MORPHO-PHYSIOLOGICAL AND BIOCHEMICAL RESPONSES OF *ZEA MAYS* L. TO GAMMA RADIATIONS

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Abstract: Gamma irradiation is widely used as a physical mutagen to enhance genetic variability and study its effects on plant germination, growth, and biochemical traits, particularly in important crops like maize. The present study investigates the impact of gamma radiation on germination, morphological, and biochemical characterization of maize (*Zea mays* L.). The seeds of maize were irradiated with 10, 15, 20, 25 kr. It was revealed from the results that by increasing radiation doses, the germination percentage decreased. The results revealed that the stored gamma irradiation in the sample was significantly lower for radicle and plumule length, plant height, number, and width of the shoot. The germination percentage was low in 25kr irradiated seeds and was higher than compared of control plants. The plants irradiated with 20kr showed high protein content (18.04), while those plants which were irradiated with 10kr showed low protein content (6.6). From the results, it was revealed that the biochemical and growth behaviour of the test plants were changed. The carbohydrate contents were increased, and the effect occurred in the height of plants, leaves number, and the width of the shoot. The findings demonstrate that gamma irradiation induces significant alterations in the germination percentage, morphological parameters, and biochemical composition of maize, offering insights for future crop improvement and stress resilience studies.

Index-terms: Carbohydrate content, Gamma irradiation, Germination percentage, Total protein content, and *Zea mays* L.

I. INTRODUCTION

Zea mays L. belongs to the family Poaceae. It is an annual monocot plant that possesses an adventitious root system, which enables it to stand upright and also measure the adjustment of water and minerals. The tenders of the stem have nodes and internodes with thin, flattened, parallel, venated leaves. Alternate leaves bearing a single node (Kämpfer et al., 2015). The illumination process of the physical alteration techniques is known as radiation. The radiation is in correlation with other physical diminishing techniques, e.g. ultraviolet, aqueous management, microwave, light treatment, and extremely high hydrostatic pressure is worth, quick and excessive light ionized the strength of polios portion (Rifna et al., 2019). The gamma beams are in the form of a group of high-energy rays that possess energy levels from around 10keV to a few 100KeV electron volts. Additionally, there are also more diverse kinds of rays, e.g. alpha (α) and beta (β) beams (Singh & Kumar, 2019). The gamma radiations is are significant physical mutagen for genetic changes in plants. To decline their mutagenic list, mutagens have been successful. In traditional hereditary studies, gamma radiation has been used for a long time in higher plants to initiate chromosomal deviations. Some researchers reported in their studies that gamma radiations reach chromosomal varieties (Huumonen, 2016; Raina, 2018; Zied & Pardo-Gimï, 2017). (Hasan et al., 2020) studied radiation impact under restricted situations on *Zea mays* L. sprouting. The decrease in chlorophyll a and chlorophyll b convergence occurs during the growth period. The stem diameter leaves figures and seedling tallness reduced with the increasing drive of introductory measure to light A and light B. (Ali et al., 2015) reported that the gamma radiation alters the gene and chromosome number, which changes the genotype that in turn leads to a modification in the phenotype. Thus declination of seed germination occurs with gamma radiation therapy. (Majeed et al., 2018) Studied the effect of gamma irradiation on the seeds of *Zea mays* L., concluded that by expanding the illumination measurement, the germination rate, shoot length, root length, and enzymatic activities declined. They studied two cultivars of Zea mays L. for different features by using gamma radiation. Genotypically, the germination of one cultivar was affected while the other remained unaffected. (Zarei et al., 2019) evaluated interrelation in yield grain and resembled features in 11 maize (*Zea mays* L.) cross breeds, which concluded a positive association of yielding grains and resembled features that yield hundreds of grains per ear and length of ear.

II. MATERIALS AND METHODS

The present study investigates the influence of gamma radiation on the morphological and phytochemical attributes of *Zea mays*. The germination rate, Plumule, and radicle length were also investigated. The experiment was performed in vitro through the CRD strategy.

