and Dhumal, 2009). Irradiations tend to induce varying extent of physiological damages, chromosomal aberrations and gene/point mutations in the plant material (Swaminathan, 1968). The modified genetic factors will be transferred to subsequent generations resulting in evolution of novel variants. Therefore, an attempt was made using gamma rays (G), electron beam (EB) and G+EB combination for generation of mutants with desirable agronomic traits in horse gram.

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MATERIALS AND METHODS

A photo-sensitive cultivar “CRIDA 1-18R” was utilized for irradiation to generate wide variability for yield and its attributing traits in horse gram. The seed materials were obtained from Central Research Institute for Dryland Agriculture, Telangana, India. The well filled seeds were equilibrated to 12% moisture content before carrying out irradiations at Bhabha Atomic Research Centre, Mumbai, India.

The treated seeds (M_0) with different doses *viz.*, 100 Gy, 200 Gy, 300 Gy and 400 Gy of gamma rays, electron beam and its combination (G+EB) were sown in a randomized block design with two replications. Plant injuries were recorded in field conditions at all phases of crop growth.

All the mutant plants (M_1) were harvested on a single plant basis.

Based on the mutagenic sensitivity studies, the desirable doses *viz*., 200 Gy and 300 Gy of gamma rays, 100 Gy and 200 Gy of electron beam and 100 Gy of G+EB combination were forwarded to M_2 generation during 2018. Each individual plant was raised as progeny rows by adopting spatial pattern of 30 × 15 cm. Traits *viz*., days to first flowering, days to maturity, plant height (cm), number of primary branches per plant, pod length (cm), number of clusters per plant, number of pods per plant, number of seeds per pod, hundred seed weight (g), biological yield (g) and single plant yield (g) were recorded on randomly selected 150 normal looking plants similar to control.

The superior genotypes exhibiting higher yield than CRIDA 1-18R were forwarded to M_3 generation during 2019 following parent - progeny row basis. Similar spacing methodology and observations were followed for mutant progenies. The data was recorded on randomly selected normal looking mutant progenies similar to check in each family.

Data recorded on M_2 and M_3 population were utilized to determine the degree and direction of induced novel micro-mutants. In this study, the variance from control was considered as error / environmental variance (σ^2e). The observed variations in mutant population were taken as phenotypic variance (σ^2p). The genotypic variance (σ^2g) is measured by the difference between phenotypic and error variance. The estimates of genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV) (Burton, 1952), broad sense heritability (H^2) (Lush, 1940) and genetic advance as percent of mean (GAM) (Johnson *et al*. 1955) were calculated using variances. Skewness (β_1) and Kurtosis (β_2) provides information on nature of trait distribution in a segregating population. The frequency pattern was estimated for M_2 and M_3 population using SPSS Software as per formula given by Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Mean performance of M_2 population

Both positive and negative shift in mean values from control were registered for the traits studied in M_2 population of CRIDA 1-18R (Table 1). Delay in flowering and maturity duration was observed among mutant population with an exception of EB: 100 Gy (Rudraswami *et al*., 2006). The shift in mean value for plant height was varying with dose and mutagens employed. Yield attributing traits *viz*., number of primary branches per plant, pod length, number of clusters per pod, number of pods per plant and biological yield had low mean values in comparison with control. The frequent occurrence of detrimental mutants in a population would be a reason for reduced trait value (Singh *et al*., 2000). On the contrary, a positive shift in mean was recorded for number of seeds per pod and hundred seed weight in all treatments. The gamma irradiated population had increased mean value (200 Gy: 2.31 g; 300 Gy: 1.21 g) for single plant yield whereas, negative shift in mean from control was observed at EB and its combination (G+EB) treatment as reports in a earlier study (Wani *et al*., 2011). Though treatments had low mean performance, several novel variants exhibiting superior trait value than control was isolated.

Transgressive variants in M_2 population

Prediction on frequency and magnitude of superior variants would offer scope in identification of mutants with improved trait value (Misra *et al*., 2008). The mutant expressing trait value higher than the highest value of control was termed as positive transgressive variant (PTV) and the trait value lower than the lowest value of control was termed as negative transgressive variant (NTV). The maximum and average transgressive variation were estimated for respective PTVs and NTVs to determine the extent of variation from check. The lower dose of electron beam can be employed in future breeding programme to evolve early duration lines in horse gram (Table 2). The promising dose for a trait was identified based on simultaneous measure of frequency, average and maximum transgressive variation. The frequent occurrence (13) of superior variants with high positive average (APTV: 7.27 g) and maximum transgressive variation (MPTV: 12.76 g) for single plant yield was exhibited at 100 Gy of EB. Based on three parameters, the enhanced trait improvement would be achieved with the following doses: G (200 Gy) for number of primary branches per plant and biological yield; G (300 Gy) for plant height; G (200 Gy and 300 Gy) and EB (100 Gy) for hundred seed weight; G (300 Gy) and EB (200 Gy) for number of pods per plant; G (200 Gy and 300 Gy) for number of seeds per pod; G+EB (100 Gy) for number of clusters per plant; and EB (200 Gy) for pod length.

Mean performance of M_3 population

The genotypes expressing high single plant yield (> 30 g) than CRIDA 1-18R were isolated and forwarded to M_3 generation. Traits *viz*., plant height, pod length, number of clusters per plant and number of pods per plant exhibited an increase in mean value from M_2 to M_3 generation (Table 3). Adoption of direct selection on yield proved highly effective in improvement of traits at M_3 generation (Khan *et al*. 2004). The shift in mean from control decreased in M_3 population compared to its respective M_2 for flowering and duration as reported by Waghmare and Mehra, 2000 earlier. The decline in mean value over control for biological yield in both generations may be a resultant of altered physiological activity or induction of mutations with negative effects. On the contrary, the induction of mutants with positive effects was observed in M_2 and M_3 population for hundred seed weight (Khan and Wani, 2006). Among mutagens, G+EB: 100 Gy recorded the highest mean value for pod length (5.05 cm), number of pods per plant (54.42) and single plant yield (25.68 g) in M_3 generation. All the mutagenic treatments of M_3 population exhibited high single plant yield compared to its respective M_2 except G: 300 Gy. The increased yield potential through adoption of early generation selection was reported earlier by Khan and Qureshi (2006).

Table 1: Estimates of mean, shift in mean and range for quantitative traits in M_2 generation.

Traits	Statistic	Control	Mutagenic treatments				
			G: 200 Gy	G: 300 Gy	EB: 100 Gy	EB: 200 Gy	G+EB: 100 Gy
Days to first flowering	Mean ± SE	41.49±0.10	46.60±0.28	48.16±0.24	44.73±0.21	44.12±0.16	48.15±0.23
	Shift in mean	-	5.11	6.67	3.24	2.63	6.66
	Range	40.00-44.00	42.00-52.00	41.00-52.00	38.00-51.00	42.00-52.00	40.00-54.00
Days to maturity	Mean ± SE	96.13±0.11	97.84±0.26	99.43±0.20	96.03±0.20	97.95±0.25	101.34±0.25
	Shift in mean	-	1.71	3.30	- 0.09	1.82	5.22
	Range	94.00-99.00	94.00-118.00	97.00-115.00	93.00-116.00	96.00-114.00	99.00-119.00
Plant height (cm)	Mean ± SE	64.75±0.27	69.95±0.47	48.46±0.59	63.50±0.53	65.33±0.56	64.49±0.61
	Shift in mean	-	5.2	-16.29	-1.25	0.58	-0.26
	Range	59.40-86.50	64.20-108.90	42.10-92.58	32.50-93.40	33.50-101.20	42.10-112.10
Number of primary branches per plant	Mean ± SE	7.88±0.03	8.49±0.08	6.23±0.07	6.92±0.07	6.97±0.08	7.44 ±0.07
	Shift in mean	-	0.61	- 1.65	- 0.96	- 0.91	- 0.44
	Range	7.00-9.00	5.00-12.00	5.00-12.00	6.00-13.00	4.00-12.00	4.00-13.00
Pod length (cm)	Mean ± SE	5.07±0.01	4.83±0.02	4.80±0.02	4.45±0.02	4.57±0.02	4.69±0.03
	Shift in mean	-	- 0.25	- 0.27	- 0.63	- 0.50	- 0.38
	Range	4.76-5.53	4.02-5.68	3.24-5.80	3.12-5.83	3.17-5.87	3.21-5.53
Number of clusters per plant	Mean ± SE	46.54±0.18	41.94±0.33	41.68±0.40	35.92±0.34	36.00±0.36	45.37±0.40
	Shift in mean	-	- 4.60	- 4.86	-10.62	-10.54	-1.17
	Range	43.00-52.00	35.00-58.00	28.00-57.00	30.00-58.00	27.00-56.00	35.00-89.00
Number of pods per plant	Mean ± SE	111.24±0.41	80.55±0.77	84.26±1.07	64.65± 0.79	73.78±0.96	83.17±0.95
	Shift in mean	-	- 30.69	- 26.98	- 46.59	- 37.46	- 28.07
	Range	96.00-121.00	41.00-136.00	46.00-167.00	35.00-131.00	41.00-165.00	35.00-121.00
Number of seeds per pod	Mean ± SE	5.38±0.02	5.86±0.04	5.76±0.04	5.51±0.03	5.45±0.03	5.42±0.03
	Shift in mean	-	0.48	0.38	0.13	0.07	0.04
	Range	5.10-6.00	5.00-6.67	3.52-6.33	3.52-6.45	3.45-6.33	3.14-6.14
Hundred seed weight (g)	Mean ± SE	3.54±0.01	3.64±0.01	3.90±0.01	3.60±0.01	3.86±0.02	3.84±0.03
	Shift in mean	-	0.11	0.36	0.07	0.32	0.30
	Range	3.39-3.78	3.40-4.44	3.28-4.48	3.21-4.25	3.26-4.59	3.27-4.67
Biological yield (g)	Mean ± SE	55.88±0.20	46.00±0.66	39.35±0.53	38.50±0.46	35.80±0.46	36.79 ±0.34
	Shift in mean	-	-9.88	-16.53	-17.38	-20.08	-19.09
	Range	48.00-62.00	27.00-92.00	25.00-72.00	29.00-94.00	22.00-82.00	25.00-64.00
Single plant yield (g)	Mean ± SE	23.13±0.11	25.44±0.24	24.34±0.21	17.37±0.25	16.07±0.19	17.32±0.17
	Shift in mean	-	2.31	1.21	-5.75	-7.06	-5.81
	Range	20.15-27.39	16.30-44.70	18.62-34.12	13.93-40.15	12.82-35.18	13.86-34.16

EB - Electron beam, G - Gamma rays, SE - Standard error.

Table 2: Frequency of superior mutant types isolated in M_2 population.

Traits	Statistic	Mutagenic treatments				
		G: 200 Gy	G: 300 Gy	EB: 100 Gy	EB: 200 Gy	G+EB: 100 Gy
Days to first flowering	NTVF	0	0	3	0	0
	NTVM	-	-	38.00	-	-
	ANTV	-	-	2.00	-	-
	MNTV	-	-	2.00	-	-
Days to maturity	NTVF	0	0	3	0	0
	NTVM	-	-	93.00	-	-
	ANTV	-	-	1.00	-	-
	MNTV	-	-	1.00	-	-
Plant height (cm)	PTVF	0	24	7	4	16
	PTVM	-	46.75	42.95	41.73	55.07
	APTV	-	12.65	16.45	17.67	4.33
	MPTV	-	17.30	26.90	25.90	17.30
Number of primary branches per plant	PTVF	18	2	2	1	2
	PTVM	10.18	11.00	12.00	12.00	11.50
	APTV	1.18	2.00	3.00	3.00	2.50
	MPTV	3.00	3.00	4.00	3.00	4.00
Pod length (cm)	PTVF	1	1	1	2	0
	PTVM	5.68	5.80	5.83	5.87	-
	APTV	0.15	0.27	0.30	0.34	-
	MPTV	0.15	0.27	0.30	0.34	-
Number of clusters per plant	PTVF	3	8	3	4	3
	PTVM	57.00	55.63	55.33	53.25	76.33
	APTV	5.00	3.63	3.33	1.25	24.33
	MPTV	6.00	5.00	6.00	4.00	37.00
Number of pods per plant	PTVF	8	4	5	5	0
	PTVM	129.62	147.00	128.32	143.82	-
	APTV	8.62	26.00	7.32	22.82	-
	MPTV	15.00	46.00	10.00	44.00	-
Number of seeds per pod	PTVF	14	18	6	5	1
	PTVM	6.41	6.33	6.22	6.26	6.14
	APTV	0.40	0.32	0.21	0.25	0.13
	MPTV	0.66	0.32	0.44	0.32	0.13
Hundred seed weight (g)	PTVF	27	29	20	7	12
	PTVM	3.86	3.91	3.99	3.83	3.85
	APTV	0.08	0.13	0.21	0.05	0.07
	MPTV	0.66	0.70	0.47	0.81	0.89
Biological yield (g)	PTVF	6	1	1	1	1
	PTVM	73.14	72.00	94.00	82.00	64.00
	APTV	11.14	10.00	32.00	20.00	2.00
	MPTV	30.00	10.00	32.00	20.00	2.00
Single plant yield (g)	PTVF	19	11	13	6	4
	PTVM	29.81	28.79	34.66	31.58	32.96
	APTV	2.42	1.40	7.27	4.19	5.57
	MPTV	17.31	6.73	12.76	7.79	6.77

ANTV - Average negative transgressive variation, APTV - Average positive transgressive variation, EB - Electron beam, G - Gamma rays, MNTV - Maximum negative transgressive variation, MPTV - Maximum positive transgressive variation, NTVF - Negative transgressive variants frequency, NTVM - Negative transgressive variants mean, PTVF - Positive transgressive variants frequency, PTVM - Positive transgressive variants mean.

Table 3: Estimates of mean, shift in mean and range for quantitative traits in M_3 generation.

Traits	Statistic	Control	Mutagenic treatments				
			G: 200 Gy	G: 300 Gy	EB: 100 Gy	EB: 200 Gy	G+EB: 100 Gy
Days to first flowering	Mean ± SE	43.32±0.23	43.36±0.21	43.96±0.30	44.71±0.14	45.08 ±0.26	45.18±0.40
	Shift in mean		0.04	0.64	1.39	1.76	1.86
	Range	42.00-46.00	42.00-48.00	42.00-47.00	42.00-48.00	42.00-48.00	42.00-49.00
Days to maturity	Mean ± SE	98.64±0.23	98.09±0.18	98.43±0.38	99.07±0.12	99.98±0.23	99.94±0.39
	Shift in mean		-0.55	- 0.21	0.43	1.33	1.30
	Range	96.00-101.00	95.00-102.00	96.00-102.00	96.00-101.00	96.00-104.00	95.00-104.00
Plant height (cm)	Mean ± SE	68.17±1.01	78.97±1.76	72.37±2.37	79.92±1.43	85.11±1.77	77.02±2.26
	Shift in mean		10.80	4.20	11.75	16.94	8.85
	Range	65.10-86.70	58.00-120.40	53.40-91.20	48.20-116.20	66.10-103.50	64.60-122.80
Number of primary branches per plant	Mean ± SE	7.16±0.12	7.33±0.15	6.22±0.18	6.47±0.14	6.93±0.19	7.15±0.24
	Shift in mean		0.17	-0.94	-0.69	- 0.24	- 0.01
	Range	7.00-9.00	5.00-12.00	5.00-8.00	5.00-11.00	5.00-11.00	5.00-10.00
Pod length (cm)	Mean ± SE	4.98±0.03	5.01±0.03	4.99±0.06	5.02±0.04	5.01±0.08	5.05±0.06
	Shift in mean		0.04	0.02	0.04	0.03	0.08
	Range	4.72-5.54	4.71-5.55	4.60-5.82	4.60-5.90	4.10 -6.20	4.50-5.80
Number of clusters per plant	Mean ± SE	42.8 0±0.74	50.12±1.94	41.17±2.03	55.32±1.75	51.75±1.45	54.42±2.02
	Shift in mean		7.32	-1.63	12.52	8.95	11.62
	Range	38.00-53.00	15.00-79.00	19.00-54.00	22.00-103.00	35.00-88.00	26.00-102.00
Number of pods per plant	Mean ± SE	98.52±1.24	110.78±3.42	95.13±2.62	118.03±2.53	108.68±2.55	121.94±3.98
	Shift in mean		12.26	-3.39	19.51	10.16	23.42
	Range	91.00-118.00	62.00-216.00	58.00-128.00	44.00-247.00	41.00-129.00	62.00-235.00
Number of seeds per pod	Mean ± SE	5.25±0.03	5.36±0.07	5.13±0.10	5.08±0.05	5.33±0.08	5.19±0.07
	Shift in mean		0.11	-0.12	-0.17	0.09	- 0.05
	Range	5.00-5.67	4.33-6.00	4.33-6.00	3.33-5.67	4.33-5.77	4.33-5.67
Hundred seed weight (g)	Mean ± SE	3.49±0.02	3.60±0.02	3.69±0.05	3.62±0.01	3.78 ±0.03	3.72±0.04
	Shift in mean		0.12	0.20	0.13	0.29	0.23
	Range	3.25-3.81	3.51-4.15	3.35-3.99	3.44-4.25	3.30-3.99	3.31-4.20
Biological yield (g)	Mean ± SE	53.48±0.59	46.45 ±2.27	40.13±2.14	47.59±1.29	44.35±1.45	47.73±2.06
	Shift in mean		-7.03	-13.35	-5.89	-9.13	- 5.75
	Range	45.00-61.00	22.00-100.00	24.00-68.00	31.00-102.00	32.00-68.00	28.00-70.00
Single plant yield (g)	Mean ± SE	20.05±0.38	23.64±0.69	19.26±0.79	24.40±0.44	23.44±0.73	25.68±0.98
	Shift in mean		3.59	-0.79	4.36	3.39	5.63
	Range	18.01-24.04	12.28 32.18	13.54-24.58	15.55-43.75	13.25-29.65	15.89-44.19

