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Gamma radiosensitivity study on papaya cv. Ranchi local & Arka Surya

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Abstract
An investigation was carried out at Horticulture Research Station, Odisha University of Agriculture & Technology, Bhubaneswar, Odisha, India during 2016-2019 to study on “radiosensitivity study on papaya”. The experiment was laid out in a Factorial Randomized Block Design with three levels *viz* two varieties, two soaking conditions and seven different gamma doses. Cobalt 60 source in gamma chamber was used to treat papaya seeds at the Radiation Standards Section, Radiation Safety Systems Division, Bhabha Atomic research Centre in Mumbai, India. In the preliminary dosimetry study, seeds from two papaya varieties, Ranchi Local and Arka Surya were irradiated with 7 different radiation doses ranging from 10 Gy to 70 Gy at every interval of 10 Gy. The source of radiation in the chamber is Co^{60}, which emits 2 gamma radiation of energy 1.33 and 1.17 MeV per disintegration. The dose rate was of the order of 17 Gy/min. Prior to irradiation in one experiment, seeds were soaked overnight in water and surface-dried and in another experiment, seeds were immersed in water during irradiation. Increasing gamma ray decreased germination percentage, shoot length, plant height (reduction of 49.7% over control), bearing height (reduction of 62.6% over control) in papaya whereas gamma rays enhance root development up to LD_{50} dose. Radio sensitivity test of germinated seeds showed that LD_{50} was 28.35 and 33.13 Gy for pre-soaked seeds and 24.05 and 23.78 Gy for seeds immersed in water for Ranchi Local & Arka Surya respectively. From the analysis of GR_{50} for both the irradiated conditions, it was found that 30 Gy (for pre-soaked seeds) and 20 Gy (for seeds immersed in water) was the most effective dose with maximum possibility of desirable mutation. 10 Gy acted as a stimulative dose for plant growth, survival percentage and vigour index.

Keywords: Papaya**,** gamma rays, LD_{50}, germination, vigour index

Introduction

Being short duration, early maturing, quick growing and dwarf in nature, papaya (*Carica papaya* L.) is grown very successfully as intercrop in the orchards of major fruit crops (Chattopadhyay, 2012) [18]. It is a digestive aid and is a stomachic, carminative, diuretic and expectorant. Among the fruits, it ranks 4th position in production (61,08,000 MT),1st position in productivity (44.9MT/Ha) from 132000 ha (MoAFW, 2017). Genetic improvement of papaya is required because its sustainable production is threatened due to increasing disease and pest pressure (Ram, 1981). Dwarf type plant stature as well as early flowering type papaya can extend the production and productivity of this fruit crop.

The genetic bottle-neck that occurs as a result of the continuous use of existing populations leads plant breeders to modernized breeding technologies. Mutation breeding has been an alternative technique preferred by breeders as it allows the possibility to form characteristics that do not exist in the nature or lost throughout the evolution. Due to the complex sex forms improving papaya with conventional methods, alternative approaches such as mutation induction have been pursued. The work on the induction of genetic alterations through X-rays by Lewis John Stadler in the late 1920s and early 1930s laid the foundation of another type of plant breeding known as mutation breeding (Shu Q.Y. *et al*., 2012) [55].

Gamma rays are common used in plant breeding programmes because there are known for their simple application, good penetration, reproducibility, high mutation frequency and less disposal problems (Chahal, G.S. and S.S. Gosal, 2002) [17]. Besides breeding, they are also used as an alternative for improvement of desired characters in agricultural crops [Brock, R.D., 1980, Van den Bulk, R.W. *et al*. 1990, Swaminathan, M.S., 1998, *Friebe B. et al.*1991, Sanamyan M.F. *et al*., 2000] [16, 61, 57, 24, 54].

