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Common onion extract (*Allium cepa*): radioprotective or radiosensitizing?

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Abstract: Currently, ionizing radiation has been used on a large scale in different areas of knowledge. However, despite the existence of several radioprotection regulations for workers, patients, and members of the public, these are not sufficient to completely limit the potential harm of ionizing radiation. In this way, there is currently an interest in finding radiomodifying substances with radioprotective or radiomitigating activity. Therefore, as a means of radioprotection, the use of radioprotective compounds is essential to preserve healthy cells from radiation-induced damage. Among these agents, the literature highlights natural compounds and extracts, one of which is *Allium cepa*, commonly known as "onion" - a plant with medicinal potential, as well as antitumoral and antioxidant properties. However, no studies have reported the application of onion extract as an antioxidant and radioprotective agent in mammalian cells. Thus, it is necessary to confirm the antioxidant and radioprotective capabilities of *A. cepa* extract in human lymphocytes, particularly for planned exposures to ionizing radiation. Accordingly, the aqueous extract of *A. cepa* bulbs was subjected to cell viability testing (MTT assay) and antioxidant capacity evaluation (ABTS and DPPH assays). Subsequently, in the presence of the extract, the micronucleus assay was performed in lymphocytes exposed to three absorbed radiation doses (ranging from 0.5 to 4 Gy). The results demonstrated that, depending on the radiation dose and extract concentration, *A. cepa* extract influences the formation of micronuclei. At the dose of 0.5 Gy, no statistically significant difference was observed between irradiated groups treated with or without the extract. At 2 Gy, an increase in micronucleus frequency was observed in the presence of the extract, whereas at 4 Gy, the opposite effect was noted. Our findings suggest that *A. cepa* extract is a compound with potential applications in the field of health-related radiation exposure, exhibiting dual behavior depending on its concentration and the radiation dose. These results pave the way for further investigations involving new extract concentrations, different absorbed radiation doses, and individual variability.

Keywords: radioprotectors, antioxidant, micronucleus, *Allium cepa*.

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Extrato comum de cebola (*Allium cepa):* radioprotetor ou radiossensibilizante?

Resumo: Atualmente, a radiação ionizante tem sido amplamente utilizada em diferentes áreas do conhecimento. No entanto, apesar da existência de diversas normas de radioproteção para trabalhadores, pacientes e membros do público, essas medidas não são suficientes para limitar completamente os possíveis efeitos nocivos da radiação ionizante. Por esse motivo, há um interesse crescente na busca por substâncias radiomodificadoras com atividade radioprotetora ou radiomitigadora. Portanto, como forma de radioproteção, o uso de compostos radioprotetores é essencial para preservar células saudáveis dos danos induzidos pela radiação. Entre esses agentes, a literatura destaca compostos e extratos naturais, sendo um deles o *Allium cepa*, conhecido popularmente como "cebola" — uma planta com potencial medicinal, além de propriedades antitumorais e antioxidantes. No entanto, nenhum estudo relatou a aplicação do extrato de cebola como agente antioxidante e radioprotetor em células de mamíferos. Assim, é necessário confirmar as capacidades antioxidante e radioprotetora do extrato de *A. cepa* em linfócitos humanos, especialmente para exposições planejadas à radiação ionizante. Para isso, o extrato aquoso dos bulbos de A. cepa foi submetido a testes de viabilidade celular (ensaio MTT) e avaliação da capacidade antioxidante (ensaios ABTS e DPPH). Em seguida, na presença do extrato, realizou-se o ensaio de micronúcleo em linfócitos expostos a três doses absorvidas de radiação (variando de 0.5 a 4 Gy). Os resultados demonstraram que, dependendo da dose de radiação e da concentração do extrato, o extrato de *A. cepa* influencia a formação de micronúcleos. Na dose de 0.5 Gy, não foi observada diferença estatisticamente significativa entre os grupos irradiados tratados ou não com o extrato. A 2 Gy, observou-se um aumento na frequência de micronúcleos na presença do extrato, enquanto a 4 Gy, foi notado o efeito oposto. Nossos achados sugerem que o extrato de *A. cepa* é um composto com potenciais aplicações na área de exposição à radiação relacionada à saúde, apresentando comportamento duplo dependendo da sua concentração e da dose de radiação. Esses resultados abrem caminho para novas investigações, envolvendo diferentes concentrações do extrato, diferentes doses absorvidas de radiação e variabilidade individual.

