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Gamma radiation effects on seed quality parameters of sorghum (*Sorghum bicolor* L. Moench)

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Abstract
A lab experiment was conducted during 2015-16 at Department of Seed Science and Technology, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad to study the influence of gamma radiation doses generated from ^{60}Cosource of Gamma chamber 5000 on seed quality parameters of sorghum varieties. The experiment was laid out in completely randomised design (CRD) with factorial concept with eighteen treatments in combination of three sorghum cultivars (CSH14- *Kharif* hybrid, C43- *Kharif* parental line and CSV29R- *Rabi* variety) and six gamma dose (T_0- Control, T_1- 250 Gy, T_2- 500 Gy, T_3- 750 Gy, T_4- 1000 Gy and T_5- 2000 Gy) with four replications. Seed quality parameters viz., germination percentage, field emergence, speed of germination, root length, shoot length and seed vigour index were evaluated immediately after irradiation and up to nine months under storage at ambient conditions.

Marked significance of interaction effects was recorded for various seed quality parameters studied immediately after exposing the seed to selected doses of gamma rays. The results indicated that gamma doses up to 750 Gy were found to exercise positive influence in enhancing all the germination, seedling and biochemical parameters. However, this gamma radiation differed significantly in their response and registered variable values for seed quality parameters. The doses beyond 750 Gy had detrimental effect by interfering with various seed quality attributes.

The analysis of bimonthly data at four intervals on seed storage potential up to nine months indicated significant influence of storage period on all the seed quality parameters including seed health. Marked decline in germination percentage, seedling dimensions and corresponding vigour index was noticed over a period of nine months. Among germination and seedling traits studied, vigour index and root and shoot length were the most sensitive seed quality parameters affected by ageing due to storage under ambient conditions, which registered higher reduction at the end of nine months. These traits can serve as reliable parameters for assessing seed quality under the influence of gamma radiation.

Keywords: Gamma radiation, seed quality parameters, germination percentage, seed vigour index, field emergence

Introduction
Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most consumed staple cereal globally and over 80% of its cultivation lies in resource poor ecosystems. Sorghum is inherently high in protein and yields well in subsistence farming environments. The crop is capable of tolerating lower inputs and more marginal field conditions. World area under sorghum is 40.67 million ha with a production of 57.60 million tonnes and productivity of 1416 kg ha^{-1} (FAOSTAT, 2017). In India, sorghum has 5.71 million ha area with a production of 4.80 million tonnes and average yield of 840 kg ha^{-1} (DoES, 2018) [6]. Given its natural tolerance to heat and drought stress, sorghum is a key crop in providing food security for millions of people in the developing world. Recent projections of sorghum based foods by health care professionals as an alternative to check life style diseases, have further enhanced the importance of this crop. The nutrient composition of sorghum indicates that it is a good source of energy, proteins, carbohydrates, vitamins and minerals. As demand for sorghum is increasing, it is essential to increase the productivity. Quality seed is key input for realizing of high yield in sorghum.

In tropics, 60-80 % of harvested sorghum seed is stored on farms or in villages by the farmers (Compton *et al.* 1993) [5]. The qualitative loss in stored seed is attributed to change in bio-chemical components such as carbohydrates, starch and proteins.

The commercial value of the seed is reduced by contamination with uric acid, insect body fragments, dead body of insects and other toxic substances and also, it exposes the seeds to attack by storage fungi. These predisposing conditions have made the storage aspect of jowar seed as an emerging challenge.

Seed quality is a complex concept comprising several physical, chemical and biological components. Seed being a biological entity, deterioration in its quality is inevitable, irreversible and actually commences immediately after attaining physiological maturity even on the mother plant itself (Helmer *et al.* 1962) [8].

Maintenance of seed viability and vigour during storage is a matter of prime concern in tropical and subtropical countries. Owing to the prevailing tropical climate, seeds of most crop species show rapid deterioration and jowar is no exception. With the development of organized seed production and marketing system, seedmen are becoming aware of the problems of seed storage and there by systematic research needs to be initiated. However, when the awareness and infrastructure develops, substantial quantity of seed may be stored for few planting seasons as a safeguard against monsoon failure, natural calamities, market demands and other exigencies.