2.1 Radiation Treatment

25 grams of seeds of hybrid *Zea mays* were taken and treated with different ranges of gamma radiation from 5kr to 20kr under room temperature with a CO^{60} gamma radiator.

2.2 In Vitro Procedure

The in vitro experiment was executed to study the effect of gamma irradiation on germination rate, radicle, and plumule length. The instruments which were used in the experiments include distilled water, filter paper, Petri dishes, a scale, a pencil, an incubator, and an autoclave. The Petri dishes were sterilized in the autoclave for 4 hours at 170ºc. The seeds of maize were germinated in these sterilized Petri dishes.

2.3 Experiment

The Petri dishes were washed with double-distilled water and aligned with two-fold Whatman's filter papers. For each treatment, 10 seeds of maize were sown in Petri dishes. After that, the plates were put in the incubator for incubation at 25ºc for 72 hours. After the incubation period, the germination rate, radicle length, and plumule length were recorded.

2.4 Field Experiment

The field experiment was performed in July in the Botanical Garden of Islamia College Peshawar. The seeds of maize were sown in the open field of the Botanical garden. The Maize seeds were sown in 10-foot-long rows. The distance between two rows was 1 foot, and the distance between the sown seeds in each row was 0.5 feet (6 inches). About 20 seeds were sown in each row area of approximately 60 feet. The date was recorded after every 15 days using cm as units. The plant height, no. of leaves, stem width, fresh and dry weight, and 100-seed weight parameters were recorded.

III. RESULTS

3.1.1 Germination Percentage

The effect of gamma radiation on the germination of *Zea mays* seeds was evaluated at varying concentrations. In the control group, 100 seeds were sown, resulting in a germination rate of $100.00 \pm 0.0\%$, indicating full germination. At a radiation dose of 5 Kr, the seeds also exhibited $100.00 \pm 0.0\%$ germination, showing no negative impact at this level. A slight reduction was observed at 10 Kr, where germination decreased to $90.75 \pm 0.75\%$. Interestingly, seeds exposed to 15 Kr demonstrated a recovery, achieving a germination percentage of $100.0 \pm 0.67\%$. However, further increases in radiation dose led to a more pronounced decline: at 20 Kr, germination dropped to $83.00 \pm 1.2\%$, and at the highest dose of 25 Kr, the germination rate significantly decreased to $65.50 \pm 0.36\%$. Overall, the results suggest that while lower doses of gamma radiation (up to 15

Kr) had minimal impact on seed germination, higher doses (20 Kr and 25 Kr) adversely affected the germination percentage of *Zea mays*.

Table 1: Effect of Gamma radiation on germination of *Z. mays*.

Concentration	Number of seeds	Germinated Seed	Germination %
Control	100	100.00 ± 0.0	100.0 ± 00
5Kr		100.00 ± 0.0	100.0 ± 00
10Kr		90.75 ± 0.75	90.75 ± 0.75
15Kr		100.0 ± 0.67	100.0 ± 0.67
20Kr		83.00 ± 1.2	83 00 ± 1.2
25Kr		65.50 ± 0.36	65.50 ± 0.36

