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SENSITIVITY AND INSENSITIVITY OF VARIOUS TRAITS TO MUTAGEN TREATMENT IN RICE (*Oryza sativa* L.)

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ABSTRACT

Rice is one of the most important food crops around the world, which can be grown under wide range of environmental conditions. Mutation breeding could be particularly useful to alter one or two traits in an elite cultivar. Hence, the present study was conducted to study the sensitivity of different traits to a mutagen in a popular rice variety BPT 2231. The traits producing lethality and injury viz., germination per cent, survival per cent, shoot length, root length and seedling height exhibited dose dependent negative and linear relationship in all the mutagenic treatment. Other biometrical traits viz., Days to 50 per cent flowering, plant height, number of tillers per plant, number of productive tillers per plant, flag leaf length, flag leaf width, panicle length, panicle weight, grains per panicle, 100 grain weight and single plant yield did not show such kind of relationship with the dose of mutagen indicating they are insensitive to all the mutagen treatment. Sensitivity of the traits to a mutagen is a crucial prerequisite for assessing growth reduction values (GR50 or GR30) to find the optimum dose of a mutagen. Hence, understanding the nature of sensitivity of a trait finds its place in an effective mutation breeding programme.

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1 Introduction

Plant breeding plays an important role in crop improvement in rice. Rice, being one of the most important cereal crop, which almost feeds half of the world's population (Tyagi et al., 2004) was a major concern for crop improvement in the later part of 19th century. Coupling crop management practices with crop varieties specific to prevailing agro-climatic conditions played a crucial role in yield maximisation. Such varieties were developed by utilising natural genetic variation through conventional breeding techniques.

Mutation breeding has been recognised as an important tool for altering the specific undesirable trait present in any elite cultivars. Mutation breeding have been used for rice improvement for various trait like plant height (Chand et al., 2005), early maturity (Haris et al., 2013) and resistance to biotic and abiotic stresses (Abdelnour-Esquivel et al., 2020; Majeed et al., 2020) etc.

The most widely used ionising radiations, gamma rays, are high energy radiations and they are sparsely ionising. They are composed of photons and can penetrate deep into the biological systems. Out of 3330 mutants registered in mutant variety database, 1671 varieties were released using gamma rays (IAEA, 2020). This shows that gamma rays mutations are more economical and can produce mutation with high frequency.

On the other hand, chemical mutagens mainly induce point mutations, unlike ionising radiations which normally produce chromosomal rearrangements and deletions (Talebi et al., 2012b). Ethyl Methane Sulfonate (EMS) is the most commonly used chemical mutagen due to its potency as a strong mutagen and the relative ease of handling compared to other mutagens.

The evaluation of genetic variability that was created in various quantitative traits as a result of these mutagens is a preliminary step and an important objective in a mutation breeding programme. Hence, understanding how every trait respond to mutagen treatment will give a clear picture about the nature of variability created in that particular trait.

A handful of studies have already been done for the exploitation of mutation breeding leading to improvement of various traits in cereals, especially rice (Aravind et al., 2019; Yasmine et al., 2019; Yunita et al., 2020). Masrurroh et al. (2016) subjected two varieties for gamma irradiation and obtained mutants with improved number of grains per panicle, 1000 grain weight and protein content. Various other agronomically important traits in rice have been improved by different mutagen treatment viz., semi dwarf stature, early maturity, profuse tillering, etc. (Chand et al., 2005). Improvement of other cereals like wheat (Nazarenko et al., 2019), barley (Akgün et al., 2019), maize (Kiruki et al., 2006), etc. have also been done using mutation breeding programme.

In the present study, rice variety BPT 2231 (Akshaya) is used to study the effect of gamma rays, EMS and its combination on

various quantitatively measured traits to analyse the sensitivity/insensitivity of the particular trait to these mutagens. The inference about the sensitivity of a trait could be an useful parameter for optimising growth reduction values of the mutagen.