In this context, effective and environmentally friendly storage methodologies with minimum interference with seed quality and storability parameters would be of immense practical utility. In many countries both fumigation with chemicals and heat sterilization have been applied with varying degree of success. However, such applications are hidden with disadvantages like toxic residue accumulation leading to potential environmental hazards and altering storage potential of seed. Hence, gamma radiation administered at selective sub lethal doses can be projected as an effective technology to sanitize the seed before storage and to minimize deterioration of seed quality and storability. Gamma rays possess high penetrating characteristics and prevent re-contamination or re-infection of sterilized sample. Effectiveness of selected sub lethal gamma dose in maintaining the sorghum seed quality parameters during an extended period of ambient storage under farmer's condition need to be ascertained.

Further, to improve the efficiency of gamma rays in terms of extending shelf life, the side effects of stress created by radiation exposure needs to be countered. The free radical generation associated with radiation stress may have to be curtailed by appropriate seed enhancement technology.

Therefore, the present study is proposed to investigate changes in seed quality parameters of promising jowar varieties at different doses of gamma radiation stored under ambient conditions.

Materials and Methods

The study was carried out at Dept. of Seed Science & Technology, PJTSAU and Indian Institute of Millet Research (IIMR), Rajendranagar during 2015-2016 season. Breeder seed of sorghum varieties viz., CSV 29R (*Rabi* variety), C 43 (*Kharif* parental line), and CSH 14 (*Kharif* hybrid) were used for the experimental purpose, which was procured from Indian Institute of Millets Research, Rajendranagar, Hyderabad.

Gamma chamber 5000 was used for giving radiation treatments. It is compact shelf shielded ^{60}Co gamma irradiator providing an irradiation volume of approximately 5000cc. The material for irradiation was placed in an irradiation chamber located in vertical drawer inside the Lead flask. This drawer can be moved up and down with the help of a system of motorized drive, which enables precise positioning of the irradiation chamber at the centre of the irradiation field. Radiation field was provided with service sleeves for grasses, thermocouple, etc. Mechanism for rotating / stirring samples during irradiation is also incorporated. The Lead shield provided around the source was adequate to keep the external radiation field well within permissible limits. The quantity absorbed radiation dose (KGy) can be defined as the amount of energy absorbed per unit mass of the matter at the point of interest.

Seeds of sorghum variety *viz.*, CSV 29R, C 43 and CSH 14 weighing 400 g for each treatment was packed in HDPE bag (400 gauge) was exposed to selected doses of gamma radiation in GC 5000 radiation chamber with^{60}COsource having 1.96 KGy hr^{-1} dose rate.

Treatments

1. CSH 14/0 Gy	7. C 43/0 Gy	13. CSV 29R/0 Gy
2. CSH 14/250 Gy	8. C 43/250 Gy	14. CSV 29R/250 Gy
3. CSH 14/500 Gy	9. C 43/500 Gy	15. CSV 29R/500 Gy
4. CSH 14/750 Gy	10. C 43/750 Gy	16. CSV 29R/750 Gy
5. CSH 14/1000 Gy	11. C 43/1000 Gy	17. CSV 29R/1000 Gy
6. CSH 14/2000 Gy	12. C 43/2000 Gy	18. CSV 29R/2000 Gy

Initial data on seed quality was generated immediately after irradiation during 1st month and four periodical observations at bi-monthly intervals on storability parameters were generated during 3rd, 5th, 7th and 9th month for a period of nine months after storage and the changes during storage were recorded with respect to following parameters.

