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ORIGINAL RESEARCH PAPER

Response of sunflower seeds (*Helianthus annuus* L.) to different concentrations of metals and doses of gamma radiation (^{241}Am)

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Abstract: The sunflower crop (*Helianthus annuus* L.) presents great tolerance to heavy metals and in pre-determined doses of gamma (γ) radiation it presents gains in plant increments. This study aimed to evaluate the response to doses of γ radiation and different concentrations of toxic metals in the vegetative development of sunflower. Mirasol sunflower seeds were subjected to different doses of ^{241}Am γ rays and concentrations of Aluminum, Cerium and Copper (mg L^{-1}). Sunflower plants were evaluated only during the vegetative period for germination, aerial length, root length, aerial and root fresh mass, aerial and root dry mass. The doses of γ radiation promoted increases in the variables in the vegetative phase, especially for 5 and 10 minutes of exposure to γ rays. The concentrations of the toxic elements Al and Ce showed significant differences in all increments, however, doses higher than 85 mg L^{-1} demonstrated losses in length and mass of sunflower plants. For the Cu element, the doses did not have a significant effect, these being non-significant and the cultivar Mirasol resistant. Future studies should be carried out evaluating the reproductive phase and its gains in increasing biomass and production.

Keywords: Sunflower; Americium; Aluminum; Cerium; Cooper; Vegetative period.

1. Introduction

The sunflower (*Helianthus annuus* L.) belongs to the Asteraceae family and is an agricultural crop i.e., rich in oil and is among the species of interest especially in large crops among oil seeds. It is widely cultivated around the world in different types of soil; where the oil is used in the production of biodiesel, food and the pharmaceutical industry (Moura et al., 2020; El_Komy et al., 2020).

The sunflower crop stands out for its large seed production in a single plant and for forming an important forage that maintains the humidity and microbiological health of the soil. This crop has shown great interest worldwide, due to its agronomic characteristics, such as tolerance to cold, drought, qualitative characteristics, tolerance to soils contaminated by toxic metals and for presenting positive and beneficial after irradiation by gamma (γ) rays (Santos et al., 2012; Moura et al., 2020).

Gamma radiation comes from the atomic nucleus, because after the emission of α and β particles, an excess of energy is often left behind, which is released in the form of γ radiation. These γ rays can be formed by the anti-matter reaction between a electron and a positron and or by the inverse Compton effect. Gamma radiation can be classified as low and medium energy (a few KeV to 30 MeV) and high and very high energy (30 MeV to 100 GeV). For the purpose of beneficial genetic mutation for plants, low-energy γ radiation is used (Roshani et al., 2021).

Several sources of mutation induction are used to improve the characteristics of germination, vegetative and reproductive development in plants, mainly in plant species of agricultural interest such as beans (Fontes et al., 2013), rice (Miranda et al., 2009), barley (Rozman, 2014), oats (Allayarov et al., 2023), rye (Velázquez-Martí et al., 2006), wheat (Di Pane et al., 2018), peanuts (Santos et al., 2010) and sunflower (Hussain et al., 2017). The γ radiation source is chief among them. Several studies have demonstrated that the use of ionizing radiation produces mutations with important characteristics with beneficial effects of low doses such as higher germination rate, productivity, high precocity rate, smaller size, greater resistance to diseases and pests in different species, increased longevity, improving fertility, preventing tumors and increasing resistance to infection by microorganisms, which are widely used in breeding programs to obtain new varieties (Vargas et al., 2008; Fontes et al., 2013).

In the natural soil environment it is possible to verify different levels of toxic metals such as Cadmium (Cd), Lead (Pb), Copper (Cu), Cerium (Ce), Aluminum (Al), Nickel (Ni), Chromium (Cr), Silver (Ag), Mercury (Hg), Selenium (Se), Zinc (Zn) among others that can be absorbed by vegetables and can cause several negative effects within all physiological and biochemical processes, being transferred to fruits and seeds that can ultimately be absorbed by humans and animals, contaminating and being responsible for several types of cancer and neurodegenerative diseases. These metals can be present in this environment either through geological processes such as the weathering of rocks, or through human contamination or through leaching or air currents that can carry particles containing these metals in anthropic processes such as burning (Tangahu et al., 2011; Forte; Mutiti, 2017).

Soil contamination by toxic metals is a serious problem in several countries because in high concentrations these metals are considered an environmental risk (Sayyde; Sayadi, 2011; De et al., 2018; Costa et al., 2021). As a result, several studies have been carried out over the years which have verified that some plant species present tolerance and promote phytoremediation. Phytoremediation is an unconventional and very economical method for decontaminating soils with high concentrations of toxic metals.

Among these vegetables, sunflower is considered a hyperaccumulator capable of absorbing a large number of toxic metals from the soil. We know that sunflowers have high tolerance to Cd, Pb, Zn, Ni, Cu and Hg, hydrocarbons such as naphthalene, benzopyrene and anthracene, among other pollutants, due to their rapid growth, high biomass production and ability to accumulate large amounts of metals. heavy and harmful hydrocarbons (Chauhan; Mathur, 2018).

Thus, the lack of work using ^{241}Am as a radioactive source and different doses of the metals Al, Ce and Cu in sunflower cultivation is the subject of this study, which aimed to evaluate different times of γ irradiation as a source, ^{241}Am and different concentrations of toxic metals in high concentrations verifying their effects on vegetative parameters in a sunflower cultivar.

2. Material and Methods

2.1. Reagents and equipment

Aluminum Chloride ($AlCl_3.6H_2O$) Dinâmica, Brazil, Copper II Chloride ($CuCl_2.2H_2O$) Dinâmica, Brazil, Cerium III Nitrate ($Ce(NO_3.6H_2O$) Neon, Brazil. Analytical balance (Shimadzu, Mod. AY220, Japan), electric oven with air circulation (SolidSteel, Mod. SSDic 1600, Brazil), measuring tape (Megha Zine, Mod. T2858), Brazil, and digital caliper (MTX, Mod. 316119, China).

2.2. Study local

The study was carried out at the Goiano Federal Institute, Rio Verde Campus, Goiás State, Brazil, between January and March 2024. The experiment had two phases. First phase: carried out in vitro at the Technological Chemistry Laboratory in the Department of Agrochemistry. Second phase: carried out *in vivo* in a greenhouse at the Hydraulic and Irrigation Laboratory.

2.3. Cultivation

In this experiment, sunflower seeds were used, cultivated Multisol, with a bushy and erect growth form, height between 1.3 and 1.7 m, flower diameter with an average of 22 cm, characteristics without branches, rough hairs, annual vegetative cycle between 60 to 130 days, moderately susceptible disease resistance to *Alternaria* and *Sclerotinia*.

2.4. Germination test

The germination test was carried out with five replications of 25 seeds, distributed in germination boxes (gerbox) on three sheets of germination paper moistened with distilled water or metal solution or dose (per time) of radiation, in the proportion of 2.5 times the weight of the paper. After sowing, the germination boxes were kept in B.D.O, at a constant temperature of 25 °C with a photoperiod of 10 h of light and 14 h without light. The count was carried out daily. Germinated seeds with a root protrusion of at least 2 mm were considered using a digital caliper, the results were expressed as percentage of germination (%) *in vitro*.

2.5. Experimental design

The experiment was carried out in a randomized block design for (radioactive metal and toxic metals) where the type of design was: 1x3x7+1 where: one is radioactive metal with three times (min.), seven repetitions per treatment and one control. For toxic metals, the same design was used with 3x3x7+1 where: three metals, three concentrations, seven replications and a control.

2.6. Toxicological effect

To evaluate the toxic effect of the metals Al, Ce and Cu, aqueous solutions with concentrations (35, 85 and 125 mg L^{-1}) were prepared. The solutions containing the metals were added to the soil 7 days before sowing. During this period, the soil was watered 4 times with 150 mL of distilled water at a field capacity of 80% RH (relative humidity).

2.7. Radioactive effect

The effect of γ radiation on sunflower seeds was tested thrice (5, 10 and 15 min) using a ^{241}Am ion source. The source was positioned over the seeds and the time was marked by a digital timer. Source description of ^{241}Am < 29.6 KBq (0.9 µCi) ^{241}Am for NIS-07 ion chamber smoke sensor purchased on the specialized market.

To detect γ rays, a Geiger-Müller counter radiation detector was used, describing detectable types (β, γ and X rays) inherent error (± 10%), sensitivity (80 cpm/µsv/h), real-time range (0-99.99 µsv/h), alarm threshold (0.5, 1.0, 2.0 and 5.0) and test accuracy (0.01 µsv/h) (Geiger, Mod. BR-6). Irradiation of sunflower seeds was used 50 min before sowing.

2.8. Planting and cultural treatments

For planting, plastic cups (770 mL) made of colorless polystyrene were used, where two holes were made to drain excess water. 550 g of high-productivity soil collected in a soybean and corn planting area more than 5 years ago was used.

Soil parameters were determined in a layer between 0-20 cm deep with the following results: Ca = 2.13, Mg = 1.43, K = 0.30, P = 3.0, S = 9.0, Na = 1.0, O.M = 61.1 and pH = 4.9. Clay = 30.3, Silt = 25.2 and sand = 44.4.

For each replication, two seeds were sown in a hole 0.5 cm deep. Then each repetition was watered with 100 mL of distilled water. After germination, watering was carried out every two days. The experiment was kept in a greenhouse with controlled temperature and humidity with air circulation for 24 hours. There was no spray application with fungicide or insecticide throughout the experiment.

2.9. Seedling analyzes

Sunflower plants were analyzed 45 days after sowing. The phytotechnical quality indicators evaluated were aerial length (AL) and root length (RL) expressed in centimeters (cm), aerial fresh mass (AF) and root fresh mass (RF) expressed in grams (g) and aerial dry mass (AD) and root dry mass (RD) after gravimetric drying at 65 °C for 48 h with results expressed in g.

2.10. Statistical analysis

The experimental design was in randomized blocks, where treatments consisted of different times for γ radiation and concentrations of metals in solution. The data were subjected to analysis of variance using the *F* test and, when a significant effect was found, regression analysis was performed using the Sisvar software (Ferreira, 2019).

3. Results

3.1 Germination

The germination rate of sunflower seeds was 96%.

3.2 Influence of radioactive metal ^{241}Am on sunflower seedlings

The analysis of variance indicated significant differences depending on the treatments (radiation time) by the ^{241}Am source for all variables AL, RL, AF, FR and RD, except for AD.

In Figure 1 it is observed that the AL was influenced by the time the seeds were exposed to the γ radiation source with significant differences between the treatments where the 5 min time presented the highest AL result with 18.65 cm and the control with 14.68 cm. The type of regression was second order polynomial.

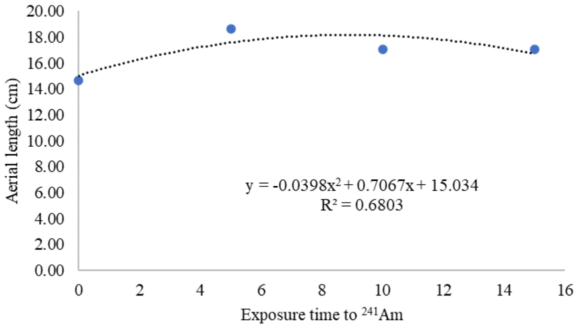

Figure 1. Exposure time to radioactive metal ^{241}Am and its influence on aerial length in sunflower seedlings. Source: Authors, 2024.

The time of exposure to γ rays also influenced the RL where the best result was observed for 5 min of exposure with values that varied between 25.45 cm and 13.90 cm for the control (Figure 2). The type of regression was second order polynomial.

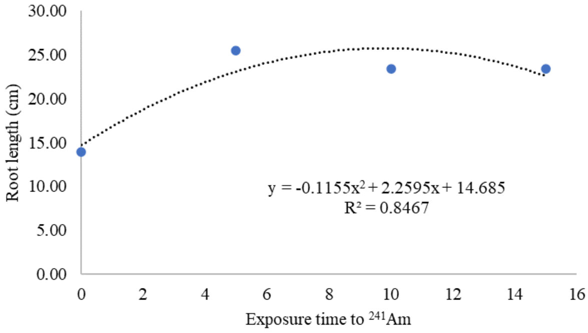

Figure 2. Exposure time to radioactive metal ^{241}Am and its influence on root length in sunflower seedlings. Source: Authors, 2024.

The AF mass Figure 3 was also influenced, presenting significant differences between the treatments, however the times 10 and 15 min did not show a significant difference between the γ ray dosages with 5.83 g each and for the control with 2.94 g. In this model, a linear trend was observed.

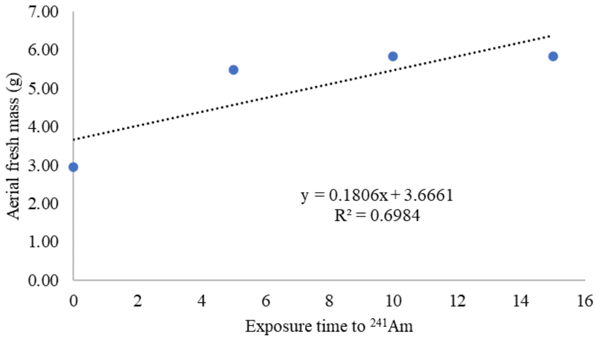

Figure 3. Exposure time to radioactive metal ^{241}Am and its influence on aerial fresh mass in sunflower seedlings. Source: Authors, 2024.

The time of exposure to γ rays was shown to influence the fresh mass of the roots, where the 5 min time showed the highest mass between the treatments with 2.26 g and the control with 0.27 g (Figure 4). The type of regression was second order polynomial.

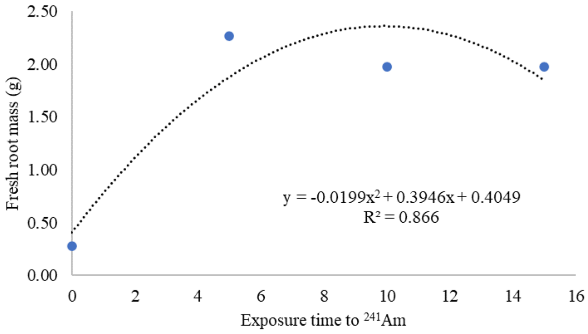

Figure 4. Exposure time to radioactive metal ^{241}Am and its influence on root fresh mass in sunflower seedlings. Source: Authors, 2024.

The time with 5 min of exposure to γ rays demonstrated a greater increase in the dry mass of roots, with values between 0.98 g (5 min) and 0.14 g for the control (Figure 5). The type of regression was second order polynomial.

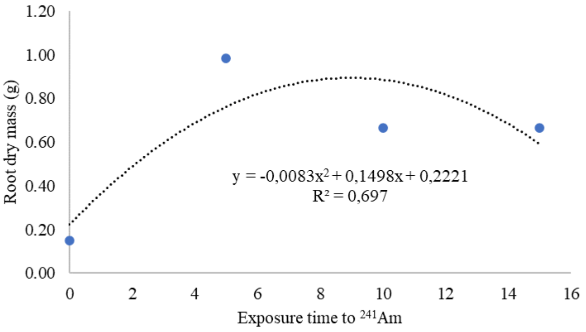

Figure 5. Exposure time to radioactive metal ^{241}Am and its influence on root dry mass in sunflower seedlings. Source: Authors, 2024.

3.2 Influence of the metal Aluminum on sunflower seedlings

For concentrations of the toxic metal Al, analysis of variance indicated significant differences depending on all treatments for AL, RL, AF, FR, AD, and RD. In Figure 6 are the regression results where the maximum tolerance dose was 80 mg L^{-1} of Al with a result of 15.32 cm for AL for sunflower plants. The type of regression was second order polynomial.

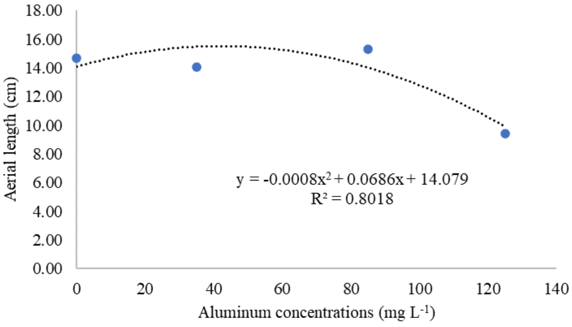

Figure 6. Different concentrations of Aluminum and its influence on the aerial length of sunflower seedlings. Source: Authors, 2024.

Root length was also influenced by concentrations of Al metal, especially at 85 mg L^{-1} where there was the greatest development at 25.0 cm in length. Higher dosages demonstrate a drop in length as observed at the highest concentration of 120 mg L^{-1} with a result of 7.75 cm. The control showed a response of just 13.90 cm (Figure 7). The type of regression was second order polynomial.

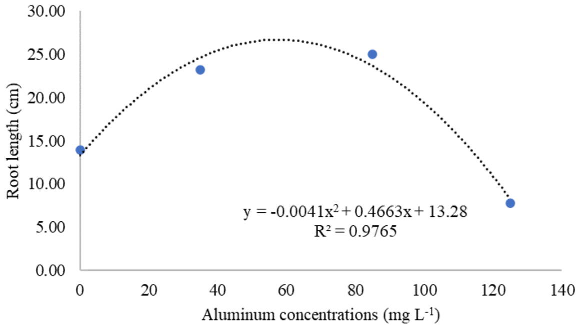

Figure 7. Different concentrations of Aluminum and its influence on the root length of sunflower seedlings. Source: Authors, 2024.

The aerial fresh mass showed the best results at a concentration of 85 mg L^{-1} with a result of 5.96 g and the control with 2.94 mg L^{-1}, the concentration of 120 mg L^{-1} demonstrated high toxicity with a loss of fresh mass of 1.0 g (Figure 8). The type of regression was second order polynomial.

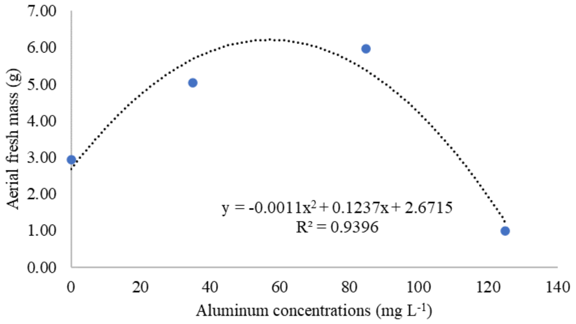

Figure 8. Different concentrations of Aluminum and its influence on the aerial fresh mass of sunflower seedlings. Source: Authors, 2024.

Concentrations greater than 35 mg L^{-1} of Al showed a decrease in the root fresh mass increase. 4.16 g was the largest gain observed in the applied concentrations (Figure 9). The regression demonstrated significance for all results in this vegetative increment for the sunflower crop. The type of regression was second order polynomial.

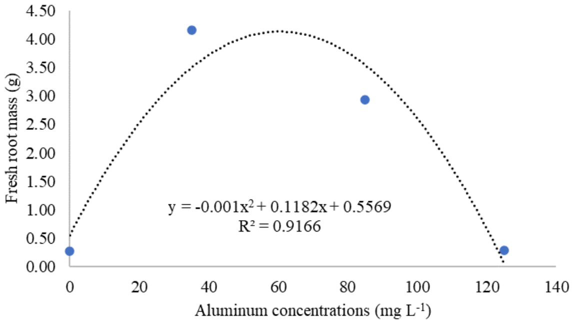

Figure 9. Different concentrations of Aluminum and its influence on the fresh root mass of sunflower seedlings. Source: Authors, 2024.

For the increase in AD mass, significant differences were observed between Al dosages. Especially for concentration 85 mg L^{-1} with better straw performance with a result of 1.11 g. Concentration greater than 85 mg L^{-1} resulted in a mass loss of 0.24 g (125 mg L^{-1}) (Figure 10). The type of regression was second order polynomial.

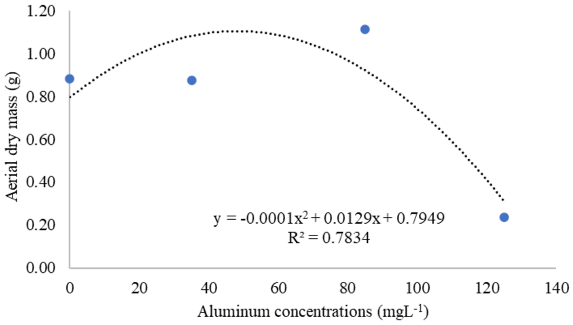

Figure 10. Different concentrations of Aluminum and its influence on the aerial dry mass of sunflower seedlings. Source: Authors, 2024.

For the dry mass of roots, the concentration of 35 mg L^{-1} demonstrated the best result of mass gain = 1.34 g, higher concentrations demonstrated loss of dry mass, especially for 125 mg L^{-1} of 0.16 g (Figure 11). The type of regression was second order polynomial.

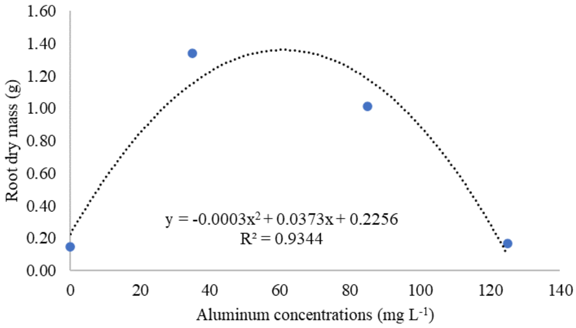

Figure 11. Different concentrations of Aluminum and its influence on the root dry mass of sunflower seedlings. Source: Authors, 2024.

3.3 Influence of the metal Cerium on sunflower seedlings

The analysis of variance indicated significant differences depending on the treatments only for the variables AL, RL, AF and RD mass. The AL showed significant differences, especially for the concentration 35 mg L^{-1} with an increase of 15.95 cm and higher concentrations loss of height in plants where the concentration of 125 mg L^{-1} resulted in plants with an average height of 11.45 cm (Figure 12). The type of regression was second order polynomial.

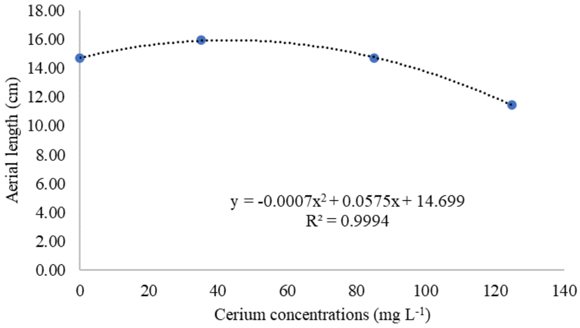

Figure 12. Different concentrations of Cerium and its influence on the aerial length of sunflower seedlings. Source: Authors, 2024.

Sunflower plants at a concentration of 35 mg L^{-1} demonstrated to be tolerant with an average value of 22.93 cm in length, however, higher doses of Ce are toxic, causing loss of RL, especially at a concentration of 125 mg L^{-1} with a value of 9.38 cm. The type of regression was second order polynomial.

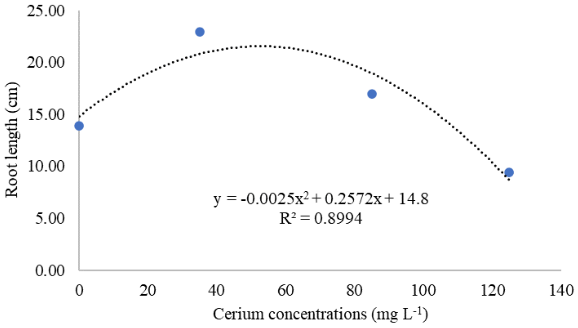

Figure 13. Different concentrations of Cerium and its influence on the root length of sunflower seedlings. Source: Authors, 2024.

The Ce element demonstrated stimulation in the production of AF mass in sunflower plants cultivar Multisol, where at a concentration of 35 mg L^{-1} there was a gain of 1.42 g. Although higher concentrations have demonstrated high toxicity, especially for 125 mg L^{-1} with a result of 0.37 g (Figure 14). The type of regression was second order polynomial.

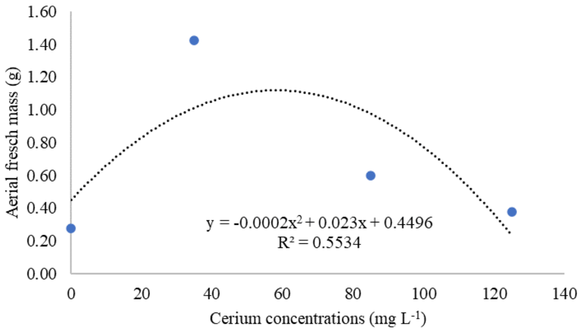

Figure 14. Different concentrations of Cerium and its influence on the aerial fresh mass of sunflower seedlings. Source: Authors, 2024.

The RD mass of the showed significant results in the regression where the concentration of 35 mg L^{-1} showed a greater gain in straw mass with a result of 0.71 g. Higher concentrations proved to be toxic to the root component, especially at a concentration of 125 mg L^{-1} with an average result of 0.18 g (Figure 15). The type of regression was second order polynomial.

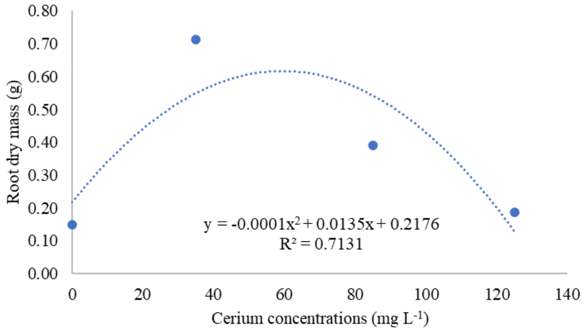

Figure 15. Different concentrations of Cerium and its influence on the root dry mass of sunflower seedlings. Source: Authors, 2024.

4. Discussion

In this study, the use of low-energy γ radiation from a ^{241}Am source demonstrated considerable gains for sunflower plants in all variables analyzed for 5 and 10 minutes of radiation.

In sunflower germination, the use of radiation is already known. Although our study did not evaluate the germination rate in seeds irradiated with γ rays, our germination rate was greater than 90% for the Mirasol cultivar. Other researchers evaluated that the total germination rate in seeds irradiated with a γ ray source using the element ^{60}Co as described in the study by Hussain et al. (2017) where researchers irradiated *H. annuus* seeds with different doses of radiation which increased the germination rate by up to 82% at 0.5 Krad ^{60}Co for another sunflower cultivar.

There is little data on the use of γ radiation on vegetative growth in sunflower. Therefore, this study made comparisons between other crops of agricultural interest. In this sense, Araújo et al. (2018) analyzed the effects of γ radiation on cotton plants (*Gossypium hirsutum*) ranging from (25 to 100 Gray (Gy)) from a ^{60}Co pump where they found a significant difference on the average height of plants, where at doses 25 and 100 Gy the plants were significantly superior when compared to the control and intermediate doses. Furthermore, reproductive increments for cotton crops were positive at low-energy radiation doses of 25 and 50 Gy, 25% higher than the control. Still in this sense, the 100 Gy radiation dose as discussed, presented taller plants, however, its production was lower than intermediate treatments.

Encouraging results were also described by Wiendl (2010) where the researcher, evaluating *Gladiador* hybrid tomato plants with doses between 5 and 10 Gy of γ radiation, described improvements in the plant's development in relation to height and the acceleration of its growth. However, the dose is important to be checked for each type of vegetable, as at concentrations greater than 12.5 to 20 Gy the effect of γ radiation inhibited the development of tomato plants, with the results being close to the control (non-irradiated). Doses of γ radiation can present negative results on several vegetables; this was confirmed by Santos et al. (2010) where they found that different doses of γ radiation negatively affected vigor and germination in peanut seeds. The same was observed for *Canavalia ensiformis* (jack beans) by Machi & Arthur, (2012) where they found that doses of γ rays between 150 and 300 Gy affected plant growth. The maximum height obtained by the plants was 11.7 cm at an intermediate dose of 100 Gy.

Radiation may also not influence vegetative and reproductive growth, possibly higher dosages may or may not be used. In this sense, Gazzaneo et al. (2007) studied the effect of γ radiation on *Vigna unguiculata* plants where they determined that concentrations between 50 and 500 Gy do not interfere or have a significant effect on the germination of cowpea seeds. Regarding plant height, the researchers described that there was an oscillation between 10.5 and 11.5 cm in radiation doses up to 400 Gy, however, a slight increase in height was seen at a dose of 50 Gy, which was not statistically significant. Only at the highest dose of 600 Gy was there a drop in the height rate of plants with 50% reduction in treated seeds.

As for toxic elements, often introduced into the environment due to an environmental accident, several vegetables have tolerance and resistance to be cultivated in these environments. Gabos et al. (2011) found that sunflower plants have the potential to be cultivated in areas contaminated with Boron (B), Cu and Zn. Our results corroborate these researchers, where our concentrations between 35 and 125 mg L^{-1} did not demonstrate a significant effect on sunflower plants, which are tolerant and resistant to the element Cu.

Our results for soil contaminated with the element Al presented results from the sunflower crop, similar data for some increments discussed in the study by Stefanello & Goergen (2019) where they verified for another agricultural crop *Cynara scolymus* (artichoke) toxicity in relation to the length of plants between At concentrations 30 to 120 mg L^{-1} of Al^{+3}, the results for dry mass showed no difference between the control and Al concentrations. For our study, the AF, AD, FR and RD mass showed reduction in concentrations greater than 85 mg L^{-1} of Al.

Among other toxic elements Bitencourt et al. (2021) evaluated different doses of sludge applied to sunflower plants and observed that the high concentration of Sodium (Na) interfered with the development of AL, suggesting that the osmotic potential of the Na-rich soil made available by the sludge and the root cells presented regulatory changes osmotic in plants resulting in difficulties in transporting water and electrolytes to the aerial part.

Pb is another important toxic element that has a harmful effect on plant tissues, and studies have found that sunflower plants contaminated with Pb solution where phytometric parameters and biomass production were evaluated, the researchers observed a significant difference only for AF mass with 1.47 g , AD mass with 0.146 g, RD mass with 0.0633 g and total dry mass with 0.21 g as observed sunflower has high tolerance in contaminated soils (Boffe et al., 2017).

The RD mass, after more than 5 min of γ radiation and at concentrations greater than 35 mg L^{-1} of Al and Ce demonstrate a drop in straw. The same is reported for Pb in the study by Boffe et al. (2021) with a result of 1,989.62 mg kg^{-1} of Pb lower when compared to the control with 2.2 mg kg^{-1} of Pb. Similar results were obtained by Silva et al. (2013) also for sunflower plants where with the increase in Pb concentration, the production of RD mass was significantly reduced.

The preparation of fresh and dry mass of sunflower roots or any other crop may be caused by excesses of Al and Ce, which hinders the absorption of Calcium (Ca) by the roots, whose nutrient is essential for the full development of vegetable roots. This same hypothesis is confirmed and affirmed by Boffe et al. (2017) for Pb and by Abreu et al. (2013) and Rodriguez-Hernandez et al. (2015).

Heavy metals, especially Al, Cd and Pb, can cause the production of excess secondary roots, where the higher the content of these toxic elements, the greater the environmental stress on the development of the taproot and consequently a greater number of secondary roots (Dutra et al., 2012; Chauhan et al., 2021). Marques et al. (2000) adds that, in clayey soils, they have a certain degree of influence, causing toxic metals to be retained in the most superficial layers between 0-20 and 20-40 cm deep, and the abundance of roots increases the amount of metal absorption. heavy ones such as Al, Ce, Cu, Pb and Cd.

The parameters evaluated in our study were all influenced by contamination, corroborating the results obtained by several authors for sunflower cultivation, where biomass production was significantly reduced by soil contamination by Al and Ce, indicating for these parameters the concentration of these metals were able to inhibit the full development of this culture (Andrade et al., 2009; Silva et al., 2013; Boffe et al., 2017).

Silicon (Si) has been considered an essential micronutrient for some groups of vegetables of agricultural interest, in the study by Oliveira et al. (2013) researchers verified in ornamental sunflower cultivars that Si doses showed improvements in the increase in plant height for the *Sol Vermelho* cultivar of 124.70% (80 cm) when compared to the cultivar that showed lower tolerance to Si cultivar *Jardim Amarelo Alto* measuring 40 cm. Although they did not observe gains in the increase in the production of dry phytomass of leaves, inflorescences and aerial parts in the Si dosages used.

Sunflower, as previously presented, is a phytoremediation plant capable of absorbing numerous toxic elements, in this sense, Souza et al. (2010) studied the action of the toxic metals Zn (10 to 80 mg dm^{-3}), Cu (20 to 80 mg dm^{-3}) and Cd (10 to 40 mg dm^{-3}) in the soil where they found that these elements stimulated changes physiological characteristics in another evaluated sunflower cultivar. Vegetative parameters such as normal development and growth were impaired, with no uniformity between the concentrations of metals used. Toxic metals can cause several negative phytotoxic effects on the leaves, where they can present chlorosis and subsequent necrosis, becoming yellow and in some cases detaching from the plant, where it accelerates the plant's senescence.

Metals such as Zn can develop chlorosis in young leaves and reduced growth, Cu can cause tissue damage and root elongation, changes in membrane permeability, inhibition of photosynthetic electron transport, immobilization of Cu in walls and vacuoles and chlorosis. Our results for Cu did not demonstrate a significant difference in any increase in the vegetative phase for the sunflower cultivar analyzed, demonstrating that the Mirasol cultivar is tolerant to doses up to 125 mg L^{-1}.

In our study we used an element obtained from rare earths (REE) which includes Ce. The Ce still presents few studies on the integration of this element in contaminated vegetable organs, mainly in sunflower crops. Duarte et al. (2019) found significant changes in the histological structures in corn (*Zea mays*) leaf tissue and leaf indices, which provided an increase in leaf structures (increase in the thickness of the mesophyll, in the diameter of metaxylems, in the area of vascular bundles and in the area of sieve cells).

Ce and Lanthanum (La) are considered possible essential plant micronutrients; however, studies must be carried out to verify the action of these elements on plants and their positive and negative effects (Kirkby; Römheld, 2007). This statement still requires many studies, as REEs are considered by most researchers as non-essential elements for plants and other organisms and may be related to the reduction of essential micronutrients for plants (Duarte et al., 2022). Still in this study, Duarte and collaborators found that *Pistia stratiotes* had a significant influence on the reduction of dry mass of roots and shoots by REEs. On the other hand, Ce influenced cell expansion and increases in leaf and root tissues. Schwabe et al. (2015) reports that Ce produces inhibitory effects on photosynthesis, respiration, uptake and metabolism of mineral nutrients and hormonal balance.

In our results, it is observed that toxicity in sunflower is associated with oxidative stress, damage to the membrane and alteration of numerous enzymatic activities, where in the same sense Guo et al. (2007) and Duarte et al. (2022) in their studies corroborate this hypothesis. Furthermore, REE (Ce) in the vascular tissue can be transferred from the roots to the aerial part through the water flow of transpiration, explaining that the dosage and concentration of this element in the soil present losses in the vegetative characteristics of the sunflower in the aerial part where its translocation was highly influenced by transpiration water, tissues and the media of suppression on sunflower development. However, the case described in this study is something new for vascular plants of agricultural interest. Duarte et al. (2022) found a thickened barrier for *P. stratiotes* in treatments with different concentrations of Ce where the element did not arrive in large quantities in the aerial part, avoiding damage to the upper plant tissue.

5. Conclusion

The exposure time of gamma rays by the ^{241}Am source demonstrated gains in increments in all phytotechnical components for the sunflower crop, except for aerial dry mass. The doses of the Al element were all significant, for Ce only aerial fresh mass and aerial dry mass were not significant, whereas for Cu all the parameters evaluated were not significant, demonstrating that sunflower is tolerant to the concentrations used in this study.

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Ethics

Not applicable.