2 Materials and methods

2.1. Plant Genetic Material

Akshaya (BPT 2231) the long duration, fertilizer responsive and high yielding rice variety released from Rice Research Unit, Bapatla was chosen for mutagenesis. The objective of the mutation breeding programme is to reduce the duration of the crop so that it can be used in varied cropping systems. The genetically pure seeds obtained from authenticated source at a moisture content of 12 per cent were used in the present investigation.

2.2. Mutagen Treatment

2.2.1 Gamma rays

The genetically pure and well-filled seeds of the variety Akshaya were counted and subjected to mutagen treatment. The seeds were properly packed in butter paper covers prior to mutagen treatment. The Cobalt 60 gamma radiation was given to the seeds in a gamma chamber at Indira Gandhi Centre for Atomic Research, Kalpakkam. The duration of exposure were fixed in such a way that the seeds were treated with five different doses from 100 Gy to 500 Gy with 100 Gy interval. A set of untreated seeds were retained for control. On the next day, the gamma rays exposed seeds were sown in a raised nursery bed for germination. The experiment was repeated for another lot seeds to facilitate combination treatment with EMS.

2.2.2 EMS treatment

Similar well-filled healthy seeds were counted and used for chemical mutagenesis with EMS. The seeds were pre-soaked for eight hours in double distilled water. The seeds were then treated with three different concentrations viz., 10, 20 and 30 mM of EMS. Intermittent shaking was done for every 30 minutes during the total treatment period of six hours. After the stipulated time, the seeds were exposed to running tap water to remove residual toxicity of EMS. Sowing of the treated seeds was done immediately after the treatment in a raised bed nursery for germination. A set of untreated seeds were retained for control.

2.2.3 Combination treatment

The second lot seeds that were treated with gamma rays were treated with 30 mM EMS. The different gamma rays irradiation viz., 100 Gy, 200 Gy, 300 Gy, 400 Gy, and 500 Gy gamma irradiated seeds were again treated with 30 mM EMS for combination treatment. The methodology adopted for treatment was similar to the above experiment. A set of untreated seeds were retained for control.

2.3. Experimental plot and design

The seedlings after 27 days were transplanted to the experimental plot at Agricultural College and Research Institute, Madurai during *kharif*, 2018. The experiment was laid out in RBD design with two replications adopting a spacing of 20 cm × 15 cm. Recommended package of practices were followed for maintaining the crop in a healthy state.

2.4. In vitro and field observations recorded

The traits *viz.*, germination per cent, survival per cent, shoot length, root length and seedling height were recorded in the vegetative stage of the crop, whereas other traits *viz.*, days to 50 per cent flowering, plant height, number of tillers per plant, number of productive tillers per plant, flag leaf length, flag leaf width, panicle length, panicle weight, grains per panicle, 100 grain weight and single plant yield were recorded in the crop maturity

stage. The stage in which these observations were made is particularly important to interpret the results.

2.5. Statistical analysis

The observations recorded in appropriate stages of the crop were subjected to first order statistical analysis in statistical analysis system (S.A.S)

3 Results and discussion

3.1. Effect of mutagens on lethality

The effect of mutagen on the traits producing lethality *viz.*, germination per cent and survival per cent are presented in Table 1. These traits exhibited dose dependent negative and linear relationship with the dose of the mutagen used for treatment. The increase in the dose of the mutagen resulted in decrease in the