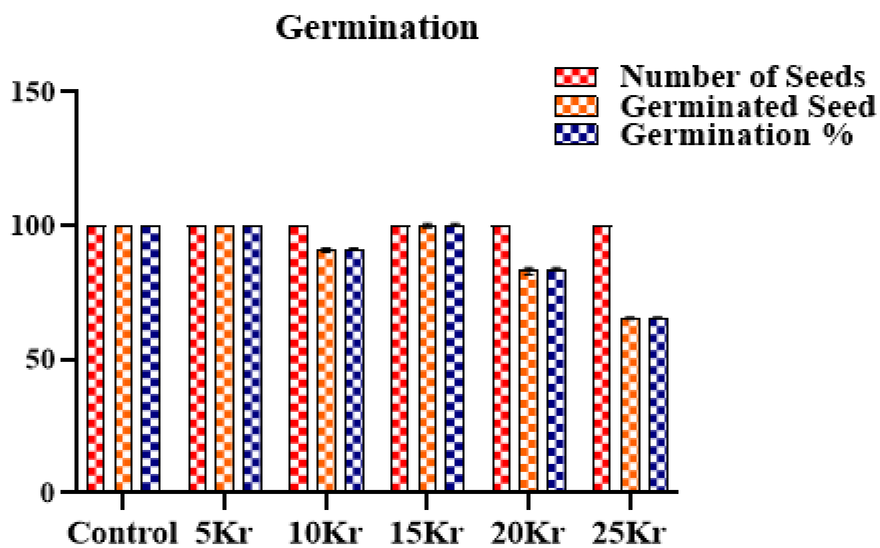

Fig. 1 Effect of Gamma radiation on germination of *Z. mays*.

3.1.2 Length and Weight

The impact of gamma radiation on the early seedling growth of *Zea mays* was assessed by measuring plumule length, radicle length, fresh weight, and dry weight under different radiation treatments. In the control group, seedlings exhibited a plumule length of 7.5 ± 0.75 mm and a radicle length of 8.5 ± 0.75 mm, with a fresh weight of 44.2 ± 0.50 g and a dry weight of 38.7 ± 0.50 g. Under 5 Kr gamma radiation, a reduction in growth parameters was observed, with plumule and radicle lengths measuring 6.0 ± 1.20 mm and 7.5 ± 0.85 mm, respectively; the fresh and dry weights were also lower at 42.0 ± 0.83 g and 37.0 ± 0.49 g. At 10 Kr, there was a slight recovery, as the plumule length increased to 7.1 ± 0.47 mm and radicle length to 8.1 ± 1.11 mm, along with a fresh weight of 43.2 ± 0.48 g and a dry weight of 38.0 ± 0.26 g. However, at 15 Kr, both plumule (6.5 ± 0.99 mm) and radicle (7.2 ± 1.02 mm) lengths, as well as fresh (41.0 ± 1.01 g) and dry (36.8 ± 1.25 g) weights, declined again. A further decrease was evident at 20 Kr, where plumule and radicle lengths measured 6.8 ± 0.65 mm and 7.1 ± 0.56 mm, respectively, with a fresh weight of 39.0 ± 0.95 g and dry weight of 35.0 ± 0.75 g. Notably, at the highest radiation dose of 25 Kr, the seedling growth was completely inhibited, as indicated by the absence of measurable fresh and dry weights, and a considerable reduction in radicle length (5.5 ± 0.37 mm) and plumule length (6.3 ± 0.71 mm). These findings suggest that increasing doses of gamma radiation adversely affected the seedling growth of *Zea mays*, with severe inhibition at higher radiation levels.

Table 2: Influence of radiation on plumule, radicle length, fresh and dry weight of the maize plant.

Concentration	Plumule length (mm)	Radicle length (mm)	Fresh weight (g)	Dry Weight(gm)
Control	7.5 ± 0.75	8.5 ± 0.75	44.2 ± 0.50	38.7 ± 0.50
5Kr	6.0 ± 1.20	7.5 ± 0.85	42. 0 ± 0.83	37.0 ± 0.49
10Kr	7.1 ± 0.47	8.1 ± 1.11	43.2 ± 0.48	38.0 ± 0.26
15Kr	6.5 ± 0.99	7.2 ± 1.02	41.0 ± 1.01	36.8 ± 1.25
20Kr	6.8 ± 0.65	7.1 ± 0.56	39.0 ± 0.95	35.0 ± 0.75
25Kr	6.3 ± 0.71	5.5 ± 0.37	0	0

