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Comparative mutagenic effectiveness and efficiency of gamma rays and sodium azide in cowpea (Vigna unguiculata (l.) Walp.)

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Abstract

A study was conducted during *kharif* 2021 and 2022 at Rajasthan Agricultural Research Institute, Durgapura, Jaipur, India to assess the mutagenic effectiveness and efficiency of γ-rays (150–250 Gy), SA (0.01–0.03%) and their combinations in cowpea. The M_1 and M_2 generations were evaluated for biological effects, mutation frequency, mutation spectrum, and recovery of useful mutants. All mutagenic treatments exhibited dose-dependent reductions in germination, survival, and seedling vigour, with 200 Gy, 0.02% SA, and 200 Gy + 0.02% SA identified as optimum treatments. Combined mutagen treatments induced greater chlorophyll and morphological variability than individual mutagens, demonstrating their synergistic effect. The treatment 250 Gy + 0.03% SA recorded the highest mutation frequency and widest spectrum of desirable mutants, whereas 200 Gy + 0.02% SA showed the highest mutagenic effectiveness and efficiency. The induced mutants for plant architecture, maturity, and seed traits provide valuable genetic resources for cowpea improvement. Overall, combined γ-rays and SA treatments proved effective for generating broad genetic variability and enhancing the scope of mutation breeding in cowpea.

Key worlds: Cowpea, gamma rays (γ-rays), sodium azide (SA), chlorophyll mutants, morphological mutants, mutagenic effectiveness, mutagenic efficiency

Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important grain legume valued for its high protein content, climate resilience, adaptability to marginal environments, and ability to improve soil fertility through biological nitrogen fixation. Despite its agronomic importance, genetic improvement in cowpea is constrained by its narrow genetic base resulting from its predominantly self-pollinated nature. Induced mutagenesis is an effective approach for generating novel genetic variability and broadening the genetic base of crop plants. Mutation breeding has played an important role in developing improved crop varieties by creating desirable allelic variations unavailable in natural populations (Mba *et al*., 2013, Raina et al., 2022). The success of mutation breeding depends on the choice of mutagen, dose, treatment duration, and the induction of useful mutations with minimum biological damage (Manju and Gopimony, 2009). Among mutagens, gamma rays are widely used because of their high penetration ability and broad mutation spectrum, whereas sodium azide (SA) is an effective chemical mutagen known to induce point mutations. Combined application of physical and chemical mutagens has been reported to enhance mutation frequency and broaden the mutation spectrum when their modes of action are complementary (Siddiqui and Singh, 2010). Therefore, comparative evaluation of their mutagenic effectiveness and efficiency is essential for identifying suitable mutagenic treatments. Mutagenic effectiveness and efficiency are key parameters for assessing the usefulness of mutagens. Chlorophyll mutations are reliable genetic markers for evaluating mutagenic potency because they are easily identifiable, heritable, and minimally influenced by environmental factors. Similarly, morphological mutations provide valuable variability for economically important agronomic traits and facilitate selection in mutation breeding programmes. Therefore, the present investigation was undertaken to compare the mutagenic effectiveness and efficiency of gamma rays, sodium azide, and their combined treatments in popular cowpea variety RC-101, based on the frequency and spectrum of chlorophyll and morphological mutants. The study aims to identify efficient mutagenic treatments for generating useful genetic variability for future cowpea improvement programmes.