Table 1 Effect of mutagenic treatment on lethality

Treatment	% Germination	% over control	% reduction over control	% survival	% over control	% reduction over control
Gamma rays						
Control	70.10	100.00	0.00	62.30	100.00	0.00
100 Gy	58.00	82.74	17.26	44.50	71.43	28.57
200 Gy	40.50	57.77	42.23	24.00	38.52	61.48
300 Gy	18.00	25.68	74.32	6.00	9.63	90.37
400 Gy	7.50	10.70	89.30	0.00	0.00	100.00
500 Gy	3.40	4.85	95.15	0.00	0.00	100.00
Mean	25.48	-	63.65	14.90	-	76.08
SE	11.30	-	-	10.57	-	-
EMS						
Control	70.10	100.00	0.00	62.30	100.00	0.00
10 mM	65.69	93.71	6.29	55.08	88.41	11.59
20 mM	57.85	82.52	17.48	46.31	74.33	25.67
30 mM	49.85	71.11	28.89	37.85	60.75	39.25
Mean	57.79	-	17.55	46.41	-	25.51
SE	4.46	-	-	5.31	-	-
Gamma rays + EMS						
Control	70.10	100.00	0.00	62.30	100.00	0.00
100 Gy + 30 mM	52.89	75.45	24.55	35.11	56.36	43.64
200 Gy + 30 mM	34.67	49.45	50.55	13.78	22.12	77.88
300 Gy + 30 mM	12.89	18.39	81.61	2.22	3.57	96.43
400 Gy + 30 mM	5.33	7.61	92.39	0.00	0.00	100.00
500 Gy + 30 mM	3.11	4.44	95.56	0.00	0.00	100.00
Mean	21.78	-	68.93	10.22	-	83.59
SE	11.22	-	-	10.27	-	-

values of these traits. Jiya et al. (2018) reported that disturbances caused by the mutagen at cellular and physiological levels interferes with the biological processes of the tissues and produces lethality and sterility.

The germination per cent of gamma rays treated seeds exhibited reduction, ranging from 17.26 per cent (100 Gy) to 95.15 per cent (500 Gy), while it was 6.29 per cent (10 mM) to 28.89 per cent (30 mM) in EMS treated plants. The reduction combination treatment exhibited prominent reduction in the trait and it ranged from 24.55 per cent (100 Gy + 30 mM) to 95.56 per cent (500 Gy + 30 mM). Similar findings stating dose dependent decrease in germination per cent was reported by Talebi et al. (2012b), Tyagi et al. (2004), Vasline (2013) and Raina & Khan (2020). Results of Talebi et al. (2012a) are contradictory to the findings of current study. These researchers have reported stimulatory effect of mutagen and they justified that this could be due to the activation of RNA or protein synthesis and this activation may occur at the early stage of treatment (Abdel-Hady et al., 2008).

The survival per cent of the seedlings also exhibited reduction ranging from 28.57 per cent (100 Gy) to 100 per cent (400 Gy and 500 Gy) in gamma rays treatment and while in case of EMS treatment, it ranged from 11.59 per cent (10 mM) to 39.25 per cent (30 mM). Combination treatment produced maximum reduction in survival per cent and it ranged from 43.64 per cent (100 Gy + 30 mM) to 100 per cent (400 Gy + 30 mM and 500 Gy + 30 mM). Wattoo et al. (2012) used basmati rice variety and reported similar dose dependent negative relationship of the survival per cent with dose of the mutagen. The reduction in survival may be due to inability of the mutagen treated cells to repair the damage done to them by mutagens. It could be used as an important parameter for assessing toxicity of a mutagen. A similar study indicating increased lethality at higher doses of mutagenic treatment was reported by Khah & Shaik (2020).

3.2. Effect of mutagen on injury

The effect of mutagen on traits producing injury viz., shoot length, root length and seedling height are presented in Table 2. The effects of mutagens on these traits were also similar to the above mentioned characters, exhibiting dose dependent negative and linear relationship.

Reduction was observed in length of the shoots in mutagen treated seedlings and it ranged from 11.14 per cent (100 Gy) to 89.30 per cent (500 Gy) in gamma rays treated plants, while it was 2.05 per cent (10 mM) to 17.42 per cent (30 mM) in EMS treated plants. Combination of these two mutagens exhibited maximum reduction in shoot length which ranged from 58.75 per cent (100 Gy + 30 mM) to 94.45 per cent (500 Gy + 30 mM). The findings were similar to the results obtained by Chakrabarti (1975) and Sikder et al. (2013)

The root length of mutagen treated seedlings exhibited reduction which ranged from 10.56 per cent (100 Gy) to 84.78 per cent (500 Gy) in gamma rays treated plants and 7.37 per cent (10 mM) to 8.8 per cent (30mM) in EMS treated plants. The combination treatment exhibited reduction in survival per cent ranging from 27.4 per cent (100 Gy + 30 mM) to 91.88 per cent (500 Gy + 30 mM). The results were similar to the findings of Minn et al. (2008), Ambavane et al. (2015) and Awais et al., (2019).