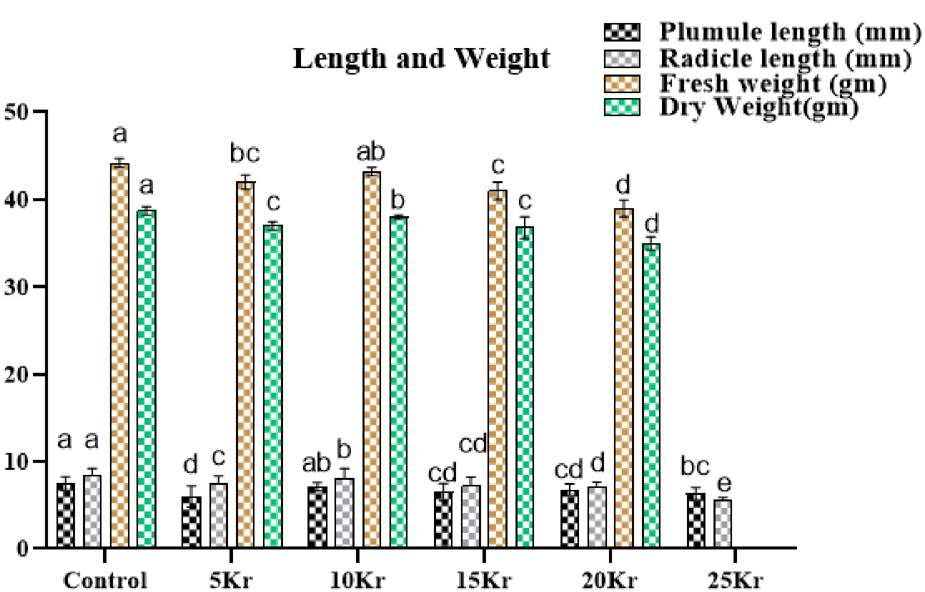

Fig. 2 Influence of radiation on plumule, radicle length, fresh and dry weight of the maize plant.

3.2 Fourth Nightly Radiational Influence on Diameter of Plant Parts After Germination

Table 3 showed that gamma radiation significantly affected maize plant height, shoot width, and the number of leaves. As compared to control plants (46.8cm), minimum inhibition in plant height was recorded in the 5kr treatment, which decreases plant height up to 38.9cm. Whereas the maximum decrease in plant height was recorded in the 25kr treatment, in which the plant height was decreased to 21.9 cm when compared with untreated plants (46.8cm). A decrease of no. of leaves 5 and 3 was verified after the treatment of 5kr and 25kr, as compared to the control 6.9. Maximum inhibition in the shooting width was recorded in the 25kr treatment, 0.4cm and minimum inhibition in the shooting width was recorded in the 5kr treatment, which is 0.8cm when linked with untreated plants (1.1cm).

3.2.1 After a Month of Germination

Table 3 revealed that gamma radiation significantly affected maize plant height, shoot width, and the number of leaves. The data was recorded after 30 days of sowing. As compared to control plants (103.5cm), minimum inhibition in plant height was recorded in the 5kr treatment, which decreases plant height up to 87.2cm. Whereas the maximum decrease in plant height was recorded in the 25kr treatment, in which the plant height was reduced to 39.6cm when compared with untreated plants (103.5cm). A minute decrease of 8 and 6 no. of leaves was observed after treatment of 5kr and 25kr radiations, respectively, when compared with untreated plants 12. Maximum inhibition in the shooting width was recorded in the 25kr treatment, 0.9cm and minimum inhibition in the shooting width was recorded in the 5kr treatment, which is 0.8cm when matched with untreated plants (1.8cm).

3.2.2 Influence of Radiation After 45 Days of Germination

Table 3 showed that gamma radiation significantly affected maize plant height, shoot width, and the number of leaves. The data was recorded after 45 days of sowing. As compared to control plants (103.5cm), minimum inhibition in plant height was recorded in the 5kr treatment, which decreases plant height up to 136.5cm. Whereas maximum decrease in plant height was recorded in the 25kr treatment, in which the plant height was reduced to 58.9 cm when associated with untreated plants (158.5cm). The minimal decrease in the number. Leaves of 14.5 and 7.9 with the treatment of 5kr and 25kr were observed correspondingly when it was associated with the untreated 17.3. Maximum inhibition in the shooting width was recorded in the 25kr treatment, 1.5cm, and minimum inhibition in the shooting width was recorded in the 5kr treatment, which is 2.3cm as compared to control plants (2.4cm).

