Environment Protection Engineering

Vol. 52 2026 No. 1

DOI: 10.37190/epe/217088

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GENOTOXIC EFFECTS OF GAMMA RADIATION ON *Allium cepa* ROOT CELLS AT DIFFERENT DOSES

This study aimed to evaluate the cytogenetic effects of gamma radiation on meristematic cells of *Allium cepa* roots by analyzing chromosomal aberrations induced by different radiation doses. Six experimental groups were examined: one control group and five groups exposed to gamma radiation doses of 10, 20, 30, 40, and 50 Gy. Irradiation was performed using a linear accelerator Siemens Primus 5472. At the 10 Gy dose, only a slight reduction in the mitotic index was observed compared to the control. In contrast, exposure to 40 and 50 Gy resulted in a pronounced and statistically significant decrease in mitotic activity ($p \leq 0.001$), indicating strong inhibition of cell division. Various chromosomal aberrations, including anaphase bridges, micronuclei, and laggard chromosomes, were detected in irradiated samples, with their frequency increasing markedly at doses between 30 and 50 Gy ($p \leq 0.001$). Overall, the results demonstrate that gamma radiation induces clear cytotoxic and genotoxic effects in *Allium cepa* root cells in a dose-dependent manner. The highest doses produced the most severe effects, characterized by reduced mitotic activity and increased chromosomal damage.

1. INTRODUCTION

In recent years, interest in the application of gamma radiation in biological research, particularly in agriculture, has increased considerably. Numerous studies focused on how gamma radiation influences plant tissue physiology and on its use in inducing mutations aimed at generating plant varieties with improved resistance to environmental stress. Due to its high energy and deep tissue penetration, gamma radiation is widely applied for inducing controlled genetic changes [1, 2].

Meristematic cells in plant roots are particularly sensitive to external factors because of their continuous mitotic activity and lack of cellular differentiation. This makes them

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suitable for cytogenetic assessments. Among plant species, *Allium cepa* is frequently used in genotoxicity testing because of its relatively low chromosome number and large chromosome size, which facilitates microscopic observation. The onion root assay has been adopted in many toxicological studies for evaluating the effects of both chemical and physical agents, as well as environmental pollutants [3, 4].

Previous studies demonstrated that gamma radiation can act as a mutagenic agent, contributing to phenotypic variation for plant improvement programs. However, the cellular response to different doses, particularly in root meristems, remains insufficiently clarified. Low doses (1–5 Gy) were reported to increase mitotic activity in some cases [5–7], while higher doses (above 30 Gy) are typically associated with cytogenetic abnormalities such as chromosome fragments, anaphase bridges, micronuclei, and binucleated cells [8–10]. The extent of these effects appears to be influenced by several variables, including radiation dose, exposure duration, and the physiological status of the plant material.

The objective of this study was to evaluate the effects of gamma radiation doses on the meristematic cells of onion roots. Standard cytogenetic endpoints were used, including the mitotic index and chromosomal aberration frequencies. These parameters allowed us to assess the degree of cellular damage as a function of radiation dose. This experimental approach also provides translational relevance, as it utilizes radiotherapy equipment designed for human treatment to explore radiation effects in plant systems. The findings from this work may offer insights not only for radiobiological plant research but also for environmental safety and plant breeding applications through controlled mutagenesis. This study also introduces distinctive methodological elements compared to previous work in the field. The use of a Siemens Primus 5472 medical linear accelerator, typically applied in clinical radiotherapy, represents a novel approach for plant cytogenetic assays, providing highly accurate and reproducible dose application. In addition, a rigorous dose verification procedure was implemented using Gafchromic™ HD-V2 films analyzed with a spectrophotometer, which ensured precise measurement of absorbed doses. These aspects clearly differentiate our study from earlier *Allium cepa* investigations and add methodological robustness to the evaluation of gamma radiation effects on plant meristematic cells.

2. MATERIALS AND METHODS

The biological material used in this study was common onions (*Allium cepa* L.), widely known as a test organism for the evaluation of cytotoxic and cytogenetic effects of physical and chemical agents [11]. Onions of the same size (30–40 mm in diameter), without external damage, grown under controlled conditions were selected to ensure biological uniformity and minimize experimental variability. The onions were washed in running water for 24 h to remove any surface contaminants and then placed base down in glass beakers filled with distilled water to stimulate root development. After 72 h, when the roots reached a length of 2–3 cm, they were prepared for gamma irradiation treatment.