Materials and Methods

The genetically diverse cowpea variety RC-101, procured from the All-India Network Project (AINP) on Arid Legumes, Rajasthan Agricultural Research Institute (RARI), Durgapura, Jaipur, was used as the experimental material. RC-101 is a high-yielding, early-maturing (60–65 days), drought-tolerant, determinate, non-viny cultivar with bold white seeds and is widely recommended for cultivation under the low-rainfall agro-climatic conditions of North India. Healthy, well-filled dry seeds (12% moisture content) of cowpea variety RC-101 were treated with six doses of gamma rays (150, 200, 250, 300, 350 and 400 Gy), six concentrations of sodium azide (SA; 0.01, 0.02, 0.03, 0.04, 0.05 and 0.06%), and their corresponding combined treatments, along with an untreated control. Gamma irradiation was carried out using a Co-60 Gamma Chamber at the Board of Radiation and Isotope Technology (BRIT), Bhabha Atomic Research Centre (BARC), Mumbai, while sodium azide treatments were administered at Rajasthan Agricultural Research Institute (RARI), Durgapura, Jaipur. Seeds were pre-soaked in distilled water for 6 h, treated with freshly prepared SA solution for 3 h, and washed under running tap water for 1 h; in combined treatments, gamma irradiation preceded SA treatment. Immediately after treatment, 200 seeds from each treatment (four replications of 50 seeds) were evaluated during Kharif 2021 for germination and seedling vigour traits by the standard wet paper towel method following ISTA (2022) guidelines in a Completely Randomized Design (CRD). Germination percentage, shoot length, root length, seedling fresh weight, seedling dry weight, seed vigour index-I and seed vigour index-II were recorded. The remaining treated seeds were sown to raise the M_1 generation in a Randomized Block Design (RBD) with three replications at a in two rows of three-meter length spacing of 45 × 10 cm at RARI, Durgapura, Jaipur, Rajasthan India (26°51' N, 75°47' E; 390 m amsl). Seeds harvested from 20 fertile M_1 plants of each treatment were advanced to the M_2 generation to study mutant segregation and genetic variability. The M_2 population was raised during *Kharif* 2022 in a Compact Family Block Design with three replications, where each M_1 plant progeny was grown as a single 3 m row at a spacing of 45 × 10 cm under recommended agronomic practices. The M_2 population was screened for chlorophyll and morphological mutations. Chlorophyll mutants were recorded up to four weeks after germination and classified according to Lamprecht (1960) and Kharkwal (1998). Mutation frequency was calculated as the percentage of mutated M_2 families/plants was calculated as per Gaul (1964) and the formula suggested by Konzak et al. (1965) served to evaluate the mutagenic effectiveness and efficiency.

Results and Discussion

Mutagenic injury in M_1 generation

Gamma rays (γ-rays), sodium azide (SA), and their combined treatments produced a progressive reduction in laboratory germination, field germination, and plant survival with increasing dose, demonstrating a clear dose-dependent inhibitory effect (Table 1). Among the treatments, 200 Gy γ-rays, 0.02% SA, and 200 Gy + 0.02% SA were close to the LD_{50} level and were therefore considered the optimum mutagenic doses. Higher doses caused excessive biological damage, whereas lower doses induced comparatively less biological injury. The observed reduction in germination and survival may be attributed to mutagen-induced chromosomal aberrations, physiological disturbances, and disruption of cellular metabolism during germination and early seedling establishment. Similar dose-dependent reductions in germination and survival following γ-ray and sodium azide treatments have been reported in cowpea by Raina et al. (2023). Identification of an optimum LD_{50} dose is a prerequisite for mutation breeding because it ensures an appropriate balance between mutation induction and biological damage, thereby increasing the likelihood of recovering desirable mutants. Similarly, all mutagenic treatments significantly reduced germination, shoot length, root length, seedling fresh weight, seedling dry weight, and seed vigour indices in the M_1 generation compared with the control (Table 2). The magnitude of inhibition increased progressively with increasing doses of γ-rays and SA concentrations, confirming a dose-dependent response. Combined treatments generally caused greater inhibition than the corresponding individual treatments, indicating an additive or synergistic effect of the two mutagens. The reduction in seedling growth and vigour is likely associated with impaired cell division, chromosomal damage, and metabolic disturbances induced by mutagen exposure. Nevertheless, intermediate treatments (200–250 Gy γ-rays, 0.02–0.03% SA, and their combinations) produced moderate biological injury while maintaining sufficient plant survival, indicating their suitability for generating useful genetic variability in cowpea. Comparable observations have been reported in cowpea and other grain legumes by Mishra et al. (2018), Kang et al. (2020) and Raina et al. (2023) confirming that intermediate mutagen doses are generally the most effective for inducing beneficial mutations while minimizing detrimental biological effects.