Germination test was conducted on pure seed fraction using 100 seeds in four replicates following between paper (BP) method at 25^{0}C temperature and 93$\pm$2 per cent relative humidity (ISTA, 2005). The germinated of normal seedlings were counted on 4th day (first count) and 10th day (final count) of germination from all the replications. The germination per cent was calculated based on the number of normal seedlings produced.

$$\text{Germination (\%)} = \frac{\text{Number of seed germinated}}{\text{Total number of seeds kept for germination}} \times 100$$

Field emergence potential of seeds from each treatment was measure as per the method suggested by Shenoy *et al.* (1990). Four hundred seeds in each treatment were sown in four replications of hundred seeds each on raised bed (4 x 1 m) of red loamy soil with a spacing of 10 cm between the rows. The number of seeds germinated in each row was calculated on 10th day and field emergence (%) was computed using the following formula,

$$\text{Field emergence (\%)} = \frac{\text{Number of seed germinated}}{\text{Total number of seeds sown}} \times 100$$

Germination test was conducted in four replicates of 100 seeds each by adopting top paper method at 25^{0}C temperature and 93$\pm$2 per cent relative humidity. Daily germination counts were performed until no further germination was observed. An index of the speed of germination was then calculated by adding the quotients of the daily counts divided by the number of days of germination (Maguire, 1962) [13].

$$\text{Speed of germination} = \sum (n/t)$$

Where, n = Number of seeds newly germinating at time 't'
t = Days from sowing

Ten normal seedlings were selected at random from each replication on the 10^{th} day (final count) from germination test and used for measuring shoot length. The shoot length was measured from the collar region to the tip of the apical bud. The mean shoot length was expressed in centimeters.
Vigour index of the seedlings obtained from the germination test was calculated using the formula suggested by Abdul-Baki and Anderson (1973) [1].

Seedling vigour index = Percentage of seed germination x Mean seedling length (cm)

The data generated were subjected to analysis of variance as per factorial experiment laid out in completely randomized design to test the significance of various treatments evaluated in the experiment as per Gomez and Gomez (1984).

Results and Discussion

In tropical regions of sorghum cultivation, major part of harvested sorghum seed is stored traditionally on farms or in villages by the farmers, thus reducing the prospects of reasonably long period of storage without losing seed quality attributes. The qualitative loss in stored seed is attributed to degradation of bio- chemical components such as carbohydrates, starch and proteins, apart from being attacked by various storage biotic stresses. These predisposing conditions have made the storage aspect of jowar seed as an emerging challenge necessitating designing cost effective and efficient storage protocols.
Mean data collected on germination percentage, speed of germination, root length, shoot length, seedling length and seedling vigour index were analyzed. The results indicated that the treatments were highly significant for all the parameters studied. The results indicated significant differences among the treatments in comparison to general mean for all the parameters studied (Table 1).

Table 1: Mean values for seed quality parameters immediately after gamma exposure

Variety x Dosage	Germination (%)	Speed of Germination	Field emergence (%)	Root Length (cm)	Shoot Length (cm)	Seedling vigour index
CSH 14 : 0 Gy	87**	44.2**	75**	14.3**	15.8**	1343**
CSH 14 : 250 Gy	81	43.3**	65**	4.8	5.8	441
CSH 14 : 500 Gy	88**	45.3**	73**	11.0**	11.5**	1001**
CSH 14 : 750 Gy	86	44.5**	71**	9.0**	10.5**	894**
CSH 14 : 1000 Gy	76	39.7	34	2.8	3.5	268
CSH 14 : 2000 Gy	71	30.7	18	1.7	2.5	161
C 43 : 0 Gy	89**	42.7**	79**	14.3**	14.8**	1272**
C 43 : 250 Gy	85	35.3	66**	4.7	5.5	470
C 43 : 500 Gy	89**	41.9**	76**	9.3**	10.8**	954**
C 43 : 750 Gy	87**	40.4	74**	8.5**	9.3**	803**
C 43 : 1000 Gy	80	33.7	38	2.5	2.5	198
C 43 : 2000 Gy	77	31.8	20	1.9	2.3	178
CSV 29R : 0 Gy	90**	41.2**	82**	15.3**	15.4**	1396**
CSV 29R : 250 Gy	85	37.8	68*	7.1	7.8	674
CSV 29R : 500 Gy	90**	42.4**	80**	13.5**	15.4**	1386**
CSV 29R : 750 Gy	88**	41.7**	77**	12.8**	14.8**	1309**
CSV 29R : 1000 Gy	81	38.9	43	3.6	3.7	302
CSV 29R : 2000 Gy	78	35.9	22	2.8	2.7	217
General Mean	83	39.3	59	7.6	8.7	737
CV %	2.019	2.062	3.541	3.679	3.172	3.531
SEm±	0.841	0.406	1.038	0.107	0.134	13.015
C.D. 5%	2.388	1.151	2.943	0.303	0.381	36.895
C.D. 1%	3.180	1.533	3.919	0.403	0.507	49.135