Gamma radiation equipment and dosimetry. Irradiation of onion (*Allium cepa*) root tips was performed at the Oncology Clinic of the UCCK using a Siemens Primus 5472 Linear Accelerator. This equipment includes a 3D computerized water phantom system and 82 multi-leaf collimators (MLC) for precise dose distribution. Before the experiment, the device was calibrated by medical technologists to ensure uniform dose distribution. The samples were placed at a distance of 30 cm from the source under controlled laboratory conditions. Doses of 10–50 Gy were applied to separate experimental groups, each group receiving a single dose, with a constant radiation intensity of 2–10 Gy/min. Samples were divided into one control group (0 Gy) and five experimental groups according to the applied radiation dose: 10 Gy (group B), 20 Gy (group C), 30 Gy (group D), 40 Gy (group E), and 50 Gy (group A). Dose monitoring was performed using Gafchromic™ HD-V2 films, placed next to the samples and later analyzed with a spectrophotometer to verify absorption. The application of acute doses in this range is supported in international literature as an effective method for testing radiation effects on plant cells [9].

Fixation and preparation of microscopic slides. After irradiation, roots were kept in distilled water for 24 hours to allow partial recovery of meristematic cells and resumption of the cell cycle. They were then fixed in a solution consisting of ethanol and acetic acid in a ratio of 3:1 for 24 hours at 4 °C. For cytological analyses, apical segments of roots (1–2 mm) were treated with 1 N hydrochloric acid at 60 °C for 5 minutes to soften the tissues, and then stained with acetocarmine and Giemsa for 15 minutes. The preparations were analyzed under an optical microscope at 1000× magnification (with immersion oil) to assess mitotic indices and identify chromosomal abnormalities. 2000 cells were analyzed for each sample.

Cytogenetic indices used in the analysis. To evaluate the impact of different doses of gamma radiation on cell division and genetic changes of *Allium cepa* root meristematic cells, three main cytogenetic indices were used:

Mitotic Index (*MI*), which reflects the percentage of cells in mitosis of the total number of cells counted. This index serves as an indicator of the division activity of meristematic tissues and was calculated according to the formula:

$$MI = \frac{\text{Number of cells in mitosis}}{\text{Total number of counted cells}} \times 100\%$$

Chromosomal aberration index (*CAI*), which reflects the percentage of mitotic cells exhibiting chromosomal damage (such as fragments, bridges, micronuclei, etc.), was calculated using the following formula:

$$CAI = \frac{\text{Number of aberrant cells in mitosis}}{\text{Total number of mitotic cells}} \times 100\%$$

Total aerration index (*TAI*), which evaluates the total number of aberrations observed in relation to all mitotic cells analysed (in %). This index helps identify the total genotoxic load and is calculated as:

$$TAI = \frac{\text{Number of aberrant cells}}{\text{Total number of analyzed cells}} \times 100\%$$

Statistical analysis. The data were analyzed using Student's *t*-test (two independent samples) to assess differences between groups. Since multiple pairwise comparisons were performed, we acknowledge the possibility of increased false positive rates. However, this approach was chosen to maintain direct comparability between each treatment group and the control. All statistical analyses were conducted using GraphPad Prism v.10, with significance set at $p \leq 0.05$.

3. RESULTS AND DISCUSSION

After treating *Allium cepa* roots with different doses of gamma radiation, microscopic analysis was done of the fixed and stained preparations to evaluate the effect on cell division. The cells in different mitotic phases were counted, and statistical analysis was done using the independent *t*-test to compare the differences between groups.

The data show that there are statistically significant differences in the frequency of mitotic phases between the treated groups and the control group (group K). For example, the group treated with 50 Gy (group A) showed very pronounced differences with the control group in all phases of mitosis ($p \leq 0.0001$), suggesting a strong effect of the high dose of radiation on the cell cycle. The same thing was noticed also for the other treated groups, where the differences with the control group were significant (usually with $p \leq 0.0001$).

In the A:E comparison (50 Gy vs. 10 Gy), a highly significant difference was observed in interphase, prophase, and metaphase ($p \leq 0.0001$), indicating that the 10 Gy dose also affects the cell division process, although to a lesser extent than higher doses. Between the intermediate dose groups (B with D, C with E), the differences are more limited and not always significant. For example, the comparison C:D does not give significant values in any phase (all $p > 0.05$), suggesting that the effect of the 30 and 20 Gy doses on cell division is similar.

An important observation is that the most pronounced differences are in interphase and prophase, while for anaphase and telophase, the *p*-values are usually higher, which means that these phases are less affected or maybe are harder to analyze accurately under the microscope. In general, the results show that gamma radiation has a dose-dependent effect on cell division, and that the effect becomes more visible with the increase of dose. Table 1 clearly presents these differences for each mitosis phase and for each comparison between the treated groups and the control.

Table 1

Statistical comparison of mitotic phase frequencies between experimental groups (A = 50 Gy, B = 40 Gy, C = 30 Gy, D = 20 Gy, E = 10 Gy, K = control) using unpaired *t*-test

Comparison	Interphase	Prophase	Metaphase	Anaphase	Telophase
A:B	0.04	0.04	0.1	1	1
A:C	0.008	0.005	0.1	0.7	0.1
A:D	0.0001	0.0001	0.0006	0.4	0.05
A:E	0.0001	0.0001	0.0001	0.4	0.001
A:K	0.0001	0.0001	0.0001	0.0001	0.0001
B:C	0.2	0.5	0.8	0.7	0.1
B:D	0.003	0.09	0.01	0.4	0.01
B:E	0.0004	0.04	0.0008	0.4	0.001
B:K	0.0001	0.0001	0.0001	0.0001	0.0001
C:D	0.06	0.2	0.06	0.6	0.4
C:E	0.004	0.08	0.004	0.7	0.01
C:K	0.0001	0.0001	0.0001	0.0001	0.0001
D:E	0.1	0.3	0.09	0.8	0.1
D:K	0.0001	0.0001	0.0001	0.0001	0.0001
E:K	0.0001	0.0001	0.0001	0.0001	0.0001

Each value represents the comparison of phase frequencies between two groups. Sample size *n* = 2000 cells analyzed per treatment group.

Table 2

Effect of gamma radiation doses on the mitotic activity and frequency of chromosomal aberrations in *Allium cepa* root meristem cells

Radiation dose [Gy]	Number of analyzed cells	Interphase	*MI* [%]	*CAI* [%]	*TAI* [%]	Number of aberrant cells in mitosis	Number of cells in different phases of the cell cycle				
							Total No. of mitotic cells	P	M	A	T
50	2000	1947	2.65	50.9	1.35	27 ±3.2	53	37	10	4	2
40	2000	1933	3.35	50.7	1.74	34 ±1.9	67	46	15	4	2
30	2000	1924	3.81	23.6	0.95	18 ±3.2	76	49	16	5	6
20	2000	1906	4.72	29.7	1.43	28 ±7.4	94	54	24	7	9
10	2000	1887	5.65	46.9	2.65	53 ±5.6	113	60	30	6	17
Control	2000	1643	17.8	6.72	1.27	24 ±8.9	357	164	81	35	77

P – prophase, M – metaphase, A – anaphase, T – telophase.

When the individual phases of mitosis are examined more closely, clear differences in their sensitivity to gamma radiation can be observed. phasesphase, prophase, and metaphase appear to be the most affected phases, as these show the highest number of comparisons with very low *p*-values ($p \leq 0.0001$), especially when treated groups are compared with the control group. This may be related to the fact that important changes happen during these phases, such as cell preparation for division, chromatin organization, and mitotic spindle formation. On the other hand, for anaphase and telophase, there are fewer significant differences, which may suggest either lower sensitivity in these stages or possibly some difficulty in accurately identifying them during microscopic observation.

From the data presented in Table 2, it is clearly seen that the increase in gamma radiation dose causes a decrease in the mitotic index and an increase in the percentage of cells with aberrations. In the control group (without radiation), the mitotic index was higher (17.8%), with only 24 cells showing mild forms of aberrations, and a very low percentage (6.62%). On the other hand, the groups treated with progressively higher doses showed a clear trend of decreasing mitotic activity. For example, in the group treated with 50 Gy, the *MI* dropped to 2.65%, while about half of the mitotic cells had different forms of chromosomal aberrations (50.9%). Also in the group with 40 Gy, a high percentage of damaged cells was observed (56.7%), indicating a strong impact of this dose on the chromosome structure during cell division.

At lower doses (10, 20, 30 Gy), moderate changes were observed. The percentage of cells with aberrations in mitosis was lower, but still distinguishable. At 10 Gy, 46.9% of the mitotic cells showed aberrations, displaying a noticeable effect even at lower doses. From microscopic observation, several different types of chromosomal damage were identified, including micronuclei, lagging chromosomes, chromosomal fragments, anaphase and telophase bridges, irregular metaphases, disoriented chromosomes, as well as binucleated cells. They were observed more frequently in the metaphase and prophase phases, indicating their sensitivity to radiation effects. Micronuclei appeared especially at doses of 10 and 20 Gy, being considered an early indicator of genetic material damage.

Another observation was the change in the distribution of cells across the mitotic phases. In the control group, the ratio between prophase, metaphase, anaphase, and telophase was balanced. However, in the treated groups, especially those exposed to 30, 40, and 50 Gy, a higher accumulation of cells was noticed in prophase and much fewer in the final stages, like anaphase and telophase. This suggests that cell division may be blocked in the early stages due to damage in the mechanisms that regulate the cell cycle.

In some preparations, especially after irradiation of 10 and 20 Gy, some cells had initiated division but failed to complete it. These cells, arrested at an intermediate stage of mitosis, are referred to as cells in delayed mitosis. This phenomenon may result from damage to microtubules or from the absence of regulatory signals required for progression into the next stage of the cycle. Such delayed cells were mostly observed in the root tip regions, where mitotic activity is normally higher.

Furthermore, in some of the preparations from the 40 and 50 Gy groups, sticky chromosomes were observed. These chromosomes appear clumped together and are very difficult to separate during anaphase. This type of damage was not previously mentioned but is quite important, as it indicates a disruption in the DNA structure or in the proteins that help chromosomes stay organized and functional. Another interesting finding was the percentage of micronuclei at different doses. Although micronuclei were found in all treated groups, they were more prominent in the group treated with 20 Gy. This suggests that higher doses do not always cause the highest percentage of damage, as at very high doses, cells may not enter mitosis at all, preventing the formation of micronuclei. In contrast, intermediate doses may cause more chromosomal fragmentation that leads to the appearance of micronuclei.

In the comparative analysis between the 20 and 30 Gy doses, it was found that the effect on the mitotic index and chromosomal aberrations was stronger at 30 Gy. This indicates that the damage sometimes follows a threshold pattern, where specific doses trigger a stronger stress response in the cells. These results confirm the idea that gamma radiation clearly affects cell division in a dose-dependent manner, causing visible changes in mitotic phase distribution, chromosome structure, and overall appearance of the treated cells.

The *CAI* is much more sensitive to gamma radiation doses than the *TAI*. The *CAI* values reached up to 50.9% in the 50 Gy group and remained almost the same at 50.7% in the 40 Gy group. These high values indicate that a large proportion of the few cells still capable of entering mitosis were severely damaged. In contrast, in the middle-dose groups, the *CAI* decreased to 23.6% and 29.7%, respectively. Probably at these doses, many cells are already affected earlier in the cell cycle and fail to enter mitosis, which lowers the proportion of dividing cells showing visible aberrations. The paradoxical trend of *CAI*, with a decrease at intermediate doses compared to 10 Gy and a subsequent increase again at higher doses, can be interpreted in relation to the *MI*. At 20–30 Gy, cell division is only partly inhibited, which reduces the percentage of cells with visible chromosomal aberrations. However, at the highest doses, the *MI* becomes extremely low, reflecting severe cytotoxicity and widespread cellular damage. Under such conditions, the few cells that still manage to enter mitosis exhibit a disproportionately high number of chromosomal aberrations, which results in an apparent rise of the *CAI*. This clarification highlights that the increase in *CAI* at high doses is not a sign of tolerance, but rather a relative effect caused by the collapse of normal mitotic activity. Under 10 Gy, the *CAI* also reached a high level (46.9%), confirming that even relatively low doses can induce considerable chromosomal damage in mitotic cells. In contrast, the control group maintained a much lower *CAI* (6.72%), which reflects the natural baseline of spontaneous aberrations in untreated dividing cells. On the other hand, the *TAI* did not show marked variation between groups. Even at 50 Gy, the *TAI* was only 1.35%, slightly higher than the control (1.27%). Interestingly, the highest *TAI* was found at 10 Gy (2.65%), which may seem unusual at first. However, at this lower dose, many cells are still able to proceed into division and therefore display aberrations, while at higher doses, a large proportion of cells are blocked before mitosis and thus cannot be included in the *TAI* count. Overall, the *CAI* proved to be a more sensitive and reliable index than the *TAI* for evaluating the genotoxic effects of gamma radiation during cell division. While the *TAI* provides a general overview, it does not fully reflect the extent of radiation-induced chromosomal damage, especially under conditions where mitotic activity is severely reduced. Therefore, the *CAI* remains the more valuable index for assessing radiation-induced genetic instability in dividing cells.