EB - Electron beam, G - Gamma rays, SE - Standard error.

Frequency distribution pattern of mutant generations

Skewness and kurtosis provide better insight on distribution pattern of variants in a population (Table 4). Directional selection resulted deviations in frequency pattern between mutant generations. Most of the yield attributing traits *viz.*, pod length, number of clusters per plant, number of pods per plant, number of seeds per pod and hundred seed weight had varied distribution pattern with reduction in high order statistic at M_3 generation. Reduction in kurtosis value for flowering (except G: 200 Gy) and maturity denotes the absence of extreme duration types in M_3 population. Adoption of intense selection at M_3 progenies of gamma rays (200 Gy) and its combination (G+EB: 100 Gy) would result in rapid genetic gain for plant height (Roy, 2000) as it showed skewed distribution towards right with leptokurtic curve. High selection intensity can be implemented in gamma rays (200 Gy) and electron beam (100 Gy and200 Gy) to evolve genotypes with increased number of primary branches. The positive skewed distribution indicated the frequent occurrence of variants with decreasing effect for biological yield at both generations. However, the leptokurtic nature of two M_3 population (G: 200 Gy and EB: 100 Gy) would contribute genotypes with increased biomass on adoption of intense selection. All the irradiated treatments of M_3 generation (except EB: 100 Gy) had either non-significant skewness or kurtosis indicating the absence of epistatic interactions for single plant yield (Pooni *et al*. 1977).

Extent of variability with H^2 and GAM

High variance over control indicated the potentiality of employed doses in different mutants generation (Table 5). Traits *viz.*, plant height, number of seeds per pod and single plant yield exhibited an increase in variability pattern from M_2 to M_3 generation at all employed doses. Similarly, the release of inherent variability contributed higher GCV and PCV estimate at M_3 generation for traits *viz.*, number of primary branches per plant, number of clusters per plant, number of pods per plant and biological yield with few exceptions. On the contrary, low extent of PCV and GCV was recorded for days to flowering and maturity at both generations (Wani, 2011). Among mutagenic treatments, G: 200 Gy and G+EB: 100 Gy exhibited high values of PCV (21.95% and 21.46%) and GCV (20.47% and 20.19%) for single plant yield at M_3 generation. The increase in variability estimates offer scope for further yield improvement at subsequent generations through effective selection (Muduli and Misra, 2008).

Selection response can be predicted better by combining the extent of variability parameters with heritability (H^2) and GAM (Kharkwal, 2003). The decline in H^2 and GAM values for days to flowering and maturity at M_3 population indicate the governance of non- additive gene action (Table 6). The decline in H^2 estimate for number of primary branches at M_3 generation may be resultant of high environmental effects. Traits *viz.*, plant height, pod length, number of

Table 4: Distribution pattern of micro-mutants for quantitative traits.