The reduction in shoot and root length of the seedlings may be because of reduction in mitotic activity in the meristematic tissues due to the effect of mutagen (Shakoor et al., 1978). Reduction in rapid division in meristematic tissues results in reduced length of shoots and roots. Khalil et al. (1986) suggested that gamma rays reduce moisture content in seeds and that may be the reason for reduced growth in seedlings.

After 20 days, the survival of seedlings were observed only up to 300 Gy and its combination treatments. These seedlings were subjected for further studies and used for recording biometrical observations.

Seedling height also exhibited similar results and shows reduction which ranged from 11.55 per cent (100 Gy) to 51.27 per cent (300 Gy) in gamma rays treatment and from 3.21 per cent (10 mM) to 18.46 per cent (30 mM) in EMS treatment. Combination treatment exhibited similar maximum reduction like other traits, which ranged from 45.17 per cent (100 Gy + 30 mM) to 52.57 per cent (300 Gy + 30 mM). Concomitant findings were reported by Sasikala & Kalaiyarasi (2010) and Sikder et al. (2013). Singh (1974) and Ussuf & Nair (1974) reported that mutagenic treatment causes the reduction in seedling growth because of the destruction of auxin and changes in the levels of ascorbic acid and several physiological and biochemical changes. However, the level of sensitivity of the experimental material vary with its genotype (Pérez-Jiménez et al., 2020).

3.3. Effect of mutagen on other biometrical traits

The other biometrical traits viz., Days to 50 per cent flowering, plant height, number of tillers per plant, number of productive tillers per plant, flag leaf length, flag leaf width, panicle length, panicle weight, grains per panicle, 100 grain weight and single plant yield were recorded and presented in Table 3. These traits showed both increase as well as decrease in their values among the mutagen treated plants in M_1 generation.

The number of days to 50 per cent flowering in gamma rays and EMS treatment showed reduction in number of days to 50 per cent flowering over the control. Increase in number of days to 50 per cent flowering over the control was observed in 200 Gy + 30 mM while other doses of combination treatment showed reduction in

Table 2 Effect of mutagenic treatment on injury

Treatment	Shoot Length	% over control	% reduction over control	Root length	% over control	% reduction over control	Height	% over control	% reduction over control
Gamma rays									
Control	8.41	100.00	0.00	10.51	100.00	0.00	11.84	100.00	0.00
100 Gy	7.47	88.86	11.14	9.40	89.44	10.56	10.47	88.45	11.55
200 Gy	3.74	44.47	55.53	6.38	60.70	39.30	6.51	54.98	45.02
300 Gy	3.57	42.45	57.55	4.86	46.24	53.76	5.77	48.73	51.27
400 Gy	1.60	19.02	80.98	3.40	32.35	67.65	NA*	NA*	NA*
500 Gy	0.90	10.70	89.30	1.60	15.22	84.78	NA*	NA*	NA*
Mean	3.46	-	58.90	5.13	-	51.21	7.58	-	35.94
SE	1.25	-	-	1.41	-	-	1.55	-	-
EMS									
Control	9.76	100.00	0.00	12.62	100.00	0.00	12.46	100.00	0.00
10 mM	9.56	97.95	2.05	11.69	92.63	7.37	12.06	96.79	3.21
20 mM	9.03	92.52	7.48	11.55	91.52	8.48	11.33	90.93	9.07
30 mM	8.06	82.58	17.42	11.51	91.20	8.80	10.16	81.54	18.46
Mean	8.88	-	8.98	11.58	-	8.21	11.18	-	10.25
SE	0.38	-	-	0.26	-	-	0.50	-	-
Gamma rays + EMS									
Control	11.54	100.00	0.00	11.02	100.00	0.00	13.24	100.00	0.00
100 Gy + 30 mM	4.76	41.25	58.75	8.00	72.60	27.40	7.26	54.83	45.17
200 Gy + 30 mM	4.62	40.03	59.97	6.12	55.54	44.46	6.92	52.27	47.73
300 Gy + 30 mM	4.56	39.51	60.49	4.38	39.75	60.25	6.28	47.43	52.57
400 Gy + 30 mM	0.77	6.67	93.33	3.36	30.49	69.51	NA*	NA*	NA*
500 Gy + 30 mM	0.64	5.55	94.45	0.65	8.13	91.88	NA*	NA*	NA*
Mean	3.07	-	73.40	4.50	-	58.70	6.82	-	48.49
SE	1.62	-	-	1.49	-	-	1.62	-	-

*Survival per cent of seedlings is zero and hence, individuals are not available for observation

the trait compared to control. The effect of mutagen on this trait was found to be erratic and their relationship with this trait is not defined. The current results were in agreement with the findings of Labrada Pons et al. (2001) and El-Degwy (2013)

All the mutagenic treatments studied exhibited reduction in mean plant height compared to the control. Although, initial height of the seedlings was dose dependent, the final plant height of the seedlings did not exhibit dose dependent relationship (Ashraf et al., 2003).

The number of tillers per plant in gamma rays and EMS treatment showed reduction in number of tillers compared to control (28.30). Increase in mean number of tillers over the control was observed in 200 Gy + 30 mM treatment combination dose, while other doses exhibited reduction in mean number of tillers. Results of the current study are in agreement with Harding et al. (2012).

The mean number of productive tillers per plant was found to be reduced in gamma rays treatment as well as in EMS treatment compared to the control (19.50). In case of combination treatment, increase in number of productive tillers per plant over the control was observed in 200 Gy + 30 mM treatment while, all other doses showed reduction in the trait.

The length and breadth of flag leaves were observed in mutagen treated and control plants. Surprisingly, all the mutant plants showed increased in flag leaf length in all the doses of treatment compared to control. Increase in flag leaf breadth over the control was observed in 100 Gy while all other doses in gamma rays treatment showed no increase in breadth of flag leaf compared to control (1.43 cm). In case of EMS treatment, increase in breadth of flag leaf over the control was observed in 10 mM treatment. The flag leaf breadth in 100 Gy + 30 mM combination treatment showed neither increase nor decrease in the value, but other doses exhibited reduction over the control.

Table 3 Effect of mutagenic treatment on various quantitative traits

Treatment	DFE	%over control	PH	%over control	NT	%over control	NPT	%over control	FL	%over control	FB	%over control	PL	%over control	PW	%over control	GPP	%over control	100	%over control	SPY	%over control
Gamma rays																						
Control	119.00	100.00	111.53	100.00	28.30	100.00	19.50	100.00	22.10	100.00	1.43	100.00	25.47	100.00	2.72	100.00	213.90	100.00	1.82	100.00	34.06	100.00
100 Gy	114.00	95.80	109.84	98.48	20.03	70.79	14.20	72.82	28.68	129.76	1.48	103.73	24.14	94.78	2.37	87.13	178.53	83.47	1.79	98.67	29.16	85.61
200 Gy	117.00	98.32	109.39	98.08	26.71	94.40	18.71	95.97	26.71	120.88	1.40	97.90	25.37	99.61	1.97	72.48	168.50	78.78	1.72	94.76	25.08	73.63
300 Gy	117.00	98.32	105.38	96.34	24.50	86.57	17.08	87.61	25.36	114.74	1.39	97.32	24.52	96.26	1.24	45.65	174.00	81.35	1.71	93.96	19.91	58.45
Mean	116.00		108.20		23.75		16.67		26.92		1.43		24.68		1.86		173.68		1.74		24.72	
SE(X)	1.00		1.42		1.96		1.32		0.96		0.03		0.36		0.33		2.90		0.03		2.68	
EMS																						
Control	119.00	100.00	111.53	100.00	28.30	100.00	19.50	100.00	22.10	100.00	1.43	100.00	25.47	100.00	2.72	100.00	213.90	100.00	1.82	100.00	34.06	100.00
10 mM	112.00	94.12	110.95	99.48	17.57	62.07	12.03	61.71	30.64	138.63	1.46	102.10	26.33	103.36	2.50	92.03	196.87	92.04	1.84	101.24	30.65	89.98
20 mM	113.00	94.96	109.61	98.28	21.70	76.68	14.87	76.24	30.86	139.65	1.41	98.60	24.49	96.17	2.25	82.60	211.10	98.69	1.79	98.62	26.80	78.68
30 mM	114.00	95.80	106.15	95.17	23.30	82.33	16.13	82.74	28.02	126.77	1.33	93.01	23.54	92.42	2.06	75.74	189.10	88.41	1.81	99.56	22.89	67.20
Mean	113.00		108.90		20.86		14.34		29.84		1.40		24.79		2.27		199.02		1.81		26.78	
SE(X)	0.58		1.43		1.71		1.21		0.91		0.04		0.82		0.13		6.44		0.01		2.24	
Gamma rays + EMS																						
Control	119.00	100.00	111.53	100.00	28.30	100.00	19.50	100.00	22.10	100.00	1.43	100.00	25.47	100.00	2.72	100.00	213.90	100.00	1.82	100.00	34.06	100.00
100 Gy+30 mM	118.00	99.16	107.59	96.46	27.86	98.44	19.43	99.63	23.59	106.72	1.43	99.90	25.23	99.05	2.37	87.18	206.29	96.44	1.85	101.72	28.37	83.30
200 Gy+30 mM	124.00	104.20	98.23	88.08	29.67	104.83	20.67	105.98	28.17	127.45	1.40	97.90	19.50	76.56	2.23	82.11	218.33	102.07	1.73	95.43	24.83	72.91
300 Gy+30 mM	118.00	99.16	108.47	97.25	24.83	87.75	17.17	88.03	25.43	115.08	1.40	97.90	24.58	96.52	1.18	43.50	209.67	98.02	1.81	99.85	19.12	56.13
Mean	120.00		104.76		27.45		19.09		25.73		1.41		23.10		1.93		211.43		1.80		24.11	
SE(X)	2.00		3.27		1.41		1.02		1.33		0.01		1.81		0.38		3.59		0.03		2.70	

DEF- Days to 50% flowering; **PH**- Plant height; **NT**- Number of tillers; **NPT**- Number of productive tillers; **FL**- Flag leaf length; **FB**- Flag leaf breadth; **PL**- Panicle length; **PW**- Panicle weight; **GPP**- Grains per panicle; **100**- Hundred grain weight; **SPY**- Single plant yield

Figure 1 Vegetative stage traits Vs Reproductive stage traits; a. Pareto chart showing treatments with decreasing order of their treatment data for traits viz., germination per cent, survival per cent, shoot length, root length and seedling height; b. Pareto chart showing decreasing order of their treatment data for traits viz., Days to 50 per cent flowering, plant height, number of tillers per plant, number of productive tillers per plant, flag leaf length, flag leaf width, panicle length, panicle weight, grains per panicle, 100 grain weight and single plant yield.

The panicle length in gamma rays treatment and combination treatment exhibited reduction over control in all the doses of the treatment, while, in case of panicle length in EMS treated plants, increase in mean length of panicles over the control was observed in 10 mM treatment and all other doses exhibited reduction in length of the panicles over the control.