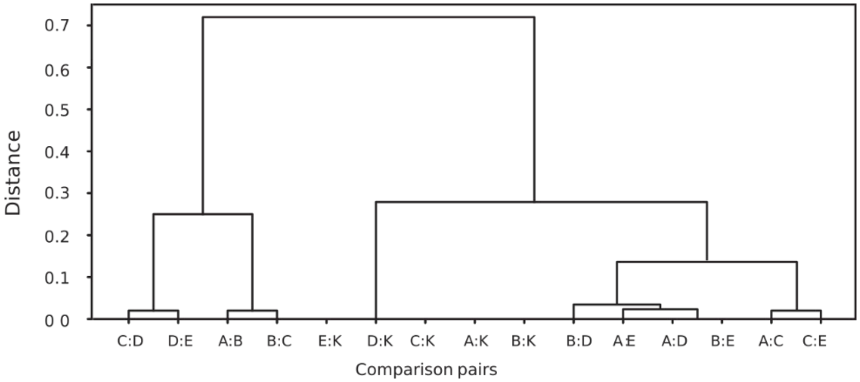

Fig. 1. Dendrogram of comparative groups (A – 50 Gy, B – 40 Gy, C – 30 Gy, D – 20 Gy, E – 10 Gy, K – control) based on *p*-values from the statistical analysis of mitotic phase frequencies. Clustering indicates similarity in cytogenetic responses among groups; $n = 2000$ cells per group

Figure 1 shows the dendrogram that reflects the relationships between the experimental groups based on the *p*-values from the statistical analyses performed for mitotic phases. The most similar groups, such as A and B or A and C, are grouped at shorter distances, which means that the differences between them were not very significant. These doses are very similar, and the radiation effect varied only slightly between them. On the other hand, groups that include comparisons with the control group, like A:K, B:K, or D:K, are located on the outer branches of the dendrogram, showing large distances. This indicates big differences between the cells in the control group and those treated with different doses of radiation. That was expected, since the control group was not exposed to radiation, so mitotic activity and chromosomal structure remained normal. Groups like D:E or C:E are placed closer together, which might mean a similar cellular response to these two radiation doses, probably because the effect of radiation wasn't as drastic at lower doses. Overall, the dendrogram supports what was already seen in the individual analyses: increasing the radiation dose increases the differences from the control group, and groups with similar doses tend to show similar biological responses at the level of the cell cycle.

In Figure 2, it is clearly seen that with the increase in gamma radiation dose, two main changes happen in the meristematic cells of *Allium cepa*: the mitotic index decreases, and the percentage of cells with chromosomal aberrations increases. In the control group, which was not exposed to any radiation, the mitotic index was the highest (17.8%). This shows that the cells in this group divided normally and had no problems in the cell cycle.

Also, the percentage of aberrant cells was very low, only 6.62%, which is considered a normal value for healthy meristem tissue. Once radiation is applied, the mitotic index drops quickly. For example, in the group treated with 10 Gy, it decreased to 5.65%, while at 50 Gy, it decreased to only 2.65%. This means that radiation decreases or even blocks cell division. In other words, the higher the dose, the fewer cells manage to enter mitosis.