3.2.3 After Harvesting

Table 2 showed that gamma radiation significantly affected maize plant height, shoot width, and the number of leaves. The data was recorded after harvesting. As compared to control plants (103.5cm), minimum inhibition in plant height was recorded in the 5kr treatment, which decreases plant height up to 176.7cm. Whereas maximum decrease in plant height was recorded in the 25kr treatment, in which the plant height was reduced to 75.2 cm when compared with untreated plants (200.3cm). A minimum decrease (17.7) in leaves was noticed under the treatment of 5kr, while the reduced leaves no 9.9) were observed when treated with 25kr, when it was matched with untreated plants, 22.4. Maximum inhibition in the shooting width was recorded in the 25kr treatment, 1.4cm, as compared to control plants (2.9cm). Whereas 5kr,15kr, and 20kr did not show any significant change in the shooting width.

Table 3: Effect of radiation on different characters, sprouting and after-harvesting durations

Parameters	Treatment	Control	5Kr	10Kr	15Kr	20Kr	25Kr
Height	D1	46.8 A	38.9 B	33.5 C	34.2 C	33.8 C	21.9 D
	D2	103.5 A	87.2 B	84.9 BC	84.1 BC	71.6 C	39.6 D
	D3	158.5 A	136.5 B	132.7 C	131.6 C	110.1 D	58.9 E
	D4	200.3 A	176.7 B	173.2 B	170.7 B	147.3 C	75.2 D
No. of leaves	D1	6.9 A	4.8 B	3.9 C	3.9 C	3.7 C	3.3 C
	D2	11.9 A	8.9 B	8.5 C	7.9 D	6.6 E	5.9 F
	D3	17.3 A	14.5 B	13.8 B	12.8 C	10.6 D	7.6 E
	D4	22.4 A	17.7 B	17.2 B	16.8 B	14.1 C	9.9 D
Shoot width	D1	1.1 A	0.8C	0.7D	0.9B	0.6 D	0.4 E
	D2	1.8 A	1.5 B	1.5 B	1.4 C	1.3 D	0.9 E
	D3	2.4 A	2.3 B	2.2 B	2.2 B	2.2 B	1.5 C
	D4	2.9 AB	2.8 AB	2.7 AB	2.6 AB	2.5A	1.4 B

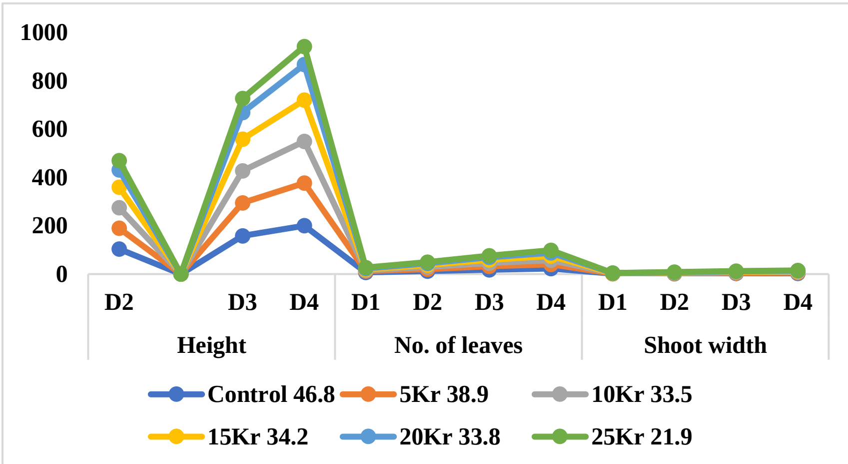

Fig 3: Effect of radiation on different characters, sprouting and after harvesting durations