Palavras-chave: radioprotetores, antioxidante, micronúcleo, *Allium cepa.*

1. INTRODUCTION

Radiation can be defined as energy present between the electrons of atoms, which can be dissipated in the form of particles or electromagnetic waves. When this energy is strong enough to remove electrons from other molecules and form ions, it is classified as ionizing radiation [1].

The use of ionizing radiation is increasing in society, particularly in sectors such as industry, food, and, primarily, in medicine. Studies indicate that at least half of cancer patients will require radiotherapy at some point during their treatment. Considering this, the use of radioprotective compounds, which protect healthy cells from radiobiological effects, becomes essential, as well as the use of agents that can enhance radiation-induced cell death in tumor cells (radiosensitizers) [2,3].

These agents can be of natural or synthetic origin; however, to be classified as a radioprotector, they must possess at least one of a set of characteristics, such as: acting in cellular repair and DNA remodeling, promoting anti-inflammatory or healing effects, inducing apoptosis, enhancing the production of blood components, and capturing free radicals, thereby promoting an antioxidant effect [4].

Recently, there has been an increase in studies involving the use of natural plant materials and phytochemicals as radioprotective agents, proving to be effective substitutes for synthetic drugs without the associated side effects [5].

Several of these studies report that plants possess various medicinal properties, such as antioxidants, anti-inflammatories, anticancer, antimicrobials, analgesics, and antibiotics. Some of these studies also demonstrate the radioprotective properties of extracts, fractions, isolated compounds, and polysaccharides from various plants [6-9]. Most of the studies in question indicate that the radioprotection offered by the extracts is primarily due to the

antioxidant action of the plants, which leads to the sequestration of reactive oxygen species (ROS), thereby reducing indirect cellular damage.

Many of these plants have been used by humans since ancient times due to their medicinal effects. There is still much untapped potential in phytochemicals derived from plants that can act as radioprotectors, due to the presence of natural bioactive molecules with antioxidant properties, such as flavonoids and polyphenols [4,9-10].

Among these plant species is *Allium cepa*, commonly known as the common onion, which is widely used in the cuisine of various countries. It possesses numerous pharmacological properties and therapeutic effects, thanks to the active compounds present within it: saponins, aglycones, quercetin, cepaenes, flavonoids, organosulfur compounds, and phenolic compounds. In living organisms, these components can act in an anti-inflammatory, antimicrobial, anticancer, and primarily antioxidant manner, an ideal characteristic for a radioprotector. [11,12].

Considering this, this study aims to firstly investigate the antioxidant and radioprotective capacity of *Allium cepa* extract in human lymphocytes, under planned exposure to ionizing radiation. This investigation was carried out through antioxidant activity assays (ABTS and DPPH), as well as through the cytogenetic micronucleus assay via cytokinesis block.

2. MATERIALS AND METHODS

This study was conducted at the Laboratório de Dosimetria Biológica do Centro Regional de Ciências Nucleares do Nordeste – CRCN-NE, approved by the Research Ethics Committee of the Centro de Ciências da Saúde da UFPE (CCS-UFPE) under CAAE: 77151723.6.0000.5208 / Opinion: 6.702.069.

2.1 Selection of donors and sample collection

Three healthy, non-smoking individuals, who met the pre-established selection criteria [12], were selected as volunteers after signing the Informed Consent Form.

Subsequently, 5 mL of peripheral blood samples of each individual were collected for each concentration of *Allium cepa* extract.

2.2 Preparation of the aqueous extract

Approximately 100 g of onion pulp (*A. cepa*) was used, triturated with the addition of 200 mL of distilled water, followed by filtration and freezing [11]. After this process, the extract was lyophilized and diluted at 0.15 M NaCl.