Radiation dose is expressed in rads (radiation-absorbed dose) which is equivalent to absorption of 100 ergs/g. The unit kilorad (kR which is 1,000 rads) which was in use earlier is replaced by gray (Gy) which is currently used. The two can be interconvert as 1 kR is equivalent to 10 Gy. A concept of LD_{50} (lethal dose 50%) is used to refer the optimum dose to be used in the experiment. By definition LD_{50} is the dose which causes 50% lethality in the organism used for irradiation in defined time. It varies with the plant species, the type and status of the material and the stage at which lethality is measured. Generally, irradiated populations are generated by using an LD_{50} dose treatment and with a dose lower than LD_{50}. Since induction of mutation is a chance event, and recovery of a mutation is dependent upon chance of the survival of that individual plant, this strategy improves the probability of obtaining a desirable mutant. In a case where LD_{50} dose is already reported, it can be used as a guideline; otherwise, it can be determined by exposing different subsamples of the target plant material (seeds) to a range of doses (low to high) and monitoring survival of the plants in field (up to flowering or maturity). In plants which are sensitive to radiation, doses lower than LD_{50} are also used to reduce the mutation load (Shu *et al*., 2012) [55]. Therefore, it is preferred to work out radio sensitivity test between LD_{25} or LD_{30} and LD_{50} to obtain mutation for desired and optimum traits (Choudhury 1983; Maluszynski *et al*., 2003) [20, 44]. This necessitates the present investigation entitled “Gamma radiosensitivity study on papaya cv. Ranchi Local & Arka Surya”.

Materials and Methods

Cobalt 60 source in gamma chamber was used to treat papaya seeds at the Radiation Standards Section, Radiation Safety Systems Division, Bhabha Atomic research Centre in Mumbai, India. The gamma chamber has a pneumatic system which carried the irradiation chamber of volume 1200 cc containing pencil type Co–60 source in a cylindrical cage, which ensures good uniformity of radiation field within the irradiation volume. The activity strength of cobalt 60 source was around 22 TBq (600 Ci) with a dose rate of 1.02 KGy/hr. The dose rate measurement was carried out using the chemical dosimeter (Ceric-cerous dosimeter). The source of radiation in the chamber is Co^{60}, which emits 2 gamma radiation of energy 1.33 and 1.17 MeV per disintegration. The seeds of papaya variety Ranchi local and Arka Surya were subjected to 0, 10, 20, 30, 40, 50, 60 and 70 Gy gamma doses. Prior to irradiation in one experiment, seeds were soaked overnight in water and surface-dried and in another experiment, seeds were immersed in water during irradiation for a better diffusion of the gamma rays. After irradiation, the seeds were removed from the water and grown in greenhouses belonging to Department of Fruit Science & Horticulture Technology, OUAT, Bhubaneswar, Odisha under controlled conditions. For each treatment 250 numbers of seeds were used. A quality control check of the irradiation was carried out using the chemical dosimeters. The experiment was laid out in a Factorial. Randomized Block Design with three levels *viz* two varieties, two soaking conditions and seven different gamma doses. Observation on Germination (%), Shoot length, Root length, vigour index & survival (%) were recorded for preliminary dosimetry study. The vigour Index was calculated using the following equation:

$$V = G(\%) \times (ASL + ARL)$$

Where

G: Germination percentage

ASL: Average Shoot Length

ARL: Average Root Length

Experimental Result and Discussion

Germination percentage

The result of gamma irradiation doses to papaya seeds revealed that significantly highest (65.83%) germination was recorded by 10 Gy as compared to other doses, irrespective of variety and seed soaking conditions. Acceleration of seed germination by low doses of gamma rays can be attributed to many factors to the increase in oxygen uptake following irradiation with low doses of gamma rays, which resulted in the production of organic and inorganic peroxy radicals, which led to breaking seed dormancy. Energy required for initial growth is already available in the seeds but low dose of gamma irradiation may increase the enzymatic activation which stimulates the rate of cell division along with vegetative growth (Sjodin J., 1962, Shah T.M. *et al.*, 2012) [56, 58]. The stimulation of germination may be due to the activation of RNA synthesis (Kuzin *et al*. 1975) [38] or protein synthesis (Kuzin *et al*., 1976) [39], during the early stage of germination after seeds irradiated (Abdel- Hady *et al*., 2008) [1].