Traits	Statistic	G: 200 Gy		G: 300 Gy		EB: 100 Gy		EB: 200 Gy		G+EB: 100 Gy	
		M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3
Days to first flowering	Skewness	0.22	2.02*	- 0.86*	1.04	- 0.14	0.02	1.86*	0.06	- 0.68*	- 0.08
	Kurtosis	- 1.74*	3.59*	- 0.73	- 0.18	- 0.61	- 0.10	3.25*	- 0.71	- 0.06	- 1.33
Days to maturity	Skewness	5.09*	0.54	5.46*	0.19	6.49*	- 1.02*	4.34*	- 0.11	1.42*	0.20
	Kurtosis	27.93*	2.97*	29.10*	- 0.74	49.18*	0.20	18.63*	2.04*	3.99*	- 0.23
Plant height (cm)	Skewness	3.27*	0.98*	2.80*	- 0.08	- 1.17*	0.60*	0.31	- 0.27	2.27*	1.57*
	Kurtosis	16.38*	1.40*	10.85*	- 1.00	11.05*	- 0.07	11.92*	- 0.92	12.89*	3.30*
Number of primary branches per plant	Skewness	0.04	1.06*	4.14*	0.52	3.32*	1.53*	0.83*	1.81*	1.87*	- 0.14
	Kurtosis	1.62*	4.06*	21.56*	0.07	20.93*	1.91*	4.14*	4.48*	12.29*	- 0.63
Pod length (cm)	Skewness	- 0.32	1.29*	- 1.70*	1.17*	- 1.07*	0.43	0.55*	0.27	- 2.80*	0.07
	Kurtosis	1.40*	0.82	9.22*	2.63*	12.76*	- 1.43*	9.05*	- 0.53	8.57*	- 0.65
Number of clusters per plant	Skewness	0.79*	- 0.09	1.18*	- 0.79	2.42*	0.59*	1.57*	1.91*	7.24*	1.46*
	Kurtosis	2.60*	- 0.17	1.62*	0.03	9.60*	- 0.27	3.91*	5.88*	76.32*	9.53*
Number of pods per plant	Skewness	- 0.46*	2.35*	2.98*	- 0.48	2.71*	1.43*	2.46*	- 1.83*	- 1.42*	3.44*
	Kurtosis	7.88*	8.18*	17.73*	4.55*	15.55*	7.15*	23.75*	6.66*	2.30*	21.18*
Number of seeds per pod	Skewness	- 0.15	- 0.47	- 1.56*	- 0.29	- 2.05*	- 0.85*	- 2.72*	- 1.33*	- 3.92*	- 0.51
	Kurtosis	- 0.76	- 0.55	5.06*	- 0.79	11.65*	- 0.03	13.48*	0.06	20.30*	- 0.68
Hundred seed weight (g)	Skewness	2.14*	3.17*	0.72*	- 0.07	1.58*	1.27*	- 1.39*	- 1.51*	- 0.02	- 0.42
	Kurtosis	9.10*	9.79*	3.35*	- 1.44	2.40*	3.90*	0.93*	1.30	4.30*	- 0.41
Biological yield (g)	Skewness	2.20*	1.30*	0.93*	1.05	6.28*	1.69*	3.73*	1.12*	3.10*	0.38
	Kurtosis	9.67*	1.39*	2.81*	1.35	64.46*	3.41*	29.70*	0.88	20.13*	- 0.89
Single plant yield (g)	Skewness	1.38*	- 0.39	- 0.03	- 0.85	4.36*	1.77*	3.69*	- 0.97*	3.61*	0.22
	Kurtosis	8.01*	- 1.06	1.00*	- 0.03	26.34*	3.80*	29.13*	- 0.09	30.71*	3.83*

EB - Electron beam, G - Gamma rays, * - Significance at 0.05 %.

Table 5: Magnitude of variability accumulated in mutagenic treatments of CRIDA1-18R.

Traits	Statistic	Control		G: 200 Gy		G: 300 Gy		EB: 100 Gy		EB: 200 Gy		G+EB: 100 Gy	
		M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3
Days to first flowering	Variance	1.40	1.10	11.32	2.44	8.83	2.04	6.52	2.09	3.60	3.76	8.14	5.24
	PCV (%)	-	-	6.52	3.60	5.59	3.25	5.14	3.23	3.86	4.30	5.37	5.07
	GCV (%)	-	-	6.11	2.67	5.13	2.21	4.55	2.23	3.02	3.62	4.89	4.50
Days to maturity	Variance	1.75	1.03	10.07	1.80	5.88	3.12	6.17	1.34	9.52	3.07	10.38	4.91
	PCV (%)	-	-	3.24	1.37	2.44	1.79	2.59	1.17	3.15	1.75	3.18	2.22
	GCV (%)	-	-	2.95	0.90	2.04	1.44	2.19	0.50	2.91	1.40	2.90	1.95
Plant height (cm)	Variance	10.85	15.66	32.82	176.55	52.50	123.63	42.08	205.56	45.76	121.40	55.14	162.68
	PCV (%)	-	-	8.19	16.83	14.95	15.36	10.22	17.94	10.35	12.95	11.50	16.56
	GCV (%)	-	-	6.70	16.06	13.32	14.36	8.80	17.24	9.04	12.08	10.30	15.74
Number of primary branches per plant	Variance	0.15	0.21	0.89	1.29	0.64	0.69	0.70	1.90	0.90	0.52	0.74	1.83
	PCV (%)	-	-	11.12	15.50	12.79	13.38	12.13	21.28	13.60	10.39	11.56	18.89
	GCV (%)	-	-	10.17	14.15	11.23	11.11	10.81	20.04	12.45	7.96	10.36	17.75
Pod length (cm)	Variance	0.03	0.02	0.06	0.06	0.09	0.07	0.07	0.20	0.08	0.19	0.11	0.11
	PCV (%)	-	-	5.03	4.96	6.25	5.31	6.07	8.96	6.29	8.74	7.00	6.68
	GCV (%)	-	-	3.79	4.24	5.29	4.65	4.89	8.58	5.23	8.36	6.12	6.18
Number of clusters per plant	Variance	4.81	8.80	16.39	213.76	24.42	90.75	17.24	307.69	19.66	32.95	23.95	130.18
	PCV (%)	-	-	9.65	29.17	11.86	23.14	11.56	31.71	12.31	11.09	10.78	20.96
	GCV (%)	-	-	8.11	28.56	10.63	21.99	9.82	31.25	10.70	9.50	9.64	20.24
Number of pods per plant	Variance	25.38	25.93	89.03	667.74	169.52	150.98	92.27	648.26	137.34	130.20	133.88	505.27
	PCV (%)	-	-	11.71	23.33	15.45	12.92	14.86	21.57	15.89	10.50	13.93	18.43
	GCV (%)	-	-	9.90	22.87	14.25	11.76	12.65	21.14	14.35	9.40	12.54	17.95
Number of seeds per pod	Variance	0.04	0.01	0.19	0.25	0.20	0.21	0.12	0.27	0.13	0.31	0.13	0.16
	PCV (%)	-	-	7.51	9.26	7.70	9.03	6.36	10.16	6.60	10.47	6.76	7.76
	GCV (%)	-	-	6.62	9.03	6.80	8.77	5.13	9.93	5.39	10.27	5.57	7.47
Hundred seed weight (g)	Variance	0.01	0.01	0.02	0.01	0.03	0.05	0.03	0.02	0.08	0.03	0.02	0.05
	PCV (%)	-	-	4.03	3.29	4.32	6.02	5.07	3.66	7.40	4.78	9.66	5.82
	GCV (%)	-	-	2.94	2.21	3.48	5.52	4.25	2.74	6.94	4.17	8.82	5.32
Biological yield (g)	Variance	6.17	9.93	65.65	294.28	41.41	100.72	31.39	168.22	31.93	22.41	17.14	136.08
	PCV (%)	-	-	17.61	36.93	16.35	25.01	14.55	27.25	15.78	10.67	11.25	24.44
	GCV (%)	-	-	16.77	36.30	15.09	23.74	13.04	26.44	14.17	7.97	9.00	23.53
Single plant yield (g)	Variance	1.80	3.50	8.79	26.92	6.60	13.58	9.15	19.24	5.42	23.79	4.11	30.38
	PCV (%)	-	-	11.66	21.95	10.55	19.13	17.41	17.97	14.50	20.81	11.71	21.46
	GCV (%)	-	-	10.39	20.47	8.99	16.49	15.60	16.26	11.84	19.22	8.77	20.19

EB - Electron beam, G - Gamma rays, PCV - Phenotypic coefficient of variation, GCV - Genotypic coefficient of variation.

Table 6: Extent of heritability and genetic advance as per cent of mean in mutant generations of CRIDA 1-18R.

Traits	Statistic	G: 200 Gy		G: 300 Gy		EB: 100 Gy		EB: 200 Gy		G+EB: 100 Gy	
		M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3	M_2	M_3
Days to first flowering	H^2 (%)	87.66	54.98	84.18	46.24	78.59	47.48	61.23	70.79	82.85	79.05
	GAM (%)	11.78	4.08	9.69	3.10	8.31	3.16	4.87	6.27	9.16	8.25
Days to maturity	H^2 (%)	82.61	42.85	70.24	64.77	71.61	17.99	85.34	64.25	83.13	77.62
	GAM (%)	5.52	1.21	3.53	2.39	3.81	0.43	5.54	2.32	5.44	3.54
Plant height (cm)	H^2 (%)	66.92	91.13	79.32	87.34	74.21	92.38	76.28	87.10	80.32	90.38
	GAM (%)	11.29	31.59	24.43	27.64	15.62	34.14	16.27	23.23	19.02	30.83
Number of primary branches per plant	H^2 (%)	83.64	83.37	77.11	69.01	79.35	88.69	83.80	58.61	80.32	88.26
	GAM (%)	5.52	26.61	3.53	19.02	3.81	38.88	5.54	12.55	5.44	34.35
Pod length (cm)	H^2 (%)	56.77	73.34	71.71	76.61	65.02	91.84	69.16	91.41	76.39	85.55
	GAM (%)	5.88	7.49	9.23	8.38	8.13	16.94	8.97	16.46	11.02	11.77
Number of clusters per plant	H^2 (%)	70.66	95.88	80.31	90.30	72.11	97.14	75.54	73.29	79.93	93.24
	GAM (%)	14.05	57.62	19.62	43.04	17.17	63.45	19.16	16.75	17.75	40.27
Number of pods per plant	H^2 (%)	71.49	96.12	85.03	82.83	72.49	96.00	81.52	80.08	81.04	94.87
	GAM (%)	17.25	46.19	27.07	22.04	22.19	42.66	26.68	17.32	23.26	36.03
Number of seeds per pod	H^2 (%)	77.73	95.22	78.07	94.50	65.02	95.57	66.65	96.22	67.90	92.74
	GAM (%)	12.02	18.16	12.38	17.57	8.52	20.00	9.06	20.74	9.45	14.82
Hundred seed weight (g)	H^2 (%)	53.51	44.91	64.78	84.26	70.10	55.86	87.76	76.23	83.44	83.47
	GAM (%)	4.44	3.04	5.76	10.44	7.33	4.21	13.38	7.51	16.60	10.01
Biological yield (g)	H^2 (%)	90.60	96.63	85.09	90.14	80.34	94.10	80.67	55.70	63.98	92.70
	GAM (%)	32.87	73.51	28.67	46.44	24.09	52.83	26.22	12.25	14.82	46.68
Single plant yield (g)	H^2 (%)	79.49	87.01	72.66	74.26	80.28	81.83	66.69	85.31	56.09	88.49
	GAM (%)	19.09	39.34	15.79	29.27	28.78	30.30	19.92	36.57	13.53	39.13

EB - Electron beam, G - Gamma rays, GAM - Genetic advance as per cent of mean, H^2 - Heritability at broad sense.

clusters per pod, number of pods per plant, number of seeds per pod, biological yield and single plant yield exhibited a gradual increase in both parameters from M_2 to M_3 generation with few exceptions. The increase in H^2 and GAM values at M_3 generation shows the preponderance of additive gene effects for yield and most of its component traits (Mensah *et al*., 2005).

CONCLUSION

Direct selection for yield proved promising for all the mutagenic treatments except 300 Gy of gamma rays. Adoption of early generation selection would be beneficial in capturing favorable combination of alleles which eventually disappear in the advanced generations. Among the mutagenic treatments, combination of G+EB: 100 Gy was found promising for single plant yield, number of pods per plant and pod length. The increased mean coupled with high H^2 and GAM at M_3 population indicates the preponderance of additive gene effects for most of the polygenic traits. Increased variability at M_3 generation provides scope for yield improvement on further selection. The positive kurtosis at lower dose of electron beam (100 Gy) and its combination (G+EB: 100 Gy) treatment indicate the presence of superior variants for single plant yield. The identified high yielding progenies (more than 40 g) will contribute for enhanced yield potential in horse gram.

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Conflict of interest

On behalf of all the authors, I wish to confirm that there is no conflict of interest in the publication of this manuscript.

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