2.3 Cell toxicity assay

To evaluate the interference of the extract on cell viability and its potential toxicity, the MTT assay was chosen [14]. For this purpose, a serial dilution (from 400 µg/mL to 25 µg/mL) of the extract in physiological saline was performed.

From the concentrations studied, two that showed a cell viability index above 50% were used to evaluate the radioprotective potential through the Cytokinesis Block Micronucleus Assay (CBMN).

2.4 Antioxidant capacity analysis ($DPPH^+$ method)

Since the literature indicates that the radioprotective capacity of natural extracts is due to their antioxidant abilities, the antioxidant activity of the *A. cepa* extract was tested by the reduction of the DPPH radical (2,2-diphenyl-1-picrylhydrazyl), following the methodology adapted from Blois et al. [15,16]. Concentrations ranging from 400 µg/mL to 25 µg/mL of the extract were tested.

After 25 minutes, absorbance readings were taken at a wavelength of 517 nm. Based on the readings and linear regression, the equation of the line and the R^2 value were obtained, which were necessary to determine the Percentage of Inhibition (I%).

2.5 Antioxidant capacity analysis by free radical capture ($ABTS^+$ method)

The ABTS spectrophotometric method was performed according to Re et al. (1999) [16]. The principle of the technique is based on the generation of the ABTS radical, which will be inversely proportional to the antioxidant capacity of the extract. A standard curve of gallic acid was constructed, with concentrations ranging from 15.6 to 500 μg/mL. At the end of the test, the values of the Percentage of Inhibition (I%) were determined.

2.6 Analysis of radioprotective capacity through the Cytokinesis Block Micronucleus Assay (CBMN)

2.6.1 Control Groups

The non-irradiated blood control was divided into untreated and treated groups at the selected concentrations, totaling three types of samples for this category. The non-irradiated and untreated blood was considered for the analysis of the background level of chromosomal alterations, i.e., micronuclei arising from clastogenic agents, and should be within the range of 0 to 40 micronuclei (MN) in 1,000 cells analyzed [13]. The non-irradiated and treated blood served to verify whether treatments with *Allium cepa* extract at these concentrations alter the natural frequency of micronuclei. The irradiated and untreated blood was considered the positive control for verifying the frequency of alterations caused by ionizing radiation at the absorbed doses under study (0.5 - 4 Gy).

2.6.2 Irradiated group treated with *Allium cepa* extract.

For the test samples, the aqueous extract of *Allium cepa* was added 30 minutes before irradiation, at two concentrations (50 and 200 μg/mL) chosen after the MTT tests [17].

2.7 Irradiation of the samples

The samples, either treated or untreated with the extract, were exposed to a ^{60}Co source. Irradiation was performed with an absorbed dose of 0.5, 2, and 4 Gy. The ^{60}Co source (Gammacell 220 irradiator) was located at the Departamento de Energia Nuclear at the Universidade Federal Pernambuco (DEN-UFPE, Brazil), where the 4 mm polyethylene barrier was used to ensure electronic equilibrium of the samples during irradiation (22°C).

The doses used were chosen according to the criteria established by the International Atomic Energy Agency, close to the LD_{50} in humans (2–3 Gy) [13]. The 0.5 Gy dose was also included in this study to investigate the behavior of the extract in sublethal doses.

2.8 Cell culture and slides preparation

After irradiation, the cell culture followed the protocol from the International Atomic Energy Agency (IAEA) manual [13].

For subsequent microscopic analysis, the slides were prepared from the cell precipitate and resuspended in 0.5 mL of fixative solution. The precipitate dropped onto a point on the slide, which was left to dry at room temperature for 24 hours. For staining, 5% Giemsa was used for 20 minutes.

2.9 Microscopic analysis

The micronucleus count was performed using an optical microscope, following the criteria of the International Atomic Energy Agency (IAEA) to determine the viable BN (bi-nucleated) cells and the acceptable micronuclei [13]. The morphological parameters used to identify micronuclei include: a diameter ranging from 1/16 to 1/3 of the size of the main nuclei, a clearly defined nuclear boundary, the absence of overlap between distinct micronuclei in the cytoplasm, and staining like or less intense than that of the main nuclei [18]. In this study, a total of 3.500 binucleated cells per group were used.