Table 1: Effect of irradiation and seed soaking on germination, shoot length, root length and seedling height in papaya cv. Ranchi Local & Arka Surya

		Germination (%)	Shoot Length (cm)	Root length (cm)	Seedling Height (cm)
Ranchi Local (A_1)		31.75	5.58	12.88	18.46
Arka Surya (A_2)		36.50	7.84	9.86	17.70
SEd (±)		0.59	0.08	0.13	0.18
$CD_{0.05}$		1.20	0.15	0.26	0.36
Pre Soaked (B_1)		43.93	7.51	11.70	19.21
Seeds in water (B_2)		24.33	5.91	11.03	16.94
SEd (±)		0.59	0.08	0.13	0.18
$CD_{0.05}$		1.20	0.15	0.26	0.36
10 Gy (C_1)		65.83	10.72	13.68	24.39
20 Gy (C_2)		49.06	8.63	15.52	24.15
30 Gy (C_3)		31.97	6.75	14.42	21.17
40 Gy (C_4)		18.40	4.85	8.46	13.31
50 Gy (C_5)		5.38	2.60	4.75	7.35
SEd (±)		0.94	0.12	0.20	0.28
$CD_{0.05}$		1.90	0.24	0.41	0.57
AXB	SEd (±)	0.84	0.11	0.18	0.25
	$CD_{0.05}$	1.70	NS	0.37	0.51

AXC	SEd (±)		1.33	0.17	0.29	0.40
	$CD_{0.05}$		2.69	0.34	0.58	0.80
BXC	SEd (±)		1.33	0.17	0.29	0.40
	$CD_{0.05}$		2.69	NS	0.58	0.80
AXBXC	SEd (±)		1.88	0.24	0.40	0.56
	$CD_{0.05}$		3.80	0.48	0.82	1.14
Control Vs Rest (Mean)	A_1	Control	72.13	10.50	7.60	20.20
		Rest	31.75	5.58	12.88	18.46
	A_2	Control	65.48	12.60	6.24	16.74
		Rest	36.50	7.84	9.86	17.70
Control Vs Rest	A_1	SEd (±)	1.41	0.16	0.30	0.38
		$CD_{0.05}$	2.94	0.34	0.63	0.81
	A_2	SEd (±)	1.52	0.21	0.33	0.43
		$CD_{0.05}$	3.17	0.45	0.70	0.91

Table 2: Interaction effect of irradiation and seed soaking on germination & shoot length in papaya cv. Ranchi Local & Arka Surya

Dose (Gy) (C)	Germination (%)							Shoot length (cm)						
	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB
	B_1	B_2		B_1	B_2			B_1	B_2		B_1	B_2		
Control	**72.13**			**65.48**				**10.50**			**12.60**			
10	74.11	51.82	62.97	78.56	58.84	68.70	65.26	10.42	8.43	9.43	12.40	11.61	12.01	10.72
20	58.26	32.22	45.24	69.16	36.62	52.89	48.30	8.16	6.86	7.51	10.44	9.05	9.75	8.63
30	35.64	22.51	29.07	51.48	18.24	34.86	31.39	6.40	4.38	5.39	8.72	7.51	8.11	6.75
40	21.18	11.56	16.37	31.52	9.32	20.42	17.99	4.20	2.65	3.43	7.14	5.42	6.28	4.85
50	8.89	1.35	5.12	10.45	0.82	5.64	5.33	2.80	1.51	2.15	4.40	1.69	3.05	2.60
Mean	39.62	23.89		48.23	24.77			6.40	4.76		8.62	7.06		

Table 3: B X C mean data for germination & shoot length in papaya cv. Ranchi Local & Arka Surya

% Germination (B X C Mean Table)							Shoot Length (B X C Mean Table)						
	10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B		10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B
Pre-soaked	76.34	63.71	43.56	26.35	9.67	43.93	Pre-soaked	11.41	9.30	7.56	5.67	3.60	7.51
SIW	55.33	34.42	20.37	10.44	1.09	24.33	SIW	10.02	7.96	5.94	4.04	1.60	5.91
Mean C	65.83	49.06	31.97	18.40	5.38		Mean C	10.72	8.63	6.75	4.85	2.60	

Table 4: Interaction effect of irradiation and seed soaking on root length & seedling height in papaya cv. Ranchi Local & Arka Surya

Dose (Gy) (C)	Root Length (cm)							Seedling Height (cm)						
	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB
	B_1	B_2		B_1	B_2			B_1	B_2		B_1	B_2		
Control	**7.61**			**6.24**				**20.21**			**16.74**			
10	12.53	14.20	13.37	12.56	15.42	13.99	13.68	22.95	22.63	22.79	24.96	27.03	26.00	24.39
20	15.82	18.05	16.94	16.83	11.38	14.10	15.52	23.98	24.91	24.45	27.27	20.43	23.85	24.15
30	14.78	21.26	18.02	13.47	8.17	10.82	14.42	21.18	25.64	23.41	22.19	15.68	18.94	21.17
40	8.98	11.53	10.26	8.61	4.72	6.67	8.46	13.18	14.18	13.68	15.75	10.14	12.95	13.31
50	7.20	4.40	5.80	6.22	1.18	3.70	4.75	10.00	5.91	7.96	10.63	2.87	6.75	7.35
Mean	11.86	13.89		11.54	8.17			18.26	18.65		20.16	15.23		