** Significant at 1% level

Germination parameters

Germination parameters are good indicators of field performance of a seed lot. Laboratory based germination data provides an estimate of seed viability under optimum conditions. In the present investigation, mean germination percentage ranges from 71.0 to 90.0 % among different treatments (Table 1). Maximum values were noticed in CSV 29R irradiated with 0 Gy (90.0 %) followed by CSV 29R: 500 Gy, C 43: 0 Gy and C 43: 500 Gy. Lowest germination percent of 71.0 was recorded in CSH 14 with 2000 Gy irradiation. Further, the results also indicated that the germination percentage at 0 Gy dose was higher than all the gamma doses in all the three varieties. Similar findings were reported by Singh and Singh (2005) who reported that seed treated with different gamma doses (0.05, 0.10, 0.25 and 0.50 kGy) in four rice cultivars (Moirangphou, Tombung, KD-2-6-3 and RCM-5) showed highest percentage of germination at 0.10 kGy or 100 Gy. Further, significant decrease in germination per cent with increasing gamma dose was noticed in the present study. The results were in accordance with research findings of Chaudhary (2002) who reported that at higher radiation dose, germination percentage reduced, while, at lower dose *i.e.*, 0.10 kGy the germination percentage was not significantly different from 0 Gy or control.
It is evident that all sorghum varieties in the present study showed higher germination percentage at gamma doses 0 Gy followed by 500 and 750 Gy which could be attributed to stimulatory effect (Hormesis). Hormesis is a phenomenon of excitation or stimulation by small doses of any agent in any system. The beneficial effect of hormesis has been well documented in many plant species of agricultural importance (Kim *et al.*, 2005). The stimulatory effects of γ-rays on germination could be attributed to the activation of RNA synthesis or protein synthesis which occurred during initial stage of germination after seeds were irradiated. The inhibitory effect on germination at higher doses of γ-rays

could be due to several reasons like histological and cytological changes, disruption and disorganization of seed layer and generation of free radicals resulting in metabolic disorders in the germinating seeds which is directly proportional to the intensity of exposure to γ-rays (Lokesha *et al*., 1992) [12].

In the present study also, germination percentage decreased with increasing gamma dose as reported earlier by many research workers (Albokari *et al*., 2012). Further, the data on germination was validated with field emergence percentage as it is gives a true reflection of seed's ability to germinate under field conditions overcoming various impedances. Twelve treatments *viz.* CSV 29R/0, 500 Gy, 750 Gy, C 43/ 0 Gy, 250 Gy, 500 Gy, 750 Gy and CSH 14/0 Gy, 250 Gy, 500 Gy, 750Gy recorded significantly higher field emergence than general mean (59%). The treatments ranged from 17.0 per cent (CSH 14/2000 Gy) to 82.0 per cent (CSV 29R/0 Gy) which were significantly different (Table 1, 2 and 3).

Table 2: Mean values for seed quality parameters of irradiated sorghum varieties during storage period

Variety x Gamma doses	Germination (%)				Speed of germination				Field emergence (%)			
	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month
CSH 14 : 0 Gy	81	69	63	59	40.9**	32.6**	29.8**	25.6**	74**	69**	62**	58**
CSH 14 : 250 Gy	78	75	66	62	41.4**	33.7**	26.7	24.1**	63**	59**	53**	51**
CSH 14 : 500 Gy	81	77**	70**	66**	44.8**	38.3**	32.5**	30.6**	71**	68**	66**	63**
CSH 14 : 750 Gy	79	76	67	64	43.3**	37.8**	31.8**	29.4**	69**	66**	64**	60**
CSH 14 : 1000 Gy	73	71	65	61	36.4	31.5	24.3	21.9	31	28	22	18
CSH 14 : 2000 Gy	66	63	59	49	29.6	28.6	24.6	21.5	17	16	14	14
C 43 : 0 Gy	83 **	71	63	60	37.4	30.8	26.6	20.8	77**	72**	64**	59***
C 43 : 250 Gy	79	76	67	62	33.8	28.7	24.7	21.7	64**	61**	55**	52**
C 43 : 500 Gy	84 **	78**	72**	68**	40.8**	34.3**	29.5**	26.4**	75**	71**	68**	67**
C 43 : 750 Gy	82 **	77**	69	66**	39.5**	33.7**	28.6**	24.7**	74**	69**	67**	64**
C 43 : 1000 Gy	75	72	67	63	32.7	28.9	24.4	22.3	36	31	27	22
C 43 : 2000 Gy	66	65	60	52	30.7	27.8	21.7	18.7	19	18	17	15
CSV 29R : 0 Gy	83 **	74	66	62	37.3	27.9	25.7	20.5	79**	73**	60**	57**
CSV 29R : 250 Gy	81	77**	69	63	35.2	26.9	22.8	19.9	66**	63**	53**	52**
CSV 29R : 500 Gy	85 **	80**	71**	70**	41.4**	37.9**	25.5	23.9	78**	73**	66**	65**
CSV 29R : 750 Gy	82 **	77**	69	68**	40.9**	36.8**	24.6	22.3	76**	71**	64**	62**
CSV 29R : 1000 Gy	78	73	66	64	36.7	23.9	21.6	18.9	42	36	24	20
CSV 29R : 2000 Gy	67	65	63	54	32.7	20.9	21.3	18.7	20	18	15	13
General Mean	78	73	66	62	37.4	30.9	25.8	22.1	57.2	53	48	45
SEm±	0.935	0.921	0.899	0.903	0.474	0.357	0.398	0.325	0.929	1.071	0.979	0.840
CV %	2.406	2.525	2.718	2.928	2.533	2.303	3.075	2.845	3.251	4.017	4.096	3.739
CD (5%)	2.652	2.611	2.548	2.559	1.343	1.011	1.128	0.920	2.632	3.036	2.775	2.382
CD (1%)	3.532	3.477	3.393	3.408	1.788	1.346	1.502	1.225	3.506	4.043	3.696	3.172

** Significant at 1% level

Table 2 (Cont.....): Mean values for seed quality parameters of irradiated sorghum varieties during storage period

Variety x Gamma doses	Root length (cm)				Shoot length (cm)				Seedling Vigour Index			
	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month	1st Bi-month	2nd Bi-month	3rd Bi-month	4th Bi-month
CSH 14 : 0 Gy	13.5**	12.8**	9.6**	8.5**	15.4**	12.6**	10.4**	8.8**	1267**	886**	661**	503**
CSH 14 : 250 Gy	4.6	3.4	2.8	2.5	4.8	4.8	3.8	2.8	346	314	255	175
CSH 14 : 500 Gy	10.5**	9.8**	7.9**	7.3**	10.6**	9.5**	9.5**	8.8**	868**	768**	649	569**
CSH 14 : 750 Gy	9.5*	8.8**	7.6**	7.8**	8.3	7.8	7.5	6.5**	673	567**	512**	411
CSH 14 : 1000 Gy	2.5	1.7	1.2	0.9	2.8	2.8	1.7	1.5	184	171	117	93
CSH 14 : 2000 Gy	1.3	1.3	0.4	0.4	1.8	1.3	1.6	1.3	123	108	95	63
C 43 : 0 Gy	14.8**	12.6**	9.6**	9.9**	13.8**	12.8**	10.5**	8.4**	1157**	927**	674**	518**
C 43 : 250 Gy	5.5	4.3	3.8	2.5	5.8	4.7	3.9	3.3	421	366	269	207
C 43 : 500 Gy	9.7**	7.9**	7.7**	6.5**	10.3**	10.3**	8.8**	7.9**	872**	798**	607**	541**
C 43 : 750 Gy	8.8**	6.7**	6.3**	5.5**	9.8**	7.8**	7.7**	6.7**	766**	603**	543**	447**
C 43 : 1000 Gy	1.8	1.8	1.3	0.9	2.8	1.9	1.5	1.8	187	140	104	93
C 43 : 2000 Gy	1.7	1.3	0.8	0.8	2.5	1.6	1.4	1.2	144	108	87	63
CSV 29R : 0 Gy	14.5**	12.8**	10.8**	9.4**	15.8**	13.7**	11.6**	9.5**	1307**	1026**	777**	601**
CSV 29R : 250 Gy	6.5	5.7	5.5	4.3	7.6	7.5	6.5	5.6	620	560	454	357
CSV 29R : 500 Gy	13.7**	11.8**	10.8**	9.5**	15.6**	13.6**	12.8**	10.8**	1332**	1093**	913**	759**
CSV 29R : 750 Gy	13.5**	10.3**	9.8**	8.8**	14.8**	12.5**	11.0**	8.5**	1231**	970**	763**	590**
CSV 29R : 1000 Gy	2.8	2.8	1.8	1.5	2.8	2.5	2.7	2.8	202	189	180	158
CSV 29R : 2000 Gy	1.8	1.6	1.5	1.3	2.0	2.3	2.8	2.3	156	153	157	127
General Mean	7.5	6.3	5.3	4.8	8.6	7.8	6.8	5.9	659	542	434	349
SEm±	0.107	0.082	0.095	0.075	0.171	0.135	0.120	0.124	17.117	11.379	10.431	10.546
CV %	2.848	2.601	3.488	3.117	4.240	3.763	3.747	4.579	5.197	4.203	4.804	6.049
CD (5%)	0.303	0.233	0.268	0.214	0.484	0.383	0.339	0.350	48.525	32.258	29.572	29.897
CD (1%)	0.403	0.311	0.357	0.285	0.645	0.510	0.452	0.466	64.622	42.960	39.382	39.815

** Significant at 1% level

Speed of germination provides good validation of seed vigour enabling categorization of strong and weak seedlings. Eleven treatments *viz*., CSH 14/ 0 Gy, 250 Gy, 500 Gy, 750 Gy, 1000 Gy, C 43/ 0 Gy, 500 Gy, 750 Gy, CSV 29R/0 Gy, 500 Gy 750 Gy were significantly superior over general mean of 39.3 (Table 1, 2 and 3). Highest speed of germination (45.3) was recorded in the treatment CSH 14/ 500 Gy and lowest (31.8) was noticed at 2000 Gy in C 43 variety. Significance of gamma doses in influencing speed of germination was evident from the results. The influence of gamma radiation on speed of germination in all genotype was same as it was on germination. Speed of germination at 500 Gy was higher than 0 Gy and decreased with increasing dose up to 2000 Gy in all sorghum genotypes. The results were in conformity with research findings of Silva *et al*. (2011) in which rice seeds of BRS Querência and BRS Fronteira were irradiated at the doses of 0, 50, 100, 150 and 200 Gy and the former showed a higher speed of germination in comparison to the latter variety at lower radiation doses (50 and 100 Gy). Further it was reported that, the cultivar BRS Fronteira, however, showed decrease in speed of germination at a dose of 200 Gy which was similar to the result in the present study, this could be due to the enhanced rate of respiration or auxin metabolism in seed.

Seedling parameters

Seedling length is widely used as an index in determining the biological effects of various physical and chemical mutagens. The results of the present study showed that the seedling length decreased with the increase in the irradiation dose and was directly proportional to dose increment.