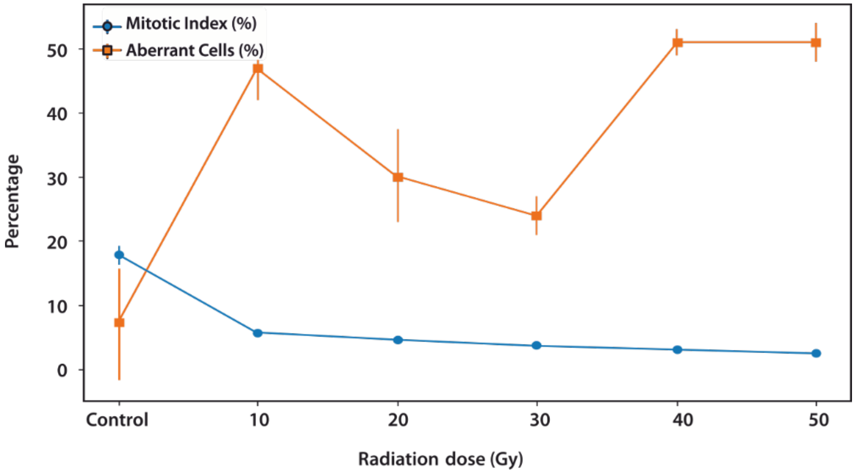

Fig. 2. Effect of gamma radiation doses on the *MI* and percentage of aberrant cells in *Allium cepa* root meristem. Data for *MI* are shown as mean values, while aberrant cells are presented as mean±SD ($n = 2000$ cells per group). Error bars represent variability across replicates for aberrant cells

At the same time, the percentage of cells with damage increases with the dose. Under 10 Gy, around 47% of the mitotic cells showed damage, while for 40 and 50 Gy, it was over 50%. Even the cells that entered mitosis did so with damaged structures, particularly chromosomes. However, at some intermediate doses, like 30 Gy, the percentage of aberrant cells was lower (23.8%) compared to 10 and 20 Gy. This might be because, at that dose, many cells were too damaged to even enter mitosis, so the few that did looked better in percentage. It seems that gamma radiation exerts a dual effect: it reduces the number of dividing cells while increasing the level of damage in the cells that continue to divide. This effect is dose-dependent and becomes more noticeable at higher levels of exposure.

Gamma radiation significantly affects cell division and genetic stability in the meristematic cells of *Allium cepa*. The progressive decrease in the *MI* with increasing radiation doses is one of the clearest indicators of cell cycle inhibition. In the control group, the *MI* was 17.8%, whereas under 50 Gy, it decreased to only 2.65%, indicating that most cells failed to enter mitosis after exposure to high doses.

Similarly, existing literature reported strong inhibition of mitosis following irradiation. The reduction of *MI* at higher doses is likely due to DNA damage and impairment of proteins involved in regulating cell division. We also observed a significant increase in the percentage of cells with chromosomal aberrations (*CAI*) and in the *TAI*. Under 40 and 50 Gy, more than half of the mitotic cells displayed visible damage. These results are consistent with those of Bolsunovskyt et al. [12], who showed a variety of aberrations, such as chromosomal bridges, fragments, micronuclei, and lagging chromosomes.

The highest frequency of aberrations was observed in prophase and metaphase, indicating that these stages are particularly sensitive to genotoxic stress. This sensitivity has also been described by Chakravarty and Sen [13] and confirmed in newer studies using techniques like the comet assay. The damage at these stages may be related to the fragility of spindle formation and chromosome condensation, which are easily disrupted by radiation. Micronuclei, small nuclear bodies that separate from the main nucleus and indicate DNA damage, were most prominent in the 10 and 20 Gy groups. These are early markers of genomic instability and, according to Ulukapi and Nasircilar [14], can be induced even by low doses of gamma radiation that are not necessarily lethal but stressful enough to interfere with DNA repair pathways.

The most evident aberrations, including chromosomal bridges, fragments, and lagging chromosomes, were observed for 48 hours post-exposure, corresponding to the period when radiation effects were most pronounced. This timing aligns with classic Allium test protocols, such as those described by Fiskesjö [11], where fixation at 48 hours is recommended to capture peak mitotic damage.

