



Effects of Certain Heavy Metals on Selected Growth and Yield Characteristics of Chili Pepper plants (*Capsicum annum* L.)

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Abstract

The objective of this study was to compare the reactivity of two genotypes of chili pepper (*Capsicum annum* L.) to potential negative toxic effects of heavy metals (lead, cadmium and nickel) on specific growth and yield characteristics. The study was performed from March 15, 2025, to November 1, 2025. The experiment was developed using a Randomized Complete Block Design (R.C.B.D.) with three replications and two factors: the first factor consisted of the two genotypes of chili pepper, and the second factor was concentrations of heavy metals: lead at three concentrations (80, 120, 160) mg kg⁻¹ soil by lead acetate, cadmium at three of (3, 4.5, 6) mg kg⁻¹ soil by cadmium sulfate, and nickel at three of (40, 60, 80) mg kg⁻¹ soil by nickel sulfate, with interactivity. Duncan's multiple range test was used to compare the mean differences at a 5% significance level. The survey consisted of the plant height measurement, number of different branches, leaf area, and yield per plant. The study findings were that the differences between the genotypes were markedly significant, with the Cayenne genotype significantly outperforming the others for most of the traits performed in the study, with an average plant height of 53.50 cm, branch number of 2.28 branches per plant (and yield per plant = 78.16 g plant⁻¹), and an average leaf area value of 18.77 cm² per plant were found to be significantly superior with the ID15 genotype. High concentration of heavy metals and interaction with these metals was found to affect the plant physiologic equilibration including synergistic toxicity, and influenced plants height, number of branches, leaf area and yield per plant. Toxic exposure to low metals, however, resulted in an antagonistic phenomenon allowing plant to continue to grow.

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Introduction

The chili pepper (*Capsicum annuum* L.) is of Solanