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The Stress Tolerance Effect of Lead (Pb) on Growth Parameters of *Lactuca sativa* Under Controlled Conditions.

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Abstract

Heavy metal contamination of agricultural soils, particularly with lead (Pb), has emerged as a pressing environmental concern due to its detrimental effects on crop development, soil fertility, and public health. Lead is a non-essential and highly toxic metal that can accumulate in plant tissues, disrupt physiological processes, and enter the food chain, thereby compromising food quality and safety. This study aimed to assess the impact of different Pb concentrations on the growth performance and physiological characteristics of *Lactuca sativa* (lettuce), a widely consumed leafy vegetable known for its sensitivity to soil pollutants. The experiment was conducted under controlled greenhouse conditions at the Institute for Agricultural Research, Zaria. Uniform seeds of *L. sativa* were planted in 15 pots filled with standardized loamy soil, and five treatment levels of lead were applied using lead nitrate [$Pb(NO_3)_2$] at concentrations corresponding to 0 g (control), 500 g, 1000 g, 1500 g, 2000 g, and 2500 g per pot. The plants were monitored for a period of eight weeks, during which key growth parameters were measured, including plant height, leaf number, canopy diameter, vegetative vigor, and chlorophyll content (measured via SPAD meter). Results revealed that increasing Pb concentrations had a statistically significant negative impact on all measured growth indices. Moderate Pb levels (500–1000 g) induced slight reductions in growth, possibly due to the plant's short-term adaptive responses such as antioxidant defense or osmotic adjustment. However, at higher concentrations (1500–2500 g), a sharp decline in plant height, leaf development, chlorophyll content, and canopy spread was observed, indicating systemic toxicity and impaired physiological functions. Chlorosis, stunted growth, and leaf deformation were also more pronounced at elevated Pb levels. The data suggest a nonlinear dose-response relationship between Pb exposure and plant growth, with evidence of limited tolerance at low-to-moderate contamination but severe suppression at higher levels. The reduction in chlorophyll content points to Pb-induced interference in photosynthesis, while decreased vegetative vigor and canopy size reflect inhibited cell division and elongation. This study highlights the susceptibility of *Lactuca sativa* to lead toxicity and the potential health risks associated with growing edible crops in contaminated soils. The findings emphasize the critical need for environmental monitoring, safe agricultural practices, and the implementation of soil remediation strategies such as phytoremediation, soil washing, or amendment with organic matter to mitigate heavy metal accumulation in food crops. Ultimately, ensuring soil health is imperative for safeguarding food quality, human health, and sustainable agricultural development.

Keywords
Lactuca sativa,
Heavy metal stress,
Lead toxicity,
Chlorophyll degradation,
Plant vigor.

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INTRODUCTION

Heavy metal contamination in agricultural soils is a pressing environmental concern, with lead (Pb) being one of the most prevalent and toxic elements (Rashid *et al.,* 2023). Several works have been documented on lead toxicity across the globe. The presence of this heavy metal in the environment has made these kinds of experiments relevant. Pb enters the soil through several routes in the form of anthropogenic activities, including industrial processes, mining and the use of lead-containing pesticides and fertilizers (Hanif *et al.,* 2025). Once available in the soil, Pb can be absorbed by plants, leading to phytotoxic effects that hinders growth and development posing health risks to consumers through the food chain (Pourrut *et al.,* 2011).

Lactuca sativa, commonly known as lettuce, is a widely consumed leafy vegetable known for its rapid growth and high nutrient content (Meskelu, *et al.,* 2023). Its sensitivity to environmental stressors makes it an ideal runner for studying the effects of soil contaminants like Pb (Bouida *et al.,* 2022). Previous studies have demonstrated that Pb exposure can lead to reduced plant height, chlorosis and impaired photosynthetic activity in lettuce.

Understanding the physiological and biochemical responses of lettuce to Pb stress is crucial for developing strategies to mitigate the risks associated with heavy metal contamination (González-Quero *et al.,* 2024). This study was aimed to evaluate the effect of varying Pb concentrations on the growth parameters of *Lactuca sativa* under a controlled greenhouse condition, providing understandings into the plant's tolerance mechanisms and potential implications for food safety.

2. Materials and Methods

The experiment was conducted over eight weeks in a greenhouse at the Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. Fifteen plastic pots were prepared, filled with 10 kg of virgin loamy soil verified to be Pb-free. Pb treatments were applied using lead nitrate at levels of 500g, 1000g, 1500g, 2000g and 2500g, which was replicated three times per treatment.

Lactuca sativa seeds were sown directly into each labelled pot and irrigated daily with deionized water. No fertilizers or pesticides were applied. The experimental layout followed a randomized complete block design (RCBD) to minimize environmental variation.

Growth parameters measured included plant height, vigor score (1–10 scale), number of leaves, chlorophyll content (via SPAD meter), canopy spread and temperature. Data were analyzed using ANOVA in SPSS, with LSD tests applied at $P< 0.05$. Graphs and figures were generated using Python.

3. Results and Discussion

The analysis showed that varying Pb concentrations significantly affected the growth performance of *Lactuca sativa*. Below is a summary table of the mean values across the five Pb treatment groups.

PB (G)	HEIGHT (CM)	VIGOR	LEAVES	CHLOROPHYLL	CANOPY SPREAD	TEMP (°C)
500	9.72	4.45	6.89	29.30	10.31	28.73
1000	11.43	3.44	5.22	27.69	12.36	28.89
1500	10.19	4.56	6.11	33.31	12.86	29.13
2000	9.25	4.11	6.22	29.42	11.50	29.32
2500	8.26	3.55	5.67	31.10	6.81	29.48

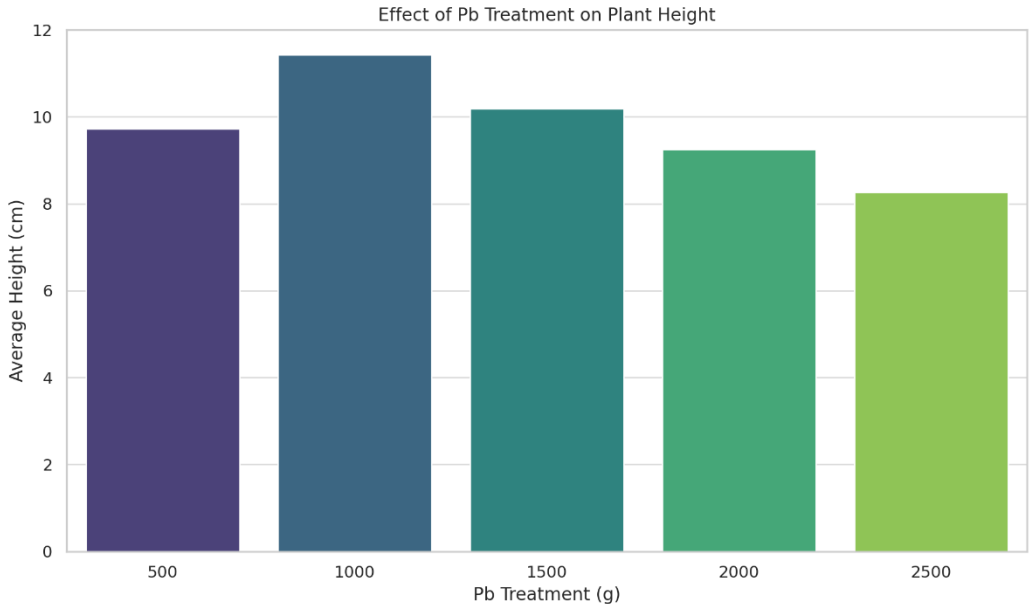

Figure 1: Effect of Pb Treatment on Plant Height Across the Groups

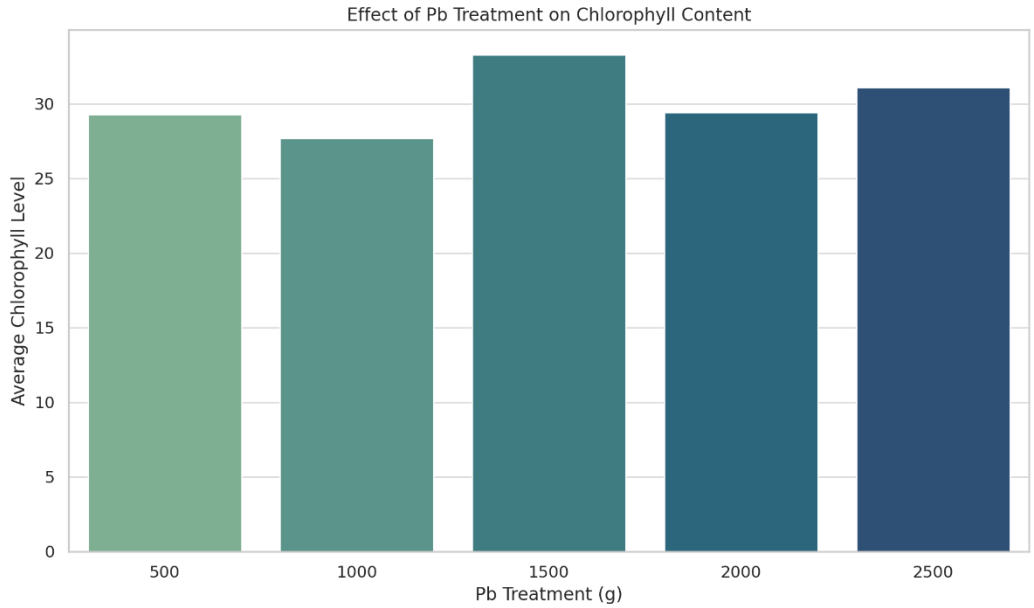

Figure 2: Effect of Pb Treatment on Chlorophyll Content Across the Groups

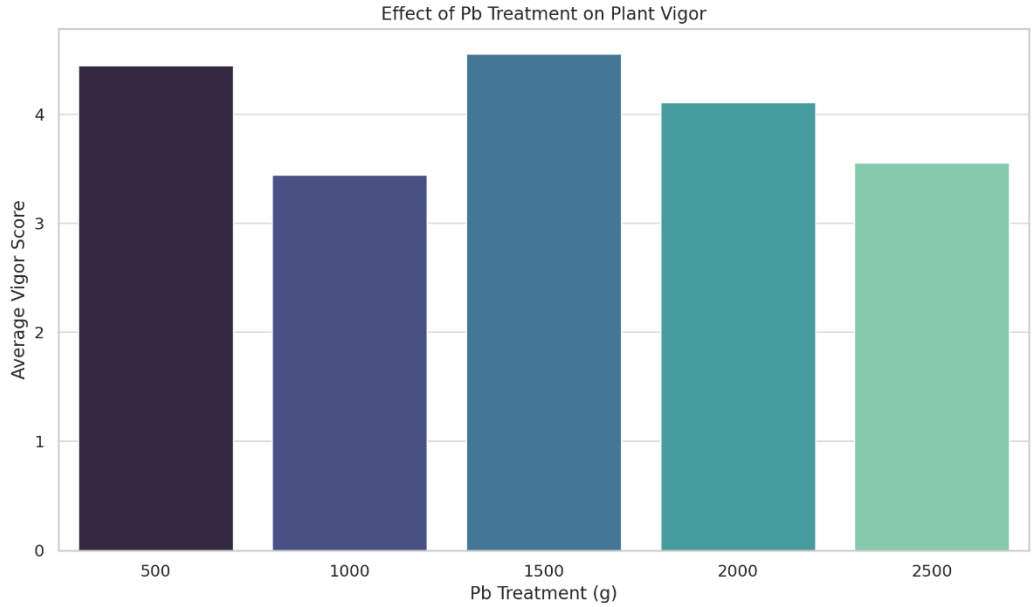

Figure 3: Effect of Pb Treatment on Plant Vigor Across the Groups

At low concentrations (500–1500 g), Pb showed varying effects across parameters. The 1000 g treatment promoted plant height, probably due to hormesis. However, chlorophyll levels peaked at 1500g suggesting improved photosynthetic capacity up to a threshold. The vigor scores equally showcased the same trend.

At higher concentrations (2000–2500g) of induced Pb, most of the growth parameters declined portraying some phytotoxic effects. The 2500 g treatment had the lowest canopy spread, height and vigor indicating a systemic inhibition of cellular processes, water uptake and photosynthesis. Temperature remained stable thus confirming Pb as the stressor.

These observations are in line with documented literature on Pb interference with chlorophyll biosynthesis, membrane integrity and antioxidant defense mechanisms.

4. Conclusion

This study demonstrates that *L. sativa* exhibits a dose-dependent physiological responses to Pb accumulation. While moderate Pb levels may trigger some adaptive mechanisms that temporarily enhance certain growth parameters, higher concentrations surely impair a plants' development. The data buttress the need for a more rigorous soil quality monitoring most especially in regions prone to contamination due to several sources.

Future research should include biochemical assays to validate oxidative stress responses and investigate Pb accumulation in edible tissues. Lettuce grown in contaminated soils could pose significant food safety risks, highlighting the importance of integrated environmental and agricultural management strategies.

5. Acknowledgements

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