Table 5: B X C mean data for root length & seedling height in papaya cv. Ranchi Local & Arka Surya

Root length (B X C Mean Table)							Seedling Height (B X C Mean Table)						
	10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B		10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B
Pre-soaked	12.55	16.33	14.13	8.80	6.71	11.70	Pre-soaked	23.96	25.63	21.69	14.47	10.31	19.21
SIW	14.81	14.72	14.72	8.13	2.79	11.03	SIW	24.83	22.67	20.66	12.16	4.39	16.94
Mean C	13.68	15.52	14.42	8.46	4.75		Mean C	24.39	24.15	21.17	13.31	7.35	

Table 6: Effect of irradiation and seed soaking on vigour index, survival, plant height and bearing height in papaya cv. Ranchi Local & Arka Surya

	Vigour Index	Survival (%)	Plant Height (cm)	Bearing Height (cm)
Ranchi Local (A_1)	694.49	47.47	128.91	59.70
Arka Surya (A_2)	831.81	48.89	140.45	83.92
SEd (±)	16.53	0.62	1.12	1.03
$CD_{0.05}$	33.48	1.25	2.27	2.08
Pre Soaked (B_1)	981.75	53.45	141.77	74.30
Seeds in water (B_2)	544.56	42.91	127.59	69.32
SEd (±)	16.53	0.62	1.12	1.03
$CD_{0.05}$	33.48	1.25	2.27	2.08
10 Gy (C_1)	1606.20	76.49	169.58	89.45
20 Gy (C_2)	1208.43	65.79	137.63	70.28

30 Gy (C_3)			690.05	53.43	114.80	60.48
40 Gy (C_4)			258.50	33.08	123.30	66.43
50 Gy (C_5)			52.57	12.11	128.10	72.43
SEd (±)			26.14	0.97	1.77	1.62
$CD_{0.05}$			52.93	1.97	3.59	3.29
AXB	SEd (±)		23.38	0.87	1.59	1.45
	$CD_{0.05}$		47.35	1.76	NS	2.94
AXC	SEd (±)		36.97	1.38	2.51	2.30
	$CD_{0.05}$		74.86	2.78	5.07	4.65
BXC	SEd (±)		36.97	1.38	2.51	2.30
	$CD_{0.05}$		74.86	2.78	5.07	4.65
AXBXC	SEd (±)		52.28	1.95	3.54	3.25
	$CD_{0.05}$		105.87	3.94	7.18	6.58
Control Vs Rest (Mean)	A_1	Control	1457.67	62.58	190.00	107.00
		Rest	694.53	47.47	128.91	59.70
	A_2	Control	1096.00	69.23	218.30	121.70
		Rest	831.83	48.89	140.45	83.92
Control Vs Rest	A_1	SEd (±)	35.12	1.45	0.99	2.18
		$CD_{0.05}$	73.27	3.06	2.06	4.54
	A_2	SEd (±)	42.68	1.49	0.36	0.49
		$CD_{0.05}$	89.03	3.1	0.74	1.02

Table 7: Interaction effect of irradiation and seed soaking on vigour index & survival in papaya cv. Ranchi Local & Arka Surya

Dose (Gy) (C)	Vigour Index							Survival (%)						
	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB
	B_1	B_2		B_1	B_2			B_1	B_2		B_1	B_2		
Control	**1457.8**			**1096.1**				**62.58**			**69.23**			
10	1700.8	1172.7	1436.8	1960.9	1590.4	1775.7	1606.2	76.18	79.32	77.75	78.26	72.20	75.23	76.49
20	1397.1	802.5	1099.8	1886.0	748.2	1317.1	1208.4	66.97	61.31	64.14	69.79	65.10	67.45	65.79
30	754.9	577.0	665.9	1142.3	286.0	714.2	690.1	58.34	42.98	50.66	61.48	50.90	56.19	53.43
40	279.2	163.9	221.5	496.4	94.5	295.5	258.5	40.36	28.43	34.40	45.13	18.40	31.76	33.08
50	88.9	8.0	48.5	111.0	2.4	56.7	52.6	16.67	4.13	10.40	21.35	6.30	13.83	12.11
Mean	844.2	544.8		1119.3	544.3			51.70	43.23		55.20	42.58		