Nine treatments *viz*., CSV 29R/ 0 Gy, 500 Gy, 750 Gy, CSH 14/ 0 Gy, 500 Gy, 750 Gy and C 43/ 0 Gy, 500 Gy, 750 Gy, recorded significantly higher root length than general mean of 7.6 cm (Table 1,2 and 3). The values ranged from 1.7 cm (CSH 14/ 2000 Gy) to 15.2 cm (CSV 29R / 0 Gy). Significant influence of gamma doses was observed in the expression of root length. But all doses exhibited inhibitory effect on root length, which was less than that of 0 Gy. Maximum root length of 15.2 cm was observed at 0 Gy and lowest mean root length was recorded at 2000 Gy (1.7 cm). Pathak and Patel (1988) reported that radiation effects on root length varied significantly among varieties. In present study also root length significantly differed among varieties. Lower reduction of root length was observed in case of CSV 29R and CSH 14 compared to C43. Similar results were reported by Borzouei *et al.* (2010) [10] and Silva *et al*. (2011) [17]. Gamma radiation showed inhibitory effect on root length at all gamma doses in comparison to non- irradiated sample. Root length had decreased with increasing dose of gamma in all interactions which could be due to reduced mitotic activity in meristematic tissues and cell arrest at G2 / M phase during somatic cell division as was earlier reported by Preussa and Britta (2003) [15].

General mean of shoot length was 8.4 cm and nine treatments *viz*., CSV 29R/ 0 Gy, 500 Gy, 750 Gy, CSH 14/ 0 Gy, 500 Gy, 750 Gy, and C 43/ 0 Gy, 500 Gy, 750 Gy showed significant superiority over others (Table 1,2 and 3). Maximum shoot length was recorded in case of CSV 29R / 0 Gy and 500 Gy (15.4 cm) and lowest in case of C 43 / 2000 Gy (2.3 cm). Shoot length for all doses was less than 0 Gy (14.9 cm). However, maximum shoot length of 12.5 cm was observed at 500 Gy and lowest mean of shoot length was recorded at 2000 Gy (2.4 cm) indicating the inhibitory effect of gamma dose on development of shoot growth. Significant influence of varieties was also noticed for shoot length. Maximum length of 10.0 cm was observed in CSV 29R and lowest shoot length (7.7 cm) in C 43 variety.

Further, in the present study shoot length had decreased with increasing dose of gamma in all three selected sorghum variety. This may be attributed to increase in plant sensitivity to gamma rays leading to reduced amount of endogenous growth regulators, especially cytokinins, due to break down, or lack of synthesis (Kiong *et al*., 2008) [11]. This was also earlier confirmed that gamma radiation had inhibitory effect on shoot length due to reduced mitotic activity in meristematic tissues in seeds.

Seedling vigour index quantifies the early efficiency of the seedling to optimum utilization of available resources and finally gives an indication about probable plant height at later crop phenology. Further, this parameter captures the variability encountered during the process of germination and early seedling growth. In the present investigation highest vigour index was recorded at 0 Gy in species CSV 29R (1396) followed by CSV 29R/ 500 Gy (1386). Nine treatments *viz*., CSV 29R/ 0 Gy, 500 Gy, 750 Gy, CSH 14/ 0 Gy, 500 Gy, 750 Gy, and C 43/ 0 Gy, 500 Gy, 750 Gy were significantly superior (Table 1, 2 and 3).

As observed in other seedling parameters, vigour index was significantly influenced by gamma doses. Highest seedling vigour index was noticed at 500 Gy (1114) which was inferior to 0 Gy (1337). However, higher gamma dose of 2000 Gy recorded significantly lower vigour index value of 186 (Table 1, 2 and 3). Further, the results also indicated variation among varieties, maximum value was recorded in CSV 29R (881) and lowest value in C 43 variety (646). Significantly superior vigour index values indicates their ability to germinate well and project good seedling growth under the stressful conditions created by gamma exposure.

Conclusion

From the results of the study it could be concluded that, gamma doses 500 and 750 Gy showed superiority in influencing all the seed quality parameters positively during storage. Irradiation effect during storage in terms of maintenance of seed quality particularly the germination percentage above Minimum Seed Certification Standards prescribed for the crop, indicated that at 500 Gy CSV 29R, C 43 and CSH 14 could maintain minimum germination standards above 70 % and 75% for 7 and 5 months respectively. The superior combinations identified in this storability study can be further validated for commercial application.

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