In the dendrogram analysis (Fig. 1), high-dose groups formed clusters clearly separated from the control group, reflecting a distinct cytological damage pattern. Groups with similar doses, such as 20 and 30 Gy, showed similar biological responses and clustered more closely together, suggesting a gradual damage progression rather than an abrupt reaction. An interesting observation from the literature is that DNA damage does not always increase linearly with the radiation dose. Bolsunovsky et al. [15] noted that beyond a certain threshold, the level of damage plateaued, suggesting that cells may activate protective DNA repair mechanisms. In a follow-up study [16], the same authors reported that some cells resumed mitosis 72–96 hours post-exposure, indicating possible recovery under certain conditions.

This recovery is likely linked to the activation of DNA repair pathways, including homologous recombination mediated by RAD51 and ATM proteins, which are critical for resolving double-strand breaks, especially during the S and G2 phases of the cell cycle [17, 18]. Another aspect worth mentioning is oxidative stress. Gamma radiation exposure generates reactive oxygen species (ROS), which damage not only DNA but also other cellular structures. Kumar et al. [5] reported increased activity of protective enzymes such as superoxide dismutase and catalase in plants exposed to radiation, suggesting an immediate cellular response to oxidative stress. This component could be an interesting subject for future research to combine cytogenetic analysis with biochemical markers.

The present results are consistent with previous studies [5, 9, 19, 20], which reported similar types of aberrations in *Allium cepa* after gamma irradiation. These authors emphasized the importance of monitoring specific damage types, such as micronuclei and lagging chromosomes, to assess the effects of varying radiation doses. According to these reports, such cluster analyses are valuable for understanding radiation effects in experimental therapy and clinical settings. Controlled and repeatable irradiations were performed using the Siemens Primus 5472 device at UCCK, establishing a model system suitable for investigating the biological effects of radiation. Another important observation is that the threshold for irreversible damage in *Allium cepa* appears to be around 40 Gy, since at this dose the *MI* drops below 3% and chromosomal damage becomes extensive. This supports the conclusions of Kumar et al. [5] and others who consider this to be the point beyond which recovery of the cell cycle is unlikely.

From an application perspective, our results are significant for plant mutagenesis and breeding programs. If genetic changes are desired without total loss of cell viability, the 10–20 Gy range appears optimal. This has also been emphasized by Ulukapi and Nasircilar [14], who describe this range as the ideal balance between mutagenic effect and cytotoxicity.

A relevant comparison can be drawn with the study by Elezaj et al. [21], who investigated the genotoxic effects of industrial pollution on *Tradescantia pallida*. Although the agent was different (*p*olluted water containing radionuclides), the observed effects, micronuclei, lagging chromosomes, and reduced *MI* were similar to those seen in our study. This supports the idea that *Allium cepa* and similar plant species are highly sensitive and reliable indicators for testing the genotoxicity of environmental stressors.

4. CONCLUSION

Gamma radiation was shown to affect cell division and the genetic structure of *Allium cepa* meristematic cells. When the dose increased, the number of dividing cells decreased gradually. The mitotic index decreased progressively with increasing dose and was reduced to a very low level at 50 Gy.

In parallel, the number of cells exhibiting chromosomal abnormalities increased in the groups treated with 40 and 50 Gy. Chromosomal bridges, fragments, micronuclei, and lagging chromosomes were predominantly observed. Most of the damage occurred in prophase and metaphase, which appear to be the most sensitive stages under radiation stress.

The presence of micronuclei was also detected at lower radiation doses. This indicates that even relatively low radiation doses can compromise DNA stability and induce subtle cellular alterations that may affect cell function. Analysis of the data and the dendrogram revealed distinct dose-dependent responses among the experimental groups. With increasing dose, the treated groups showed progressively greater divergence from the control group, indicating a gradual and non-random pattern of damage.

Another important finding was that beyond a threshold dose of approximately 40 Gy, the extent of damage exceeded the cellular repair capacity. The mitotic index decreased below 3%, and most dividing cells exhibited abnormal characteristics. From a practical perspective, doses of 10 or 20 Gy appear more suitable for inducing genetic changes without destroying the tissue. This dose range may be particularly relevant for plant breeding studies and for improving the understanding of radiation effects on living systems. Overall, the present study demonstrates that *Allium cepa* is a sensitive and reliable model for assessing genotoxic effects. This model can be applied both under laboratory conditions and in field environments exposed to radiation or other environmental stressors.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Oncology Department of the University Clinical Center of Kosovo and its staff for their support in enabling the gamma irradiation procedures.

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