The weight of a panicle in all the mutagenic treatment showed reduction in the trait compared to control. It exhibited dose dependent negative relationship with the dose of the mutagen in all the mutagenic treatments. The reduction in the weight with increasing dose of the mutagen may be attributed to production of increased sterile spikelets at higher doses. The results obtained from the current study were in agreement with the findings of Gowthami et al. (2016).

The number of grains per panicle in gamma rays treated plants as well as EMS treated plants showed reduction in number of grains per panicle over the control (213.90) in all the treatment doses. The reduction in number of grains per panicle over the control was observed in 100 Gy + 30 mM and 300 Gy + 30 mM combination treatment while increase in the number of grains per panicle over the control was observed in 200 Gy + 30 mM treatment. The results from previous findings (Imam & Chakraborty, 2018) also suggest that there is a lack of relationship between dose of mutagen and the number of grains per panicle.

Increase in mean hundred grain weight over the control (1.82) was observed in 100 Gy treatment while other doses showed reduction in mean hundred grain weight over the control. The hundred grain weight in 10 mM EMS treatment exhibited increase in the value, while, all other doses exhibited reduction in weight over the control. Reduction in hundred grain weight over the control was

observed in 200 Gy + 30 mM treatment while all other doses were similar to the control. A similar result was obtained by Masrur et al. (2016). They used two rice varieties and reported increase as well as decrease in the mean grain weight, when the gamma rays dose was increased from 100 Gy to 500 Gy. They concluded that irradiation with 200 Gy gamma could be used for the improvement of grains per panicle and 1000 grain weight.

The single plant yield in all the mutagenic treatment exhibited dose dependent negative and linear relationship with the dose of the mutagen. The reduction in this trait may also be attributed to the increased number of sterile spikelets at higher doses of the treatment. The results were in agreement with the findings of El-Degwy (2013).

All these biometrical traits that were taken in the later stages of the crop do not show any dependency to the mutagen treatment. The dependency of panicle weight and single plant yield may also however be attributed to increased number of sterile spikelets. Akilan et al. (2019) have also reported such increase in the number of sterile spikelets with increasing dose of the mutagen. Insensitivity of these traits may be due to efficient repair mechanisms that plants adopt to eliminate the toxic effects of mutagen. Hence, traits that are observed in later stages of the crop do not exhibit sensitivity to any mutagen. The results of the current study were in agreement with the previous findings of Desai et al. (2018), Imam & Chakraborty (2018) and Gowthami et al. (2016).

The sensitivity behaviour of traits recorded in vegetative stage Vs reproductive stage were compared and depicted using Figure 1. The treatment data were placed in decreasing order in these pareto chart. The treatment doses increases as their value decreases in figure 1a, whereas, treatment doses were irregular as the treatment value decreases in figure 1b.

Conclusion

Different traits were observed in the mutagen treated plants to study the sensitivity of the traits to the mutagen in the popular variety BPT 2231. In this view, the observations were recorded in the M₁ generation in two different crop growth stages, early vegetative stage and maturity stage. It was concluded that, traits observed in the early vegetative stage exhibited dose dependent negative and linear relationship, while, the traits observed in maturity stage did not show such relationship in all the mutagenic treatments. This may be attributed to efficient repair mechanisms to eliminate the toxic effects of mutagen in treated plants.

The knowledge about the sensitivity and insensitivity of the traits are very crucial for assessing growth reduction values (GR50 or GR30) to find the optimum dose of mutagen. There is no point in calculating optimum dose of a mutagen using insensitive traits as a measure. Hence, traits showing sensitivity to a mutagen viz., germination per cent, survival per cent, shoot length, root length and seedling height, have to be used for fixing GR values to find the optimum dose of a mutagen.

Author's contributions

GA and MA conceived the work and designed the experiments. MA mutated the seed material and performed the experiments. CV, ES and KA provided advice on experiments. MA analysed the results. MA and GA wrote and revised the manuscript.

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Conflict of interest

The authors declare that they have no conflict of interest

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