3.3 Biochemical analysis of maize seeds

The biochemical composition of *Zea mays* seeds under different gamma radiation treatments was also examined. In the control group, seeds contained 65.03% carbohydrates, 8.14% protein, 4.9% fats, 14.13% moisture, 2.1% Fibers, and 5.7% ash. Seeds treated with 5 Kr radiation showed a slight increase in carbohydrate content (65.4%) but a decrease in protein (7.6%) and fats (4.7%), with moisture content slightly reduced to 14.03%, Fibers increased to 2.3%, and ash content rose to 5.9%. At 10 Kr, carbohydrates further increased to 66.6%, while protein content declined noticeably to 6.6%, fats slightly decreased to 4.5%, moisture remained stable at 14.1%, Fibers rose to 2.4%, and ash slightly decreased to 5.8%. In the 15 Kr treatment, the carbohydrate percentage remained relatively high at 66.13%, with protein at 7.22%, fats at 4.7%, moisture at 14.05%, Fibers at 2.3%, and ash at 5.6%. For seeds exposed to 20 Kr, carbohydrates slightly decreased to 65.76%, protein content nearly matched the control at 8.04%, fats remained steady at 4.7%, moisture content slightly decreased to 14%, Fibers content stayed at 2.3%, and ash content declined to 5.2%. Notably, at the highest dose of 25 Kr, all biochemical components (carbohydrates, proteins, fats, moisture, Fiberss, and ash) dropped to zero, indicating severe damage and loss of seed viability at this radiation level (Table 4).

Table 4. Effect of gamma radiation on biochemicals of *Z. mays.*

Concentration	Carbohydrate %	Protein %	Fats %	Moisture %	Fibers %	Ash %
Control	65.03	8.14	4.9	14.13	2.1	5.7
5Kr	65.4	7.6	4.7	14.03	2.3	5.9
10Kr	66.6	6.6	4.5	14.1	2.4	5.8
15Kr	66.13	7.22	4.7	14.05	2.3	5.6
20Kr	65.76	8.04	4.7	14	2.3	5.2
25Kr	0	0	0	0	0	0