3. STATISTICAL ANALYSIS

After analyzing the slides, statistical calculations were performed, such as Papworth's U-test, to verify whether the distribution of micronuclei in the cells follows the Poisson distribution at the studied absorbed dose. The *U* test is a normalized unit of the dispersion index, where, for a perfect Poisson distribution, the index should be equal to one. However, with a 95% confidence interval, *u* values can vary between ±1.96, where values of *u* greater than 1.96 indicate significant overdispersion, and *u* values less than -1.96 indicate significant underdispersion. [13].

The ANOVA and Tukey's *t* tests were applied to assess the behavior between the different concentrations of the extract, as well as to verify the radioprotective efficacy of the extract. Differences were considered significant when the p-value was less than 0.05 ($p < 0.05$) [19].

4. RESULTS AND DISCUSSIONS

In the evaluation of cellular toxicity presented by the extract, the results shown in Table 1 were obtained. In this case, cell viability values are inversely proportional to the toxicity level of the extract. It can be observed that, at all tested concentrations, none showed cell death above 30%, indicating that all of them are safe for use in *in vitro* assays [20].

Table 1: Results of the cellular toxicity study, through the MTT assay, for the aqueous extract of Allium cepa.

Concentration of Sample (µg/mL)	Mean Absorbance	Cell Viability (%)
25	1	78.86
50	0.930	73.37
100	1.171	92.35
200	1.103	86.99
400	1.097	86.48

These results are consistent with the findings of Lee and collaborators (2023), where it was observed that, at concentrations ranging from 20 to 160 μg/mL, the aqueous extract of *A. cepa* induced cell viability above 70% in macrophage cultures [20]. Thus, any of the concentrations within the selected working range (25 to 400 μg/mL) were considered safe for application in the other tests of this study.

For the antioxidant activity assays of the extract, the results of both tests performed are shown in Table 2. It can be observed that, in the methodologies and concentrations used, the percentage of free radical inhibition remained below 10%, which is considered very low in comparison to the positive control (ascorbic acid, the standard antioxidant) [15].

In the ABTS test, it was observed that all the percentages of inhibition of oxidative radicals presented negative values, which would suggest that the extract did not show antioxidant activity. However, in the DPPH tests, there is an indication of antioxidant activity of the extract, albeit low.

Table 2: Results of antioxidant activity of A. cepa extract. I%: inhibition percentage of free radicals.

Concentration (μg/mL)	Mean Absorbance		% Inhibition	
	ABTS	DPPH	ABTS	DPPH
25	0.574	0.786	-16.194	1.810
50	0.572	0.768	-15.789	1.810
100	0.556	0.798	-12.550	0.310
200	0.560	0.802	-13.360	-0.120
400	0.522	0.755	-5.668	5.740

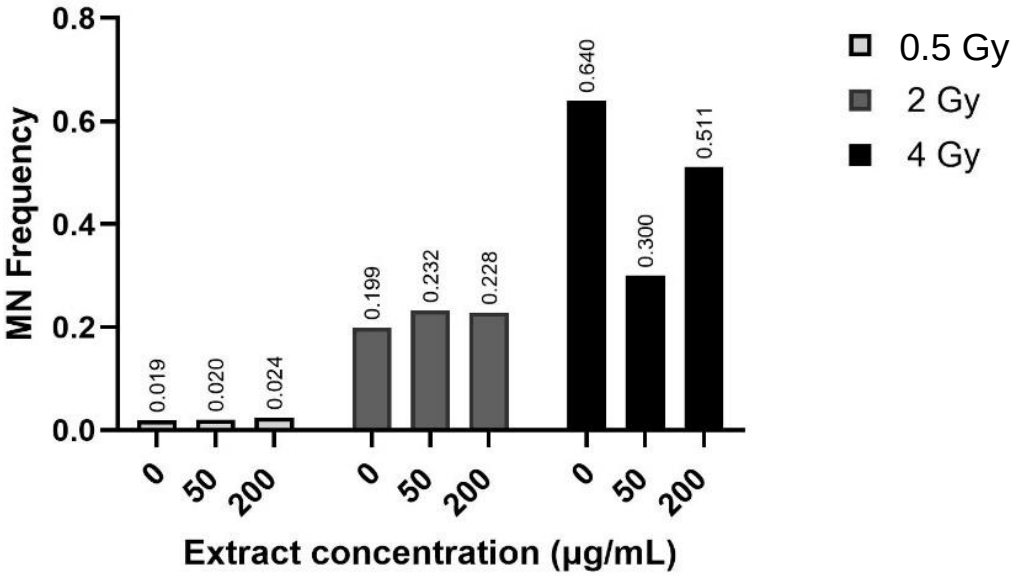
These findings are consistent with the study by Lee et al. (2023), which also observed low antioxidant activity in the aqueous extract of *A. cepa*, particularly when compared to standard antioxidants like ascorbic acid [21]. In this study, the antioxidant potential of onion skin extracts was evaluated using the DPPH test, the lipid peroxidation inhibition method, and the ferric thiocyanate (FTC) method. Among the three tests, the DPPH method showed the highest antioxidant activity. The FTC method demonstrated minimal antioxidant potential, while the lipid peroxidation inhibition method did not reveal any antioxidant effect

of the extracts. These results suggest that onion skin extracts neutralize radicals by donating hydrogen or electrons, rather than inhibiting lipid peroxidation.

Therefore, in the evaluation of the antioxidant capacity of *Allium cepa* extracts, it is evident that using multiple methodologies is crucial. This approach will provide a more comprehensive understanding of the extract's antioxidant potential, as different tests may highlight various aspects of its activity.

In Figure 1, it is possible to observe the micronuclei frequency of the CBMN tests obtained. At all doses, the conformity of the MN cell distribution with the Poisson distribution was tested using the *U-test*. It can be concluded that in all sample groups there was significant overdispersion in the distribution. The literature reports the behavior of overdispersion in most MN distributions at the 2 Gy dose in irradiated lymphocytes when compared to the Poisson distribution [13, 18, 22]. Therefore, the model used in this study was considered valid for evaluating the radioprotective effect of the extract.

Figure 1: Micronuclei frequency at lymphocytes irradiated in absence or presence of A. cepa extract. MN: micronuclei; Gy: absorbed dose.



The frequency of micronuclei for the negative control (only blood, non-irradiated) was 0.001, which is consistent with the literature that indicates values between 0 and 40 MN per 1000 cells [13]. The same behavior was observed in the groups containing the extract but not irradiated. This confirms that the extract of *A. cepa*, by itself, does not induce chromosomal breakage or the formation of MN, and therefore is not genotoxic at these concentrations.

As expected, for the irradiated control group (blood only, irradiated), an increase in the frequency of micronuclei was observed, as this sample was irradiated with all doses. According to the literature, there is a relationship between the absorbed dose and the frequency of MN, confirming that as the absorbed dose increases, the frequency of MN also increases [13]. The ANOVA analysis between the groups showed $p < 0.05$, indicating statistically significant differences between the groups with different treatments. These differences occurred due to the general comparison between irradiated and non-irradiated groups, which was expected.

When considering the 0.5 Gy dose in isolation (Table 3), the frequency of micronuclei (MN) in this sample group is lower than in the groups exposed to higher doses, as lower radiation doses result in less chromosomal damage, leading to fewer micronuclei formation [13]. The extract alone did not cause an increase in MN frequency, confirming that it is non-toxic at the tested concentrations, as also observed in the MTT assay.

Table 3: Results of the Micronucleus Assay with Cytokinesis Block (CBMN) at 0.5 Gy dose. MN: number of micronuclei, Y: frequency of micronuclei per group.

	Negative control	50 µg/mL Extract	200 µg/mL Extract	Irradiated control	Irradiated with 50 µg/mL	Irradiated with 200 µg/mL
MN	4	13	14	66	71	83
Y	0.001	0.004	0.004	0.019	0.020	0.024

In comparison with the MN frequencies of the irradiated without extract (irradiated control), no reduction in MN frequency was observed in the presence of the extract at either concentration. Under these conditions, the extract did not exhibit a protective effect.

Furthermore, it was observed that the two concentrations of the extract did not show statistically significant differences in the induction of MN formation when compared to each other.

These findings are like those reported for *Allium sativum* (garlic) extract. In the referenced study, a freshly prepared aqueous extract of garlic was tested in mice for its potential *in vivo* protective effect against gamma-radiation-induced chromosomal damage, at a range of doses from 0.25 to 2 Gy. It was observed that the extract influenced micronucleus frequency only at higher radiation doses, and dose-related effects of the treatment were observed only at 2 Gy [22].

At the 2 Gy dose, a statistically significant difference was observed between the negative control and the irradiated sample, confirming the validity of the assay. However, a significant difference was also observed between the irradiated blood without extract (irradiated control) and the irradiated samples with extract at both tested concentrations (Table 4).

In the presence of the extract, it was observed that radiation further induced the formation of micronuclei (MN). At the concentration of 50 µg/mL of the extract, the highest frequency of MN (0.232) was observed, compared to the irradiated control without the extract (0.199) and the non-irradiated control. Additionally, at the concentration of 200 µg/mL of the extract, a higher frequency of MN (0.228) was also observed.

Table 4: Results of the Micronucleus Assay with Cytokinesis Block (CBMN) at 2 Gy dose. MN: number of micronuclei, Y: frequency of micronuclei per group; *: $p < 0.05$ in comparison to the irradiated control.

	Negative control	**50 µg/mL Extract**	**200 µg/mL Extract**	**Irradiated control**	**Irradiated with 50 µg/mL**	**Irradiated with 200 µg/mL**
MN	26	24	29	695	812	798
Y	0.007	0.007	0.008	0.199	0.232*	0.228*

These findings are similar to those of Aghamohammadi *et al.* (2015), who observed the induction of cell damage and death in human glioblastoma cell lines, caused by the synergy between radiation doses and the *Zataria multiflora extract*. In the same study, no radiosensitizing effect of the extract was observed in non-cancerous cells [24].

However, using the Tukey *t-test* to compare our treatment versus treatment results, it was observed that the two concentrations of the extract, when compared to each other, do not show statistically significant differences in the induction of MN formation (p-value: 0.644). Therefore, pre-treatment with either concentration before irradiation with 2 Gy leads to augmented frequencies of micronuclei.

At the 4 Gy dose, a statistically significant difference was observed between the irradiated group without extract and the treated groups (Table 5). In the presence of the extract, a reduction in MN frequency was observed. Using the Tukey *t-test*, it was found that the extract concentration also influences MN formation, with the 50 µg/mL concentration resulting in fewer MN. Therefore, the extract at 50 µg/mL exhibited a greater radioprotective effect.

Table 5: Results of the Micronucleus Assay with Cytokinesis Block (CBMN) at 4 Gy dose. MN: number of micronuclei, Y: frequency of micronuclei per group, % of damage: estimated irradiation damage to the group; *: $p < 0.05$ in comparison to the irradiated control.

	Negative control	50 µg/mL Extract	200 µg/mL Extract	Irradiated control	Irradiated with 50 µg/mL	Irradiated with 200 µg/mL
MN	4	13	14	1919	1049	1788
Y	0.001	0.003	0.004	0.639	0.299*	0.510*

Those results show that *A. cepa* extract works in a dose and concentration-dependent manner to protect or induce radiation damage to human cells. This behavior was previously observed for amifostine, a synthetic drug widely used as a radioprotector [25]. Also, these findings open a new opportunity for further studies.

This kind of "bidirectional" or dose-dependent dual effect from *Allium cepa* (onion) extract likely comes from the interplay between its pro-oxidant and antioxidant activities—both of which are concentration- and stress-dependent [26].

Allium cepa contains quercetin, organosulfur compounds, and phenolics, which are potent ROS scavengers and metal chelators [26]. At 4 Gy, radiation generates a massive ROS burst that can overwhelm cellular repair capacity. Under this high-stress condition, the extract's

antioxidant systems should kick in strongly neutralizing ROS, stabilizing membranes, and upregulating endogenous defenses (e.g., Nrf2 pathway activation, increased glutathione). Then, the net effect is: DNA and membrane protection, hence a radioprotective behavior [27].

At 2 Gy, oxidative stress is moderate enough to trigger signaling but not complete catastrophic damage. Certain flavonoids (including quercetin) can act as pro-oxidants in the presence of transition metals or under mild stress, producing low levels of ROS [27]. These ROS can amplify DNA breaks or interfere with DNA repair machinery (e.g., by inhibiting topoisomerases or PARP), effectively sensitizing cells to radiation. Additionally, quercetin can modulate cell cycle checkpoints, holding cells in radiosensitive phases (G_2/M) [28].

In this way, these effects underpin the broader mechanism: at high radiation doses, the antioxidant effect of flavonoids like quercetin may dominate and protect cells, while at lower doses, their redox modulation could contribute to radiosensitization [27-30].

In summary, we observed dose-dependent enzyme modulation, as reported by other studies: high doses with *A. cepa* phytochemicals may strongly induce antioxidant enzymes (SOD, catalase), while moderate doses may not [29]. Also, cell types make the difference: the transition point may shift depending on baseline redox status and repair capacity. And, for those findings, a possible hormesis could be obtained as: low stress + phytochemicals push damage, high stress + phytochemicals activate survival pathways [30].

Recently, there has been an increase in studies involving natural plant materials and phytochemicals as efficient substitutes for synthetic radioprotectors [31]. Some of the studies in question aim to investigate the radioprotective potential of plants or combinations of different plant-based products.

Indeed, several studies report that plants possess a wide range of medicinal properties, including antioxidant, anti-inflammatory, anticancer, antimicrobial, analgesic, and antibiotic effects. Some of these studies demonstrate radioprotective properties of extracts, fractions, isolated compounds, and polysaccharides from various plants, such as black cumin (*Nigella*

sativa) [32], caimito (*Chrysophyllum cainito*) [33], Ceylon ironwood (*Mesua ferrea*) [34], ginseng (*Panax ginseng*) [35], among others. In this way, plant extracts are a universe of possibilities to be studied for radioprotection.

5. CONCLUSIONS

Our preliminary results demonstrated that, despite *A. cepa* being reported as a potential antioxidant, this effect was not confirmed through the ABTS, DPPH, and CBMN tests in this study. Furthermore, as discussed, additional assays may be employed to evaluate the antioxidant capacity of the extract, beyond those applied in the present study, given that various antioxidant mechanisms exist in addition to simple free radical scavenging.

Our findings indicate that the *Allium cepa* extract, like others found in literature, acts in a dose and concentration-dependent manner, leading to the induction of cellular damage at radiation doses starting from 2 Gy, which resulted in an increased frequency of micronuclei.

However, at the 4 Gy dose, the extract demonstrated radioprotective capacity, as indicated by the reduction in observed micronucleus frequency. This reduction was more pronounced at the lower concentration tested.

Irradiation of the samples with the 0.5 Gy dose, either in the presence or absence of the extract, did not result in statistically significant differences, suggesting that the extract does not influence MN frequency at this dose range.

Since it's a preliminary study, we suggest that further tests with other concentrations of the extract, different radiation doses, and varying individuals be conducted to definitively confirm or exclude its radioprotective and/or radiosensitizing capability. Additionally, it is important to investigate the cellular signaling pathways affected by the extract and its effects on different cell lines, as there are other mechanisms of radioprotection and radiosensitization beyond those involving free radicals.

Thus, this study opens new opportunities for research in the fields of molecular biology, biodosimetry, and radioprotection, potentially leading to the publication of new studies on the topic.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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