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# ASSESSMENT OF LEAD CONCENTRATIONS ON GERMINATION AND SEEDLING GROWTH OF *TRITICUM AESTIVUM* VAR ORS SENNA

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## ABSTRACT

**Objective:** The objective of this study was to evaluate the effects of different lead concentrations on seed germination and the development of wheat seedlings.

**Theoretical Framework:** The study of seed germination and seedling growth of wheat in soils contaminated with lead encompasses environmental, economic, and social factors, making it particularly relevant in regions where the presence of heavy metals compromises agricultural sustainability.

**Method:** A randomized experimental design was used with four repetitions. Wheat seeds were divided into four batches with eight repetitions of 50 seeds each, and each repetition was sown on a germination paper substrate (Germitest®) previously moistened with distilled water in a volume equivalent to 2.5 times the weight of the paper. The water used for soaking the four batches was supplemented with different concentrations of lead acetate, resulting in final lead concentrations of 0.0, 200.0, 400.0, and 600.0 mg $L^{-1}$, generating four different treatments. The paper rolls were kept in germination chambers at a constant temperature of 25 ± 2 ºC and a constant photoperiod of 24 hours. Growth assessment was conducted on the fourth and eighth days after sowing by counting the normal and abnormal seedlings, dead seeds, primary root and shoot length. An analysis of variance (F-test at 5%) with quadratic regression (2nd degree) was employed to analyze the variables.

**Results and Discussion:** Lead reduced the viability of wheat seeds, affecting variables such as germination rate, hard or dead seeds, root and shoot length.

**Research Implications:** The results underscore the necessity for rigorous monitoring and effective management of lead levels in agricultural soils, particularly in regions prone to heavy metal accumulation from anthropogenic sources.

**Originality/Value:** Data regarding the lead effects on the germination of cultivated plants remain scarce and inconclusive. It is still necessary to elucidate various metabolic aspects of this interaction, which justifies the use of these plants and metal concentrations to deepen the existing knowledge on the subject.

**Keywords:** Toxicity, Heavy Metals, Wheat Seedlings.

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## AVALIAÇÃO DE CONCENTRAÇÕES DE CHUMBO NA GERMINAÇÃO E DESENVOLVIMENTO DE PLÂNTULAS DE *TRITICUM AESTIVUM VAR* ORS SENNA


### RESUMO

**Objetivo:** O objetivo deste trabalho foi avaliar os efeitos de diferentes concentrações de chumbo em relação a germinação de sementes e desenvolvimento de plântulas de trigo.

**Referencial Teórico:** O estudo sobre a germinação de sementes e o crescimento de plântulas de trigo em solos contaminados com chumbo é uma temática que integra fatores ambientais, econômicos e sociais, sendo particularmente relevante em regiões onde a presença de metais pesados compromete a sustentabilidade agrícola.

**Método:** Utilizou-se o delineamento experimental inteiramente casualizado com quatro repetições. As sementes de trigo foram divididas em quatro lotes com oito repetições de 50 sementes cada, sendo cada repetição semeada em substrato de papel Germitest®, previamente umedecido com água destilada em volume equivalente a 2,5 vezes o peso do papel. A água utilizada para embebição dos quatro lotes foi suplementada com diferentes concentrações de acetato de chumbo, resultando em concentrações finais de chumbo de 0,0; 200,0; 400,0 e 600,0 mg $L^{-1}$, gerando quatro tratamentos distintos. Os rolos de papel foram mantidos em germinadores a temperatura constante de 25 ± 2 ºC e fotoperíodo constante de 24 horas. Avaliaçlões de crescimento foram realizadas no quarto e oitavo dias após a semeadura, sendo contabilizadas plântulas normais, anormais, sementes mortas, comprimento da raiz primária e comprimento da parte aérea. Para a análise das variáveis, empregou-se a análise de variância (teste F a 5%) com regressão quadrática (2º grau).

**Resultados e Discussão:** O chumbo reduziu a viabilidade das sementes de trigo, afetando as taxas de germinação e de sementes duras e mortas, assim como os comprimentos da raiz e da parte aérea.

**Implicações da Pesquisa:** Os resultados ressaltam a necessidade do monitoramento rigoroso e gerenciamento eficaz dos níveis de chumbo em solos agrícolas, especialmente em regiões propensas ao acúmulo de metais pesados de fontes antropogênicas.

**Originalidade/Valor:** Dados sobre os efeitos do chumbo na germinação de plantas cultivadas permanecem escassos e inconclusivos. Ainda é necessário elucidar diversos aspectos metabólicossobre essa interação, o que justifica o uso dessas plantas e de diferentes concentrações do metal para aprofundar o conhecimento existente sobre o assunto até o momento.


**Palavras-chave:** Toxicidade, Metais Pesados, Plântulas de Trigo.

## EVALUACIÓN DE LAS CONCENTRACIONES DE PLOMO EN LA GERMINACIÓN Y DESARROLLO DE PLÁNTULAS DE *TRITICUM AESTIVUM VAR* ORS SENNA


### RESUMEN

**Objetivo:** El objetivo de este estudio fue evaluar los efectos de diferentes concentraciones de plomo en la germinación de semillas y el desarrollo de plántulas de trigo.

**Marco Teórico:** El estudio de la germinación de semillas y el crecimiento de plántulas de trigo en suelos contaminados con plomo integra factores ambientales, económicos y sociales, siendo particularmente relevante en regiones donde la presencia de metales pesados compromete la sostenibilidad agrícola.

**Método:** Se utilizó un diseño experimental completamente aleatorizado con cuatro repeticiones. Las semillas de trigo se dividieron en cuatro lotes, cada uno con ocho repeticiones de 50 semillas. Cada repetición se sembró en papel germinativo (Germitest®) previamente humedecido con agua destilada en un volumen equivalente a 2,5 veces el peso del papel. El agua utilizada para la imbibición de los cuatro lotes se suplementó con diferentes concentraciones de acetato de plomo, resultando en concentraciones finales de plomo de 0,0; 200,0; 400,0 y 600,0 mg $L^{-1}$, generando así cuatro tratamientos distintos. Los rollos de papel se mantuvieron en germinadores a una temperatura constante de 25 ± 2°C y un fotoperiodo continuo de 24 horas. La evaluación de la germinación se realizó en el cuarto y octavo días después de la siembra, registrándose plántulas normales, anormales, semillas

muertas, longitud de la raíz primaria y longitud de la parte aérea. Para el análisis de las variables, se empleó análisis de varianza (prueba F al 5%) con regresión cuadrática (de segundo grado).

**Resultados y Discusión:** El plomo redujo la viabilidad de las semillas de trigo, afectando las tasas de germinación y aumentando la proporción de semillas duras y muertas, así como disminuyendo las longitudes de la raíz y de la parte aérea.

**Implicaciones de la investigación:** Los resultados resaltan la necesidad de un monitoreo riguroso y una gestión eficaz de los niveles de plomo en suelos agrícolas, especialmente en regiones propensas al acumulamiento de metales pesados de origen antropogénico.

**Originalidad/Valor:** Los datos sobre los efectos del plomo en la germinación de plantas cultivadas son escasos e inconclusos. Aún es necesario esclarecer diversos aspectos metabólicos de esta interacción, lo que justifica el uso de estas plantas y de diferentes concentraciones de este metal para profundizar el conocimiento existente sobre el tema hasta el momento.

**Palabras clave:** Toxicidad, Metales Pesados, Plántulas de Trigo.

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## 1 INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most widely consumed cereals and plays a fundamental role in the production of staple foods such as bread, pasta and cakes, items that are part of the daily diet of humans Worldwide (Dixon *et al.* 2009; FAO, 2014). Currently, wheat is farmed in all five continents with arable land and occupies a cultivation area larger than any other crop (FAO, 2025). According to the Foreign Agricultural Service from the United States Department of Agriculture, in the harvest season of 2023/24, the World´s cultivation area of wheat was of approximately 222.8 mi hectares with an average yield of 3.55 metric tons per hectare. For the 2024/25 season, predictions suggest a decrease in the cultivation area by 0.2% and a yield increase of 1.11% (USDA:FAS, 2025a).

In Brazil, wheat is of considerable economic and nutritional importance. Although, the country has been farming wheat since 1738 (Brum & Heck, 2005), Brazil is still not self-sufficient in its production (USDA:FAS, 2025b). Wheat production chain encompasses an extensive process from input production to processing and distribution for final consumption. Therefore, the sector faces significant commercial challenges (CONAB, 2024).

Brazilian farmers face difficulties in competing with Argentinean producers due to the lack of comparative advantages (Brum & Muller, 2008). Historically, Argentina has held a prominent position in the international wheat market, being recognized as one of the leading

exporters with established trade practices that have consolidated its global presence (Patricia and Georges, 2013; USDA:FAS, 2025b).

Wheat seed germination and seedling development in lead-contaminated soils addresses a topic that encompasses environmental, economic, and social factors. It is particularly relevant in regions where the presence of heavy metals compromises agricultural sustainability (Angon *et al*. 2024). Lead, a metal widely studied due to its high toxicity, is among the most common metals in environmental contamination (Wuana & Okieimen, 2011). It exhibits cumulative properties and resistance to degradation, which enhances its long-term impact on both the environment and living organisms (Silva & Lima, 2019). One of the most concerning characteristics of lead is its ability to bind to soil. Therefore, it can be absorbed by plants and affect fundamental processes such as seed germination and the early development of the crop (Gonçalves *et al*. 2021).

The presence of lead in the soil results from a range of anthropogenic activities, including industrial processes, mining, urban development, the use of fertilizers, and agro-livestock waste (Wuana & Okieimen, 2011). In addition, other sources also contribute to lead accumulation in the soil, such as the use of agricultural pesticides, the combustion of fossil fuels, and the deposition of industrial dust, factors that further intensify environmental contamination (Almeida & Souza, 2021; Carvalho & Silva, 2022; CONAB, 2023). Consequently, lead becomes integrated into the agricultural ecosystem, directly affecting soil health and, subsequently, crops that depend on it.

Wheat seeds, a central element for the viability of crop production, are highly sensitive to soil conditions and, consequently, to the presence of contaminants (Rizvi *et al*. 2020). In soils with elevated levels of heavy metals, toxicity adversely affects germination rate, seedling vigor, and root development, ultimately compromising crop productivity (Ducatti *et al*. 2018; Murari *et al*. 2020; Pereira & Lopes, 2020; Mariano-da-Silva *et al*. 2024a; Mariano-da-Silva *et al*. 2024b; Smaniotto *et al*. 2024; Mariano-da-Silva *et al*. 2025). The presence of heavy metals can interfere with essential physiological processes in plants as these elements, once absorbed, trigger alterations in biochemical pathways, ranging from cellular respiration to photosynthesis (Gonçalves *et al*. 2021). This underscores the importance of understanding the impact of such metals on the early development of wheat to identify thresholds and adopt management practices that minimize the risk of contamination.

This context demands wheat production in Brazil to be examined from the perspective of heavy metal contamination, assessing how lead concentrations affect the development of such essential crop. With the expansion of cultivated areas into regions with potential

contamination sources, it becomes critical to analyze the response of wheat seedlings in lead-contaminated soils to ensure the sustainability of production without compromising soil and water quality (Silva & Lima, 2019).

Thus, this research aimed to demonstrate that the presence of lead affects the early development of wheat, highlighting its toxicity through different exposure concentrations. The study is grounded in the concepts that discuss the dynamics of heavy metals in soil and their interference in agricultural systems (Silva & Lima, 2019; Gonçalves *et al*. 2021).

Although a considerable number of investigations have addressed the cytotoxic effects and stress mechanisms caused by heavy metals in biological systems, data regarding the effects of lead on the germination of cultivated plants remain scarce and inconclusive. It is still necessary to elucidate various metabolic aspects of this interaction, which justifies the use of these plants and different lead concentrations to deepen the existing knowledge on the subject.

## 2 MATERIAL AND METHODS

### 2.1 EXPERIMENTAL SETTINGS

Wheat seeds (*T. aestivum* var. ORS Senna) were obtained in October 2024 at the cooperative "CooperItaipu", located in the city of Pinhalzinho – SC – Brazil. According to data provided for the seed batch, the seeds exhibit a germination rate of 99.99% and a purity of 97.7%. Initially, seeds were placed in a Biochemical Oxygen Demand (BOD) chamber at a constant temperature of 6 ± 2 °C for 7 days (BRASIL, 2009). The experiment was conducted at the Seed and Grain Laboratory of the Federal University of Fronteira Sul, *campus* Chapecó. The trial was carried out using a completely randomized experimental design with four replications (Pimentel-Gomes, 2007). Seeds were divided into four batches, each consisting of eight replications of 50 seeds. Each replicate was sown between two sheets of Germitest® paper substrate previously moistened with a volume of water equivalent to 2.5 times its weight. The water used to moisten the paper in all batches was supplemented with different concentrations of lead acetate ($Pb(C_2H_3O_2)_2$), so that the final lead concentrations were 0.0, 200.0, 400.0, and 600.0 mg $L^{-1}$, resulting in four distinct treatments. The paper rolls were maintained in germination chambers (ELETROlab®, model 202/4) at a constant temperature of 25 ± 2 ºC and a photoperiod of 24 hours (BRASIL, 2009; Sá *et al.*, 2011).

### 2.2 GERMINATION, GROWTH AND DRY MATTER

Evaluations were carried out on four randomly selected replicates from each treatment on the fourth and eighth days after sowing. The evaluation of normal and abnormal seedlings, and ungerminated seeds was performed by quantifying the seedlings/seeds and converting the data into percentages. Growth evaluation was performed using a millimeter ruler, measuring the length of the primary root and shoot, with average results expressed in cm seedling$^{-1}$ (BRASIL, 2009; Sá *et al*. 2011).

### 2.3 STATISTICAL ANALYSIS

ANOVA assumptions were checked (normality, homogeneity and independence) for all data collected during the trials. When all assumptions were satisfied, ANOVA was used to analyze the variables (F-test at 5%). Since dependency among the treatments was established, an analysis of variance employing regression was used to examine the variables (Pimentel-Gomes, 2007; Nogueira, 1997).

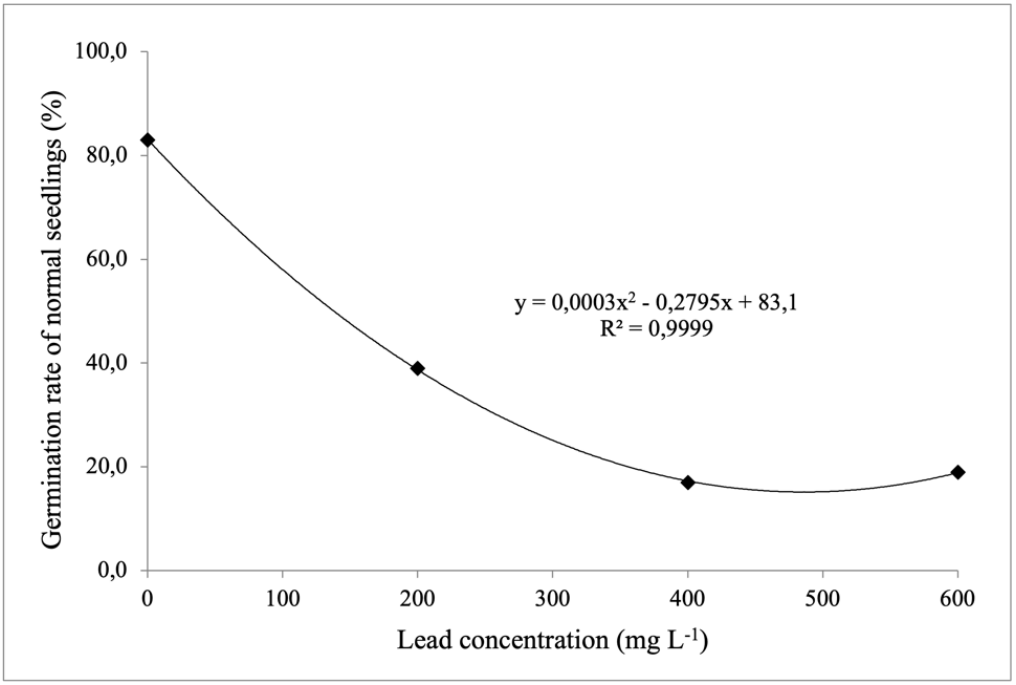
## 3 RESULTS AND DISCUSSION

With respect to the germination rate of normal seedlings, percentage of dead or hard seeds, root and shoot length, both linear and quadratic regression models were statistically significant. However, the quadratic (second-degree) regression model was considered more appropriate to describe the relationships among these variables. The quadratic model could better capture potential curvatures and complexities in the data trends, providing a more accurate fit to the observed patterns when compared to the linear model, which assumes a strictly proportional relationship between the variables.

According to ANOVA (F-test), a significant effect was observed for both the first-degree (linear) and second-degree (quadratic) regression models for the variable germination rate of normal seedlings, with the higher-degree regression considered more significant (Table 1). Figure 1 illustrates the relationship between lead concentrations (mg L$^{-1}$) and the germination rate of normal seedlings.

**Figure 1**

*Second-order polynomial equation referring to germination rate of normal seedlings of Triticum aestivum var. ORS Senna subjected to different lead concentrations.*




It is possible to observe that the quadratic coefficient in Figure 1 is not significantly different from zero (0.0003), indicating that there is no curvilinear relationship between the germination rate (normal seedlings) and lead concentrations. This suggests that, beyond the critical lead concentration the germination rate of normal seedlings does not increase.

The coefficient of determination ($R^2$) for the quadratic regression is high (0.9999), indicating that the regression model explains nearly all the variability observed in data. The vertex of the parabola corresponds to a lead concentration of 465.83 mg $L^{-1}$, suggesting this value as the critical threshold concentration.

According to ANOVA (F-test), no significance was observed for either the linear or quadratic regression models for the variable abnormal seedlings (Table 1). The germination rates (% abnormal seedlings) are presented in Table 2.

**Table 1**

*Analysis of variance table*

| Parameter | Source of variation | Degrees of freedom | Sun of squares | Mean of square | Fcal |
|---|---|---|---|---|---|
| Normal seedlings (%) | Linear regression | 1 | 9159.2 | 9159.20 | 1248.98* |
| | Polynomial regression | 1 | 2116.0 | 2116.00 | 288.55* |
| | Regression derivation | 1 | 0.800 | 0.800 | 0.109 |
| | Residual | 12 | 88.000 | 7.3 | |
| | Total | 15 | 11364.000 | | |
| | Standard deviation = 6.856% | | | | |
| Abnormal seedlings (%) | Linear regression | 1 | 0.050 | 0.050 | 0.004 |
| | Polynomial regression | 1 | 12.250 | 12.250 | 1.028 |
| | Regression derivation | 1 | 54.450 | 54.450 | 4.569 |
| | Residual | 12 | 143.000 | 11.917 | |
| | Total | 15 | 209.750 | | |
| | Standard deviation = 15,865% | | | | |
| Ungerminated seedlings (%) | Linear regression | 1 | 9116.45 | 9116.45 | 499.53* |
| | Polynomial regression | 1 | 1806.25 | 1806.25 | 98.97* |
| | Regression derivation | 1 | 42.05 | 42.05 | 2.30 |
| | Residual | 12 | 219.000 | 18.25 | |
| | Total | 15 | 11183.750 | | |
| | Standard deviation = 8,397% | | | | |
| Root length (cm seedling$^{-1}$) | Linear regression | 1 | 19.375 | 19.375 | 222.717* |
| | Polynomial regression | 1 | 3.267 | 3.267 | 37.555* |
| | Regression derivation | 1 | 0.055 | 0.055 | 0.628 |
| | Residual | 12 | 1.044 | 0.087 | |
| | Total | 15 | 23.741 | | |
| | Standard deviation = 14,366% | | | | |
| Shoot length (cm seedling$^{-1}$) | Linear regression | 1 | 4.935 | 4.935 | 65.761* |
| | Polynomial regression | 1 | 2.520 | 2.520 | 33.581* |
| | Regression derivation | 1 | 0.479 | 0.479 | 6.382 |
| | Residual | 12 | 0.901 | 0.075 | |
| | TOTAL | 15 | 8.835 | | |
| | Standard deviation = 15.560% | | | | |

Tabulated F value: F (0.05; 1; 12) = 4.75
* Significant at the 0.05% significance level.

**Table 2**

*Abnormal seedlings of Triticum aestivum var. ORS Senna subjected to different lead concentrations.*

| Parameter | Lead concentration (mg L$^{-1}$) | | | |
|---|---|---|---|---|
| | 0.0 | 200.0 | 400.0 | 600.0 |
| Abnormal seedlings (%) | 9.5 $^{ns}$ | 8.0 $^{ns}$ | 13.0 $^{ns}$ | 8.0 $^{ns}$ |
| | CV = 15,865% | | | |

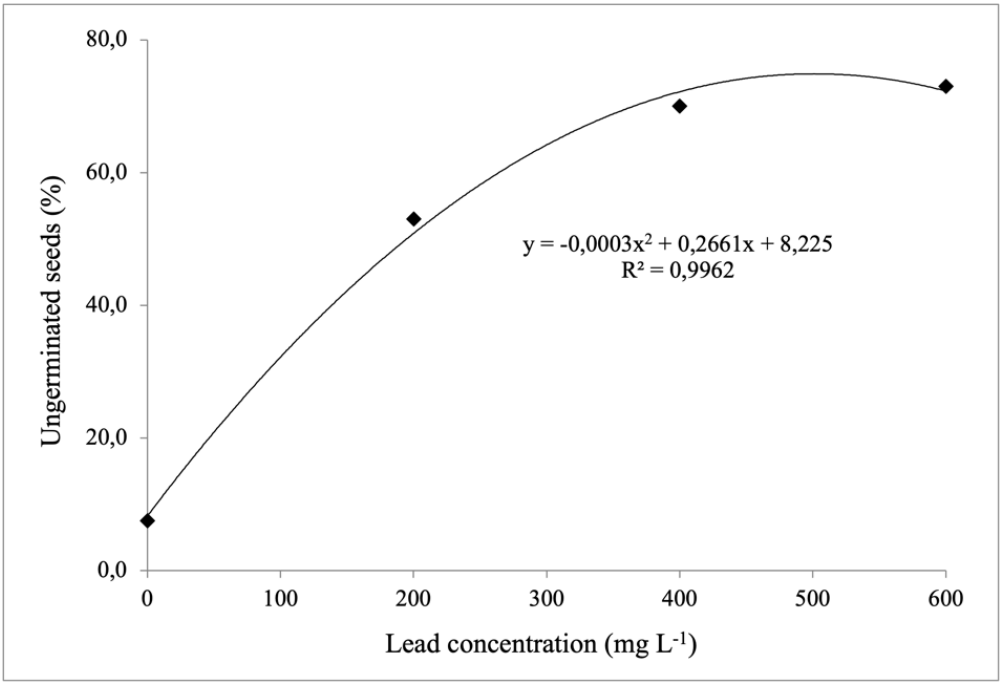
$^{ns}$ not signifficant according to the F-test (5%).

However, for the variable hard or dead seeds, the F-test indicated significant effects for both the linear and quadratic regression models, with the higher-degree regression model considered more significant (Table 1). Figure 2 illustrates the relationship between lead concentrations (mg L$^{-1}$) and the percentage of hard or dead seeds.

In Figure 2, it is evident that the quadratic coefficient is not significantly different from zero (0.0003). It indicates that there is no curvilinear relationship between the percentage of hard or dead seeds and lead concentrations. Therefore, beyond the critical lead concentration, the rate of hard or dead seeds does not continue to increase.

**Figure 2**

*Second-order polynomial equation referring to ungerminated seeds rate of Triticum aestivum var. ORS Senna subjected to different lead concentrations.*




The coefficient of determination ($R^2$) for the quadratic regression is high (0.9962), indicating that the regression model explains the observed variability in data. The vertex of the parabola corresponds to a lead concentration of 443.5 mg $L^{-1}$, which represents the critical concentration for this variable.

These results demonstrate that the tested lead concentrations caused a sharp reduction in germination rates and an increase in the percentage of hard or dead seeds, mainly when higher lead concentrations were used (Figure 2).

The exposure of plants to lead-contaminated environment results in physiological and morphological disturbances, leading to a decrease in germination rate (Kumar & Aery, 2016). One possible explanation for this effect is the internal imbalance in meristematic tissues caused by excessive lead absorption, which may induce fluctuations in the concentrations of essential

metals such as copper, zinc, iron, manganese, molybdenum, and nickel, elements that play critical roles in plant biochemistry and physiology (Zhuang *et al.* 2009).

Tomato (*Solanum lycopersicum* L.) and eggplant (*S. melongena* L.) seeds germinated under varying lead concentrations. However, when lead levels were increased, a reduction in germination was observed. This reduction was possibly related to decreased cellular division in the meristems or to chromosomal abnormalities caused by cellular homeostasis disruption (Gautam *et al.* 2015).

The decrease in germination percentage of lettuce (*Lactuca sativa*) seeds was inversely proportional to lead concentration, with higher doses resulting in lower germination rates (Pereira *et al.* 2013). The permeability of seeds to heavy metals is associated with seed coat structure (Wierzbicka & Obidzińska, 1998), and lettuce seeds were more affected at higher concentrations as the pericarp and seed coat provide limited protection against lead at lower levels. For sesame seeds (*Sesamum indicum* L.), similar results to those reported in the present study were observed. Across the eleven lead concentrations tested by Araújo, the germination rate declined consistently and significantly (Araújo, 2014).

According to ANOVA (F-test), both the linear and quadratic regression models were found to be significant for the variable root length, with the second-degree (quadratic) regression being considered the most appropriate model to explain this significance (Table 1). Figure 3 illustrates the relationship between lead concentrations (mg $L^{-1}$) and the variable root length.

Analyzing the regression equation in Figure 3, it is possible to observe that the quadratic coefficient is not significantly different from zero (0.00001). This indicates that there is no curvilinear relationship between root length and lead concentrations. This also suggests that beyond the critical lead concentration, root length does not continue to decrease.

The coefficient of determination ($R^2$) observed for this regression is high (0.9976), indicating that the regression model explains the observed variation in data. The vertex of the parabola corresponds to a lead concentration of 585.0 mg $L^{-1}$, which represents the critical threshold for this variable.

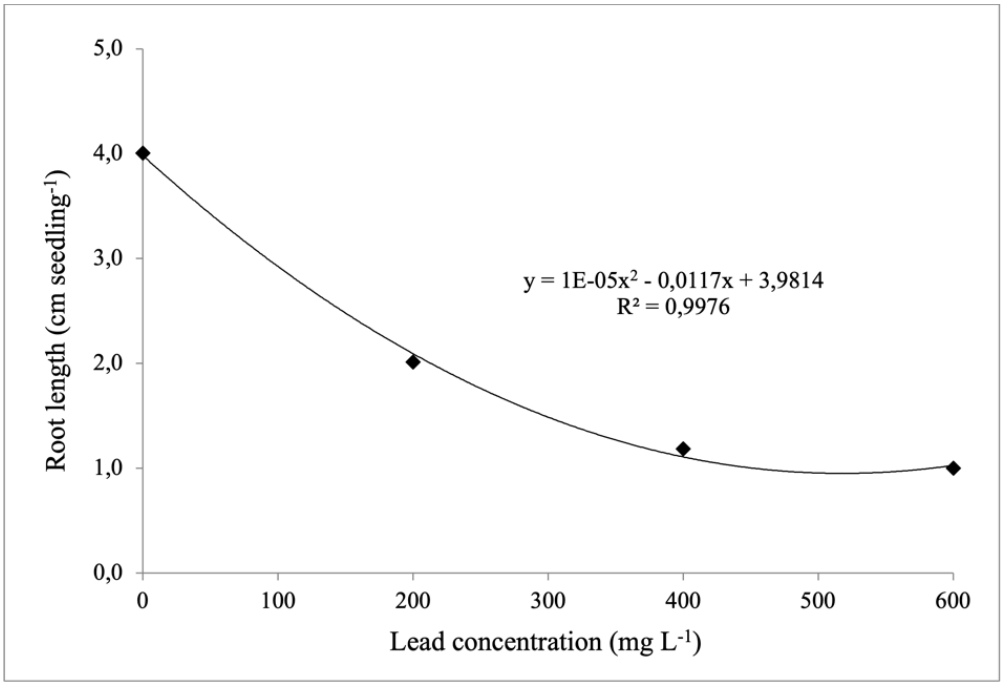
The results presented in Figure 3 clearly demonstrate the alteration in root length of wheat seedlings, and show that as lead concentration increases, root length decreases proportionally.

The inhibition of root growth caused by lead appears to result from the suppression of cell division in the root meristem region, leading to a darkening of the root system (Eun *et al.*, 2000; Pereira *et al.* 2013). In addition, lead entry into plant cells alters cell membrane

permeability, resulting in toxicity. This occurs because lead interacts with functional groups of metabolically active enzymes, replaces essential ions, and forms complexes with phosphate groups of ADP and ATP (Kumar *et al.* 2019). The effects of such toxicity include inhibition of enzymatic activity, disruption of mineral nutrition (homeostasis breakdown), hormonal imbalances, water regulation disorders, DNA damage due to the overproduction of reactive oxygen species (ROS), and inhibition of ATP production, which impairs other metabolic functions in the plant (Sharma & Dubey, 2005; Pourrut *et al*. 2011; Sethy & Ghosh, 2013).

**Figure 3**

*Second-order polynomial equation referring to root length of Triticum aestivum var. ORS Senna seedlings subjected to different lead concentrations.*




These deleterious effects have been reported in various commercially important plant species. In tomato seedlings (*S. lycopersicum* L.), root length was negatively impacted by lead contamination (Moraes *et al*. 2014). Lead causes a significant decrease in mitotic indices of cells, which results in seedlings with impaired root systems (Pereira *et al*. 2013). Some authors suggest that such changes may be associated with chromosomal abnormalities (DNA breakage), which may affect proper organogenesis of root structures (Adam & El-Ashry, 2010).

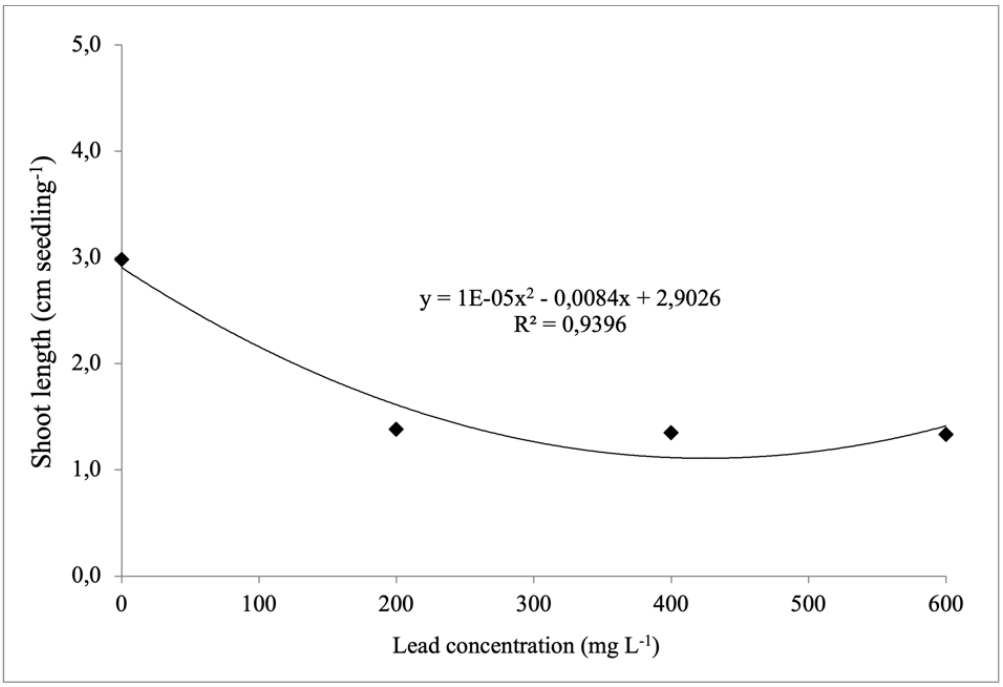
Tomato seeds (*S. lycopersicum* L.) exposed to lead faced a reduction in root length as the heavy metal concentration increased. Compared to the control, a 1% lead concentration led to a 16-fold decrease in root length and highlighted the severity of damage caused by different

lead concentrations (Mami *et al*. 2019). Similarly, root length reductions were observed for three Brassica species (*Brassica juncea*, *B. napus*, and *B. campestris*) when subjected to lead exposure (Shehzad *et al*. 2022).

According to ANOVA (F-test), significant effects were observed for both the first-degree and the second-degree regressions for the shoot length variable, with the higher-degree regression being considered more significant (Table 1). Figure 4 illustrates the relationship between different lead concentrations (mg $L^{-1}$) and shoot length.

**Figure 4**

*Second-order polynomial equation referring to shoot length of Triticum aestivum var. ORS Senna seedlings subjected to different lead concentrations.*




It is evident that the quadratic coefficient from Figure 4 is not significantly different from zero (0.00001), once again, demonstrating that there is no curvilinear relationship between shoot length and lead concentrations. This indicates that beyond the critical lead concentration, shoot length will not increase.

The coefficient of determination ($R^2$) from the quadratic regression is high (0.9996). It indicates that the regression model explains the observed variability in data. The vertex of the parabola corresponds to a lead dose of 420.0 mg $L^{-1}$, which suggests that this is the critical lead concentration for this variable.

Lead, upon contact with the root system, may accumulate in roots or be translocated to the aerial parts of the plant. This tendency varies among plant species, depending on their physiological characteristics (Sharma and Dubey, 2005; Pourrut *et al*. 2011).

Similar results to those reported in the present experiment have been presented by other researchers. The effects of lead on the germination of two rice (*Oryza sativa*) varieties caused a reduction in the development of the plants' aerial parts as lead concentrations increased (Mishra *et al*. 1998). For the forage species *B. humidicola* cv. Tupi and *Panicum maximum* cultivars Aruana and Tanzania under different lead concentrations, toxic effects on the aerial parts were detected only in the cultivar Aruana (Rosniecek *et al*. 2020).

Plants tend to limit the translocation of lead to their shoots, mainly by accumulating it in the roots. The endodermis may also serve as a partial barrier to the translocation of this heavy metal (Eun *et al.* 2000). However, with increasing doses and prolonged exposure, the roots' capacity to retain lead becomes overwhelmed. This results in its movement to the aerial parts of plants. Moreover, plants exposed to lead restrict the flow of soluble elements from the roots to the aerial parts, thereby compromising plant growth (Sharma & Dubey, 2005).

## 4 FINAL CONSIDERATIONS

In conclusion, the data clearly indicate that lead contamination significantly impairs the early development of wheat seedlings. Elevated lead concentrations adversely affect key growth parameters, such as germination rate, root elongation, and shoot development. Regression analyses revealed a critical lead threshold (around 420 to 585 mg $L^{-1}$) beyond which the deleterious effects on plant development become markedly pronounced.

Consequently, these findings underscore the necessity for rigorous monitoring and effective management of lead levels in agricultural soils, particularly in regions prone to heavy metal accumulation from anthropogenic sources. Further research is warranted to refine these threshold values and to elucidate the underlying biochemical mechanisms of plants, ultimately aiding in the development of mitigating strategies to enhance crop resilience and ensure sustainable agricultural production.

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