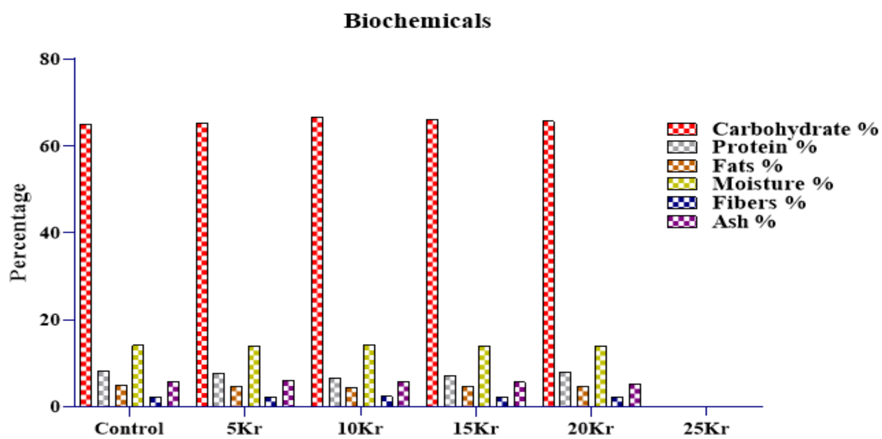

Fig. 3. Effect of radiation on biochemical analysis

IV. DISCUSSION

The present study investigates the effect of gamma irradiation on germination, physical, and phytochemical description of maize. From the results, it was clear that gamma radiation significantly affected radicle length, plumule length, and germination percentage. The radicle and plumule length showed maximum inhibition in higher dosages in growth as compared to the control. The results showed similarity with the results of (Thirumal, 2016) which studied which showed that higher dosages of more than 0.1 kGy repressed the root length and shoot length of maize plants. The results also showed similarity with the results of Borzouei et al. (2010), which concluded that the root length of all irradiated plants was reduced when compared with untreated radiated plants. When it was associated with untreated plants, the percentage of sprouting was also decreased. The highest decrease in sprouting percentage was observed in the plants which as irradiated with high dosages, whereas low irradiated dosages plants showed a minimum germination percentage as compared to control plants. The results showed similarity with the results of (Horn, 2016 & Nayak et al., 2015), which showed that in smaller dosages, germination percentage was not significantly different from control plants. Higher dosages reduced the germination percentage. The fresh and dry weight of treated plants was reduced in all treatments as compared to control plants, whereas the maximum decrease in fresh and dry weight was observed in higher dosages. The results are in a similarity to the results of (Hameed et al., 2008), which concluded that plant fresh weight and dry weight were reduced in higher dosages. The application of radiation decreased the tallness, leaves, and shoot diameter were also lower as compared to control plants. A maximum decrease in plant height, number of leaves, and shoot width was observed in high-dose treated plants. The plant height and shoot width were reduced as compared to control plants, and in high irradiated treated plants, plant height and shoot width showed a maximum reduction. The results showed similarity with the results of (Tasneem, 2004), which concluded that greater use of gamma radiation 40- 120krad) reduced the height of the plant, leaves a number, and the branching capability of the plant. The number of leaves was also reduced in treated plants, which was limited due to high dosages of radiation. The outcomes were similar to the findings of (Ahmad & Khalid, 2021), which investigated that the plants radiated with 20-25krad gamma radiation showed a reduction in plant size and branches, number and size of leaves. The contents of carbohydrates were higher than compared of other nutrients. The results are in uniformity with the results of (Maity et al., 2009), which showed that the irradiated seeds showed an increase in soluble sugars and carbohydrate contents. The protein contents and fats were decreased compared to the control. The results showed similarity with the results of (Nasab et al., 2023), which concluded that when the irradiation increases, the fat contents of cereals decreases. The moisture content was not affected significantly in all treatments. The fibers and ash contents were slightly increased as compared to control plants. The results also showed similarity with the results of (Al-Bachir, 2021) which observed that gamma irradiation showed no influence of the fiber, protein, lipid, and ash contents of both maize and sunflower seeds. There were no considerable changes in the values of density and refractive index between control and irradiated plants.

CONCLUSION

The present study clearly demonstrated that gamma radiation significantly impacts the morpho-physiological and biochemical characteristics of *Zea mays* across different radiation doses. Low doses of gamma radiation (5–10 Kr) exhibited minimal adverse effects on seed germination and early seedling growth, with some treatments even showing slight improvements in certain growth parameters. However, with increasing radiation doses (20–25 Kr), there was a progressive decline in germination percentage, plumule and radicle lengths, fresh and dry biomass, and overall plant vigor. Notably, seeds exposed to the highest dose (25 Kr) displayed severe inhibition of growth, with a complete loss of fresh and dry weights and major reductions in biochemical contents. In terms of biochemical composition, carbohydrate content slightly increased at lower radiation doses, while protein and fat contents decreased, aligning with trends reported in earlier studies. Higher radiation doses led to a total collapse of biochemical constituents, indicating severe cellular and metabolic damage. The growth parameters including plant height, shoot width, and number of leaves were also significantly reduced at higher radiation levels throughout the different growth stages and after harvesting. The maximum detrimental effects were consistently observed at 25 Kr, while lower doses showed comparatively lesser or negligible impacts. Overall, gamma radiation induced both stimulatory and inhibitory effects depending on the dose applied. Low to moderate doses could be potentially utilized to induce desirable mutations and enhance certain traits, but higher doses proved detrimental, severely hampering the plant's growth, development, and biochemical integrity. These findings provide valuable insights into the dose-dependent effects of gamma radiation and suggest that careful optimization of radiation levels is essential for its application in crop improvement programs targeting stress resilience and genetic variability in *Zea mays*.

REFRENCES

Ahmad, I. M., & Khalid, S. (2021). Impact of gamma irradiation on morphological and genetic characterization of Pea (Pisum sativum L.).

Al-Bachir, M. (2021). Microbial, chemical and sensorial properties of irradiated sunflower (Helianthus annuus L.) Seeds. *Journal of Stress Physiology & Biochemistry, 17*(2), 88-97.