Table 8: B X C mean data for vigour index & survival in papaya cv. Ranchi Local & Arka Surya

Vigour Index (B X C Mean Table)							% Survival (B X C Mean Table)						
	10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B		10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B
Pre-soaked	1830.84	1641.53	948.60	387.80	99.96	981.75	Pre-soaked	77.22	68.38	59.91	42.74	19.01	53.45
SIW	1381.57	775.33	431.50	129.21	5.18	544.56	SIW	75.76	63.21	46.94	23.41	5.21	42.91
Mean C	1606.20	1208.43	690.05	258.50	52.57		Mean C	76.49	65.79	53.43	33.08	12.11	

Table 9: Interaction effect of irradiation and seed soaking on plant height & bearing height in papaya cv. Ranchi Local & Arka Surya

Dose (Gy) (C)	Plant Height (cm)							Bearing Height (cm)						
	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB	A_1		Mean A_1B	A_2		Mean A_2B	Mean AB
	B_1	B_2		B_1	B_2			B_1	B_2		B_1	B_2		
Control	**190.00**			**218.30**				**107.00**			**121.70**			
10	178.40	155.30	166.85	192.20	152.40	172.30	169.58	87.00	68.00	77.50	95.60	107.20	101.40	89.45
20	163.20	95.60	129.40	176.40	115.30	145.85	137.63	80.00	40.00	60.00	79.80	81.30	80.55	70.28
30	102.40	110.60	106.50	117.80	128.40	123.10	114.80	49.00	42.00	45.50	72.80	78.10	75.45	60.48
40	117.70	117.80	117.75	121.90	135.80	128.85	123.30	55.00	49.00	52.00	75.30	86.40	80.85	66.43
50	122.50	125.60	124.05	125.20	139.10	132.15	128.10	67.00	60.00	63.50	81.50	81.20	81.35	72.43
Mean	136.84	120.98		146.70	134.20			67.60	51.80		81.00	86.84		

Table 10: B X C mean data for plant height & bearing height in papaya cv. Ranchi Local & Arka Surya

Plant Height (B X C Mean Table)							Bearing Height (B X C Mean Table)						
	10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B		10 Gy	20 Gy	30 Gy	40 Gy	50 Gy	Mean B
Pre-soaked	185.30	169.80	110.10	119.80	123.85	141.77	Pre-soaked	91.30	79.90	60.90	65.15	74.25	74.30
SIW	153.85	105.45	119.50	126.80	132.35	127.59	SIW	87.60	60.65	60.05	67.70	70.60	69.32

50 Gy had marked lowest germination (5.38%). Moreover, 60 & 70 Gy inhibit germination. The germination of treated plants had shown a sharp dose rate relationship, which decreased with the increase in the dose. Higher exposures were usually inhibitory (Bora 1961; Radhadevi and Nayar 1996; Kumari and Singh 1996) [41, 52, 37]. The inhibition of seed germination at high doses may have resulted from a damage to chromosomes and subsequent mitotic retardation similar to those seen in irradiated carrot tissue cultures (Al-Safadi and Simon, 1990) [5]. These results are in accordance with those of Kumar and Mishra, 2004 in okra, Khan *et al*., 2005 and Toker *et al*., 2005 in chickpea, Karthiha and lakshi, 2006 in soybean, Mahla *et al*., 1999 in coriander, Bhosala and More, 2014 in Asshwagandha.

Shoot length
Interaction of variety, seed soaking condition and gamma doses revealed that Arka Surya var. in pre-soaked (PS) condition at 10 Gy had highest (12.4 cm) shoot length as compare to control (12.60cm). Gamma ray imposed a significant impact on the shoot length. It was observed that shoot lengths decreased in a linear mode from lower to higher concentrations of gamma doses irrespective of varieties and seed soaking conditions. Similar results have also been reported by Talebi and Talebi (2012) [59] and Ambavane *et al*. (2015) [6]. According to Blixt (1970) [13] when gene controlled biochemical processes or chromosomal anomalies caused major lesion at cellular level then it inhibits shoot length. Low doses apparently inhibit auxin synthesis while larger doses can destroy auxin activity directly. As with higher wound responses, irradiated tissues often produce endogenous ethylene (Maxie *et al*. 1966; Dwelle 1975; Chervin *et al*. 1992; Liu *et al*. 2008) [45, 22, 19, 42]. The results confirm the earlier findings of Singh *et al*., 2010 in papaya, Kumar *et al*., 2013 in mulberry, Jayakumar and Selvaraj, 2003 in sunflower, Borzouei *et al*., 2010, Norfadzrin *et al*., 2007.

Root length
Ranchi Local var. in SIW condition at 30 Gy had highest root length (21.26 cm) as compare to control (7.61 cm). Gamma rays enhance root development. This result is in accordance with Melki and Sallami (2008) in chickpea, Melki & Marouani in hard wheat (2009) [46], Bassam Al-Safadi and Philipp W. Simon (1996) [4] in carrot who observed a significant elongation of the root system in irradiated seedlings. It was also observed that in both the varieties of papaya under pre-soaked condition root length increased upto 20 Gy and decreased thereafter but when seeds immersed in water root length increased up to 30 Gy and decreased afterwards. It can be explained from the dose response curve of LD_{50} and GR_{50}. The LD_{50} value was 28.35 and 33.13 Gy for pre-soaked seeds & 24.05 and 23.78 Gy for seeds immersed in water for Ranchi Local & Arka Surya variety respectively. From the analysis of GR_{50} for both the irradiated conditions, it was found that 30 Gy (for pre-soaked seeds) and 20 Gy (for seeds immersed in water) was the most effective dose with maximum possibility of desirable mutation. This study shows that 30 & 20 Gy is a stimulative dose.

Seedling growth
Interaction of variety, seed soaking condition and gamma doses revealed that Arka Surya var. in pre-soaked condition at 20 Gy had highest seedling height (27.27 cm) as against control (18.84cm).It was observed that there was a increasing trend with increase in irradiation doses up to LD_{50} dose and decreased thereafter. Low dose irradiation will induce growth stimulation by changing the hormonal signalling network in plant cells or by increasing the antioxidative capacity of cells to easily overcome daily stress factors such as fluctuation of light intensity and temperature in growth conditions (Kim *et al*. 2004; Wi *et al*. 2007) [31, 63]. In contrast, the growth inhibition induced by high-dose irradiation has been attributed to the cell cycle arrest at the G_2/M phase during somatic cell division and (or) varying damage to the entire genome (Preussa and Britt 2003) [51]. These overall results are quite similar to those from our earlier reports (Lee *et al*., 1998; Kim *et al*., 1998, 2000, 2001a, 2002a) [41, 29, 30, 32], in which low-dose gamma-irradiation stimulated seedling growth in Chinese cabbage, red pepper, onion, spinach, bottle gourd, pumpkin, and soybean.

Vigour index
In the present study, it was marked that Arka Surya var. in pre-soaked condition at 10 Gy had highest vigour index (1960.9) as compare to control ()under the interaction of variety, seed soaking condition and gamma doses. The same treatment has a stimulatory effect on germination rate and growth of seedling (i.e. shoot length and root length) so, vigour index follows the same trend as it is calculated from these parameters (Dhakshanamoorthy *et al.*,2010) [21]. The increased plant vigour caused by irradiation could be explained by stimulation of biosynthesis of some amino acids (lysine, phenylalanine) (Antonov *et al*., 1989) [8]; modification of some enzymes activity, e.g. polyphenol oxidase, catalases and pyroxidases, which are greater in the leaf of treated plants (Lage and Esquibel,1997; Ghiorghita *et al*., 1985; Freidman, 1985; Grossman and Craig, 1982) [25, 23, 26]; increase of primary biochemical processes, uptake of mineral nutrients (Al-Oudat, 1990) [3] and photosynthesis (Antonov, 1985)[7]. This result is in agreement with the findings of Arvind-Kumar and M.N, Mishra, 2004 in okra, Nargis S *et al.*, 1998 in tomato, Aynehband A and Afsharinafar K., 2012 in amaranth, Akshatha and Chandrashekar KR., 2013 in *Pterocarpus santalinus.*

Survival percentage
Ranch Local var. in SIW condition at 10 Gy had highest survival percentage (79.32%) while lowest (4.13%) was at 50 Gy in the same variety and soaking condition. The observations of seedlings survival clearly showed that the increased doses of gamma rays having lethal effect on seedlings survival. This increase in survival rate could be attributed to a selection by gamma radiation for cells resistant to radiation leading to the regeneration of vigorous roots and later to vigorous plants. The inhibition of survival percentage at high doses may have resulted from a damage to chromosomes and subsequent mitotic retardation. This result is similar to those seen in irradiated carrot (Al-Safadi and Simon, 1990) [5], in fenugreek (Bashir *et al*., 2013) [12], Verma *et al.,* 2017 in fennel and Minisi *et al*., 2013 in *Moluccella laevis*.

Plant growth
Interaction of variety, seed soaking condition and gamma doses revealed that Ranchi Local var. in SIW condition at 20 Gy had lowest plant height (95.60 cm; reduction of 49.7% over control), lowest bearing height (40cm; reduction of 62.6% over control).In both the varieties Ranchi Local & Arka Surya under pre-soaked condition plant height decreased upto 30 Gy and increased thereafter but when seeds immersed in water plant height decreased up to 20 Gy and increased afterwards and it ranges from 95.60 to 178.40cm and 115.30 to 192.20cm respectively under different gamma doses and seed soaking treatments. Bearing height significantly decreased in all the treatments compared to control. It was seen that the gamma applications had an enhancing effect on stem diameter of the both cultivars.

20 Gy in SIW is the stimulative dose for plant growth. Low dose irradiation induced growth stimulation by changing the hormonal signalling network in plant cells or by increasing the antioxidative capacity of cells to easily overcome daily stress factors such as fluctuation of light intensity and temperature in growth conditions (Kim *et al*. 2004; Wi *et al*. 2007) [31]. In contrast, the growth inhibition induced by high-dose (above LD_{50} dose in present study)irradiation has been attributed to the cell cycle arrest at the G_2/M phase during

somatic cell division and (or) varying damage to the entire genome (Preuss and Britt 2003) [51].

The effect was more pronounced in SIW condition than pre-soaked condition which can be attributed by the indirect action of gamma rays in water that the biological effect of gamma rays is based on the interaction with atoms or molecules in the cell, particularly water, to produce free radicals (Kovács and Keresztes 2002) [34]. These radicals can damage or modify important components of plant cells and have been reported to affect differentially the morphology, anatomy, biochemistry, and physiology of plants depending on the radiation dose (Ashraf *et al*. 2003) [10].

Standardization of LD_{50}, GR_{50} & GR_{30}

An empirical formula was derived from the radio sensitivity test of germinated seeds presented in Fig.1, which was used to calculate lethal dose for 50% population (LD_{50}). The LD_{50} value was 28.35 and 33.13 Gy for pre-soaked seeds & 24.05 and 23.78 Gy for seeds immersed in water for Ranchi Local & Arka Surya variety respectively.

Similarly the shoot length data of germinated papaya seeds was used to derive an empirical formula for determination of GR_{50} & GR_{30} which is presented in Fig.2. The GR_{50} was thus calculated to be 31.64 and 37.50 Gy for pre-soaked seeds & 28.28 and 30.11 Gy for seeds immersed in water for Ranchi Local & Arka Surya variety respectively. GR_{30} was also calculated from the same equation and found out to be that 44.30 and 52.50 Gy for pre-soaked seeds & 39.59 and 42.15 Gy for seeds immersed in water for Ranchi Local & Arka Surya respectively.

From the analysis of GR_{50} for both the irradiated conditions, it was found that 30 Gy (for pre-soaked seeds) and 20 Gy (for seeds immersed in water) was the most effective dose with maximum possibility of desirable mutation.

Conclusion

Increasing gamma ray decreased germination percentage, shoot length, plant height (reduction of 49.7% over control), bearing height (reduction of 62.6% over control) in papaya whereas gamma rays enhance root development up to LD_{50} dose. Radio sensitivity test of germinated seeds showed that LD_{50} was 28.35 and 33.13 Gy for pre-soaked seeds and 24.05 and 23.78 Gy for seeds immersed in water for Ranchi Local & Arka Surya respectively. From the analysis of GR_{50} for both the irradiated conditions, it was found that 30 Gy (for pre-soaked seeds) and 20 Gy (for seeds immersed in water) was the most effective dose with maximum possibility of desirable mutation. 10 Gy acted as a stimulative dose for plant growth, survival percentage and vigour index.

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