Table 1
Estimation of lethal does (LD_{50}) at different doses of gamma rays and sodium azide

Conc.	No. of seed Sample	Germinations (%) in Lab.	Germinations (%) in Field	Survival (%)	LD
Control	300	95.00	91.33	91.33	-
150 Gy γ rays	300	64.50	60.33	57.67	36.86
200 Gy γ rays	300	58.50	48.67	44.00	51.82
250 Gy γ rays	300	50.00	41.33	40.00	56.20
300 Gy γ rays	300	42.50	36.00	35.67	60.94
350 Gy γ rays	300	34.50	25.67	19.00	79.20
400 Gy γ rays	300	30.00	22.33	14.67	83.94
0.01% SA	300	66.00	64.67	62.67	31.38
0.02% SA	300	60.00	49.33	44.67	51.09
0.03% SA	300	42.00	43.67	38.33	58.03
0.04% SA	300	40.50	34.67	32.67	64.23
0.05% SA	300	35.00	28.67	24.67	72.99
0.06% SA	300	30.00	23.33	18.00	80.29
150 Gy γ rays + 0.01% SA	300	61.50	60.00	57.67	36.86
200 Gy γ rays + 0.02% SA	300	58.50	49.67	43.33	52.56
250 Gy γ rays + 0.03% SA	300	54.00	40.33	37.33	59.13
300 Gy γ rays + 0.04% SA	300	47.00	29.67	25.67	71.89
350 Gy γ rays + 0.05% SA	300	35.00	26.33	20.33	77.74
400 Gy γ rays + 0.06% SA	300	29.00	20.00	15.33	83.21

Table 2
Mean and inhibition per cent of different treatments in M_1 generation under laboratory conditions

Treatments	G	I (%)	SL	I (%)	RL	I (%)	SFW	I (%)	SDW	I (%)	SVI-I	I (%)	SVI-II	I (%)
Control	95.00	0.00	28.75	0.00	10.54	0.00	3.59	0.00	1.12	0.00	2615.23	0.00	102.33	0.00
150Gy γ rays	64.50	32.11	19.64	31.69	7.71	26.88	3.29	8.29	0.85	24.82	1268.36	51.50	54.68	46.56
200Gy γ rays	58.50	38.42	18.08	37.14	5.45	48.33	2.60	27.72	0.78	29.83	1055.43	59.64	46.16	54.89
250Gy γ rays	50.00	47.37	17.04	40.74	5.54	47.50	3.30	8.22	0.78	30.54	907.66	65.29	41.04	59.90
300Gy γ rays	42.50	55.26	6.73	76.60	4.40	58.31	2.53	29.46	0.63	43.51	299.09	88.56	28.26	72.39
350Gy γ rays	34.50	63.68	5.95	79.31	3.35	68.29	2.23	38.02	0.53	52.89	228.59	91.26	20.38	80.09
400Gy γ rays	30.00	68.42	4.52	84.29	3.62	65.66	2.47	31.34	0.47	57.41	159.81	93.89	17.23	83.16
0.01% SA	66.00	30.53	19.29	32.92	6.61	37.38	1.52	57.80	1.03	8.30	1272.67	51.34	68.04	33.51
0.02% SA	60.00	36.84	17.41	39.46	6.36	39.75	1.58	56.13	0.92	18.57	1079.25	58.73	56.73	44.56
0.03% SA	42.00	55.79	15.88	44.76	5.58	47.14	2.48	30.85	0.69	37.92	937.82	64.14	41.37	59.57
0.04% SA	40.50	57.37	11.94	58.49	5.35	49.28	2.12	40.95	0.54	51.25	579.55	77.84	26.48	74.12
0.05% SA	35.00	63.16	8.80	69.39	4.66	55.84	2.09	41.71	0.48	56.98	361.75	86.17	19.65	80.80
0.06% SA	30.00	68.42	7.69	73.25	4.34	58.83	2.06	42.76	0.41	63.06	277.30	89.40	15.12	85.23
150Gy + 0.01% SA	61.50	35.26	18.29	36.39	7.52	28.70	2.83	21.31	0.89	20.28	1125.40	56.97	55.03	46.22
200Gy + 0.02% SA	58.50	38.42	12.56	56.33	5.72	45.77	2.69	25.21	0.77	31.47	734.56	71.91	45.16	55.86
250Gy + 0.03% SA	54.00	43.16	10.97	61.84	5.33	49.49	2.53	29.53	0.68	38.68	593.48	77.31	36.94	63.90
300Gy + 0.04% SA	47.00	50.53	8.80	69.39	4.50	57.34	2.14	40.46	0.55	50.82	413.97	84.17	26.02	74.58
350Gy + 0.05% SA	35.00	63.16	7.67	73.32	4.54	56.96	1.57	56.41	0.45	59.43	291.11	88.87	17.41	82.99
400Gy + 0.06% SA	29.00	69.47	6.80	76.34	3.45	67.27	1.41	60.86	0.44	60.85	237.55	90.92	15.30	85.05
Mean	49.13		12.98		5.50		2.37		0.69		759.92		38.60	
C.D.	3.96		1.56		0.29		0.19		0.16		103.86		8.81	
SE(m)	1.39		0.55		0.10		0.07		0.06		36.58		3.10	
SE(d)	1.97		0.78		0.14		0.09		0.08		51.73		4.39	
C.V.	5.34		8.48		3.72		5.63		15.96		9.63		14.44	

I (%)= Inhibition(%), G= Germination %, SL= Shoot length (cm), RL= Root length (cm), SFW= Seedling fresh weight (g), SDW= Seedling dry weight (g), SVI-I= Seed vigour index-I and SVI-II= Seed vigour index-II

Chlorophyll and Morphological Mutations

The frequency of chlorophyll and morphological mutations induced by γ-rays, SA and their combined treatments is presented in Tables 3 to 5. No mutants were observed in the untreated control, confirming that all mutations were induced by the mutagenic treatments. In the present study, six chlorophyll mutant types namely albina, chlorina, xantha, tigrina, viridis and xantha-viridis while a wide range of morphological mutants involving plant height, growth habit, leaf, flower, pod, maturity, and seed traits were recovered in the M_2 generation (Fig. 1, 2). Among the individual mutagens, γ-rays produced a higher frequency and broader spectrum of chlorophyll mutations than SA. Chlorophyll mutation frequency increased with increasing γ-ray dose, reaching a maximum (0.20%) at 250 Gy, whereas the highest frequency under SA (0.10%) was recorded at

0.03%. The combined treatment (250 Gy + 0.03% SA) was the most effective, producing the highest chlorophyll mutation frequency (0.20%) and the broadest mutation spectrum, indicating a synergistic interaction between the two mutagens (Table 4). Similar observations have been reported in cowpea by Raina et al. (2022) and Chaudhary et al. (2024). The mutation spectrum varied among treatments, reflecting differences in their mode of action. Gamma rays induced a wider range of chlorophyll mutants, whereas SA predominantly induced chlorina and xantha mutants. The combined treatments generated the broadest spectrum, suggesting enhanced genetic variability. Chlorina and xantha were the most frequent mutant classes, while albina mutants occurred least frequently because of their lethal nature, as also reported by Raina et al. (2022).

Table 3
Frequency of morphological and chlorophyll mutants in M_2 generation

S. No.	Treatments	Total no. of plants observed	Total no. of progenies observed	Morphological mutants	Chlorophyll mutants	Total no. of mutant	Total no. of progenies represents mutations	Mutation frequency (Population basis)	Mutation frequency (Family basis)
1.	Control	2000	20	-	-	-	-	-	-
2.	150 Gy γ rays	2000	20	3	1	4	2	0.20	10
3.	200 Gy γ rays	2000	20	4	2	6	3	0.30	15
4.	250 Gy γ rays	2000	20	4	4	8	5	0.40	25
5.	0.01% SA	2000	20	1	-	1	1	0.05	05
6.	0.02% SA	2000	20	3	1	4	2	0.20	10
7.	0.03% SA	2000	20	3	2	5	4	0.25	20
8.	150 Gy γ rays + 0.01% SA	2000	20	3	2	5	2	0.25	10
9	200 Gy γ rays + 0.02% SA	2000	20	4	3	7	6	0.35	30
10.	250 Gy γ rays + 0.03% SA	2000	20	5	4	9	7	0.45	35

Table 4
Frequency and spectrum of chlorophyll mutants induced by Gamma rays, sodium azide and their combinations in M_2 generation

Treatments	Types of Chlorophyll Mutants								
	Total no. of plant observed	Albina	Chlorina	Xantha	Tigrina	Viridis	Xanthaviridis	Total mutants	F (%)
Control	2000	-	-	-	-	-	-	-	-
150 Gy γ rays	2000	-	1	-	-	-	-	1	0.05
200 Gy γ rays	2000	-	-	1	-	1	-	2	0.10
250 Gy γ rays	2000	-	1	1	1	-	1	4	0.20
Total mutants (Gamma)	6000	-	2	2	1	1	1	7	0.116
0.01% SA	2000	-	-	-	-	-	-	-	-
0.02% SA	2000	-	1	-	-	-	-	1	0.05
0.03% SA	2000	-	-	1	-	-	1	2	0.10
Total mutants (SA)	6000	-	1	1	-	-	1	3	0.050
150 Gy γ rays + 0.01% SA	2000	1	-	-	-	1	-	2	0.10
200 Gy γ rays + 0.02% SA	2000	-	1	-	1	-	1	3	0.15
250 Gy γ rays + 0.03% SA	2000	1	-	2	1	-	-	4	0.20
Total mutants (Gamma + SA)	6000	2	1	2	2	1	1	9	0.150

Table 5
Frequency and spectrum of morphological mutants induced by Gamma rays, sodium azide and their combinations in M_2 generation

Treatments	Types of Morphological Mutants								
	Total no. of plants observed	Plant height	Growth habit	Leaf	Flower	Pod	Seed	Total mutants	F (%)
Control	2000	-	-	-	-	-	-	-	-
150Gy γ rays	2000	1	-	1	-	-	1	3	0.15
200Gy γ rays	2000	-	-	1	-	1	2	4	0.20
250Gy γ rays	2000	1	1	-	-	1	1	4	0.20
Total mutants (Gamma)	6000	2	1	2	-	2	4	11	0.183
0.01% SA	2000	-	-	1	-	-	-	1	0.05
0.02% SA	2000	1	-	-	-	1	1	3	0.15
0.03% SA	2000	-	-	1	-	1	1	3	0.15
Total mutants (SA)	6000	1	-	2	-	2	2	7	0.116
150Gy γ rays + 0.01% SA	2000	-	2	-	-	-	1	3	0.15
200Gy γ rays + 0.02% SA	2000	1	-	1	1	-	1	4	0.20
250Gy γ rays + 0.03% SA	2000	-		2	-	1	2	5	0.25
Total mutants (Gamma + SA)	6000	1	2	3	1	1	4	12	0.200

A similar trend was observed for morphological mutations (Table 5). Mutation frequency increased with increasing dose or concentration of both mutagens, with γ-rays producing more mutants than SA. However, the combined treatments were superior, with 250 Gy + 0.03% SA recording the highest mutation frequency (0.25%), followed by 200 Gy + 0.02% SA (0.20%). The combined treatments also generated the widest spectrum of

morphological mutants involving seed, leaf, growth habit, plant height, flower, and pod traits, demonstrating their greater efficiency in creating genetic variability. These results corroborate the findings of Savant (2023) and Souframanien and Dhanasekar (2024). The M_2 generation exhibited diverse morphological mutants, including variations in plant height, growth habit, leaf, flower, pod, and seed traits (Fig. 2). Desirable mutants such as dwarf, bushy, early-maturing, and bold-seeded types were identified, which could serve as valuable genetic resources for cowpea improvement. Similar observations on the breeding value of induced mutants have been reported by Laskar et al. (2015) and Raina et al. (2017). Overall, the results demonstrate that the combined treatment of γ-rays and SA was more effective than either mutagen alone in inducing a higher frequency and broader spectrum of useful mutations in cowpea.

Mutagenic Effectiveness and Efficiency

The estimates of mutagenic effectiveness and efficiency are presented in Table 6. Among the gamma-ray treatments, mutagenic effectiveness increased with increasing radiation dose and reached a maximum (0.10) at 250 Gy. Similarly, mutagenic efficiency based on pollen sterility (Mp/S) and survival injury (Mp/I) increased progressively from 150 to 250 Gy, indicating that although higher doses caused greater biological damage, they also induced a higher proportion of useful mutations. Similar dose-dependent responses of gamma rays have been reported in cowpea and other legumes by Nair et al. (2014) and Patial et al. (2015). Sodium azide exhibited considerably higher mutagenic effectiveness than gamma rays because of its ability to induce point mutations at low concentrations. Mutagenic effectiveness increased from 125.00 at 0.01–0.02% SA to 166.66 at 0.03% SA, while mutagenic efficiency also improved with increasing concentration. These results are consistent with the findings of Singh et al. (2013), Nair and Mehta (2019) and Abo-Hegazy et al. (2025) who reported that sodium azide is a highly effective chemical mutagen with relatively low biological damage. The combined application of gamma rays and SA was superior to the individual mutagens in terms of mutagenic efficiency. The treatment 200 Gy + 0.02% SA recorded the highest mutagenic effectiveness (1.88) and mutagenic efficiency (Mp/S = 1.32; Mp/I = 0.73), indicating the best balance between mutation induction and biological damage. Although 250 Gy + 0.03% SA produced the highest frequency of mutated progenies (35%) and the broadest mutation spectrum, its effectiveness (1.17) and efficiency (Mp/S = 1.30; Mp/I = 0.67) were slightly lower because of greater biological injury at the higher dose. Similar relationships between mutagen dose, biological damage, and mutagenic efficiency have been reported by Laskar and Khan (2017) and Abo-Hegazy et al. (2025).

Table 6
Estimation of effectiveness and efficiency of gamma rays, sodium azide and their combinations in M_2 generation

S.N.	Treatments	(%) Pollen sterility	(%) Survival injury	% mutated plant progenies	Mutagenic effectiveness	Mutagenic efficiency	
		(S)	(I)	(Mp)		Mp/S	Mp/I
1.	150 Gy γ rays	18.62	33.20	10	0.07	0.54	0.30
2.	200 Gy γ rays	23.81	40.92	15	0.07	0.84	0.49
3.	250 Gy γ rays	27.81	50.02	25	0.10	0.90	0.50
4.	0.01% SA	17.53	27.41	05	125.00	0.29	0.18
5.	0.02% SA	17.64	37.45	10	125.00	0.57	0.27
6.	0.03% SA	18.98	39.77	20	166.66	0.79	0.38
7.	150 Gy γ rays + 0.01% SA	16.07	33.20	10	1.66	0.93	0.45
8.	200 Gy γ rays + 0.02% SA	22.79	41.31	30	1.88	1.32	0.73
9.	250 Gy γ rays + 0.03% SA	26.97	52.51	35	1.17	1.30	0.67

Overall, 250 Gy was the most efficient gamma-ray treatment, whereas 0.03% SA showed the highest effectiveness among the chemical mutagen treatments. However, 200 Gy + 0.02% SA emerged as the optimum treatment for efficient recovery of useful mutants because it provided the best balance between mutation induction and biological damage. In contrast, 250 Gy + 0.03% SA produced the highest mutation frequency and the broadest spectrum of morphological mutants, making it the most suitable treatment for generating maximum genetic variability. These findings confirm that the combined application of gamma rays and sodium azide is a more efficient strategy than the individual mutagens for inducing useful genetic variability in cowpea.

Conclusion

The combined application of gamma rays and sodium azide was more effective than individual mutagens in inducing useful genetic variability in cowpea. While 200 Gy + 0.02% SA proved to be the optimum treatment based on mutagenic effectiveness and efficiency, 250 Gy + 0.03% SA

generated the highest mutation frequency and broadest spectrum of desirable mutants, making it most suitable for cowpea improvement through mutation breeding.

Declarations

Author Contributions: VB and SKJ wrote the main manuscript text and RS and RS prepared figures. All authors reviewed the manuscript.

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Data Availability Statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval: The plant material used in this study was cultivated and collected in accordance with applicable local and national guidelines. No specific permissions or licences were required for the collection and use of the plant material.

Competing Interests The authors declare no competing interests

Research Involving Animal Participants: This study did not involve any animal experimentation.

Consent to participate declaration: Not applicable

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Figures

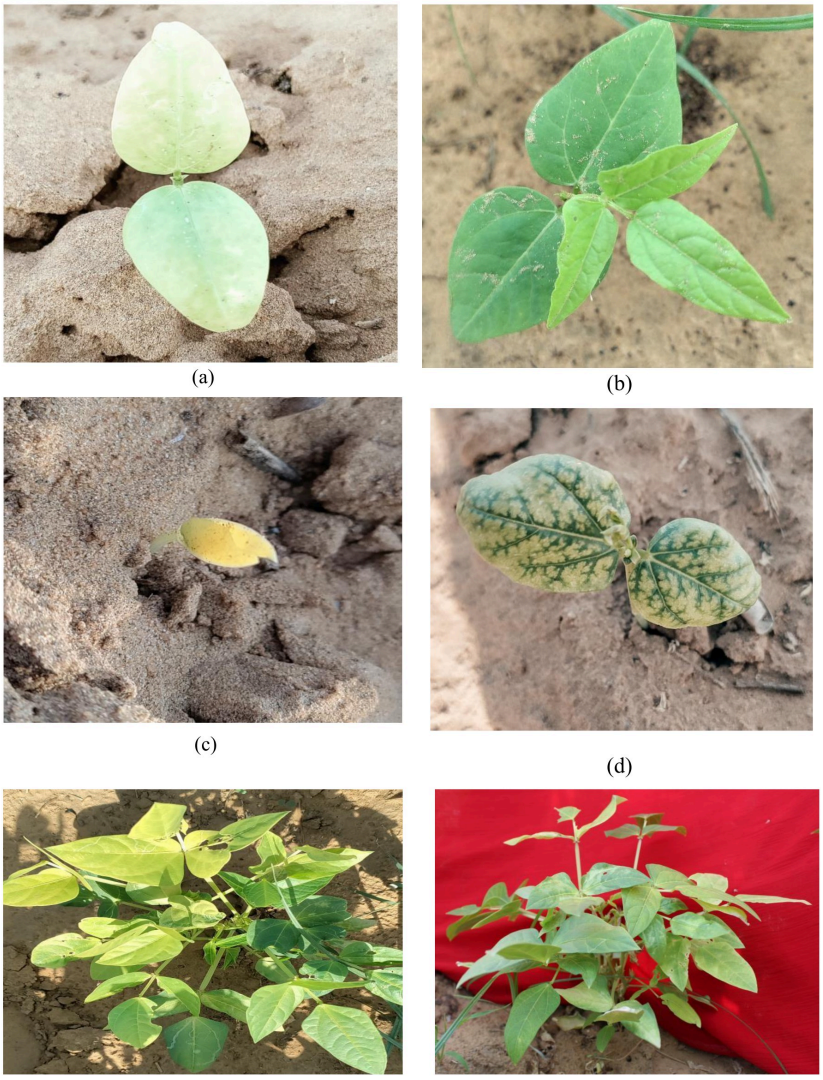


Figure 1 Different chlorophyll mutants observed in M_2 generation [(a) Albina, (b) Chlorina, (c) Xantha, (d) Tigrina, (e) Viridis and (f) Xantha viridis]

Figure 1

Different chlorophyll mutants observed in M_2 generation [(a) Albina, (b) Chlorina, (c) Xantha, (d) Tigrina, (e) Viridis and (f) Xantha viridis]



Figure 2 Different morphological mutants observed in M_2 generation [(a) Normal plant (control) (b) seed (control) (c) dwarf, (d) semi dwarf, (e) bushy (f) Prostrate, (g) Spreading, (h) Non flowering and bushy, (i) Tall Mutants, (j) Black pod, (k) NonShatering, (l) Seed shape and surface, (m)Seed coat color, (n) Seed coat pattern and (o) Bold seeded]

Figure 2

Different morphological mutants observed in M_2 generation [(a) Normal plant (control) (b) seed (control) (c) dwarf, (d) semi dwarf, (e) bushy (f) Prostrate, (g) Spreading, (h) Non flowering and bushy, (i) Tall Mutants, (j) Black pod, (k) NonShatering, (l) Seed shape and surface, (m)Seed coat color and (n) Seed coat pattern]

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