Ali, H., Ghori, Z., Sheikh, S., & Gul, A. (2015). Effects of gamma radiation on crop production. In *Crop Production and Global Environmental Issues* (pp. 27-78): Springer.

Borzouei, A., Kafi, M., Khazaei, H., Naseriyan, B., & Majdabadi, A. (2010). Effects of gamma radiation on germination and physiological aspects of wheat (Triticum aestivum L.) seedlings. *Pak. J. Bot, 42*(4), 2281-2290.

Hameed, A., Shah, T. M., Atta, B. M., Haq, M. A., & Sayed, H. (2008). Gamma irradiation effects on seed germination and growth, protein content, peroxidase and protease activity, lipid peroxidation in desi and kabuli chickpea. *Pak. J. Bot, 40*(3), 1033-1041.

Hasan, M., Hanafiah, M., Taha, Z., & Alhilfy, I. (2020). Effect of low-intensity laser irradiation on field performance of maize (*Zea mays* L.) Emergence, phenological and seed quality characteristics. *Applied ecology and environmental research, 18*(4), 6009-6023.

Horn, L. N. (2016). *Breeding cowpea (Vigna unguiculata [L.] Walp) for improved yield and related traits using gamma irradiation.* University of KwaZulu-Natal, Pietermaritzburg,

Huumonen, K. (2016). *Studies on genomic instability induced by radiation and chemicals.* Itä-Suomen yliopisto,

Kämpfer, P., Busse, H.-J., McInroy, J. A., & Glaeser, S. P. (2015). Elizabethkingia endophytica sp. nov., isolated from Zea mays and emended description of Elizabethkingia anophelisKämpfer et al. 2011. *International journal of systematic and evolutionary microbiology, 65*(7), 2187-2193.

Maity, J. P., Chakraborty, S., Kar, S., Panja, S., Jean, J.-S., Samal, A. C., . . . Santra, S. C. (2009). Effects of gamma irradiation on edible seed protein, amino acids and genomic DNA during sterilization. *Food chemistry, 114*(4), 1237-1244.

Majeed, A., Muhammad, Z., Ullah, R., & Ali, H. (2018). Gamma irradiation i: effect on germination and general growth characteristics of plants–a review. *Pakistan Journal of Botany, 50*(6), 2449-2453.

Nasab, S. S., Zare, L., Tahmouzi, S., Nematollahi, A., Mollakhalili-Meybodi, N., Abedi, A.-S., & Delshadian, Z. (2023). Effect of irradiation treatment on microbial, nutritional and technological characteristics of cereals: A comprehensive review. *Radiation Physics and Chemistry, 212*, 111124.

Nayak, D., Patil, N., Behera, L., & Jadeja, D. (2015). Effects of gamma rays on germination and growth in Jatropha curcas L. *Journal of Applied and Natural Science, 7*(2), 964.

Raina, A. (2018). *Studies on the Induction and Screening of High Yielding Mutants in Cowpea [Vigna Unguiculata (L.) Walp.].* Aligarh Muslim University,

Rifna, E., Ramanan, K. R., & Mahendran, R. (2019). Emerging technology applications for improving seed germination. *Trends in food science & technology, 86*, 95-108.

Singh, P., & Kumar, R. (2019). Radiation Physics and Chemistry of Polymeric Materials. In *Radiation Effects in Polymeric Materials* (pp. 35-68): Springer.

Tasneem, A. (2004). Postharvest treatments to reduce chilling injury symptoms in stored mangoes.

Thirumal, G. (2016). *Study of the different factors influencing the shelf life of carrier based biofertilizers.* Professor Jayashankartelangana State Agricultural University Hyderabad, India,

Zarei, T., Moradi, A., Kazemeini, S. A., Farajee, H., & Yadavi, A. (2019). Improving sweet corn (Zea mays L. var saccharata) growth and yield using Pseudomonas fluorescens inoculation under varied watering regimes. *Agricultural Water Management, 226*, 105757.

Zied, D. C., & Pardo-Gimï, A. (2017). *Edible and medicinal mushrooms: technology and applications*: John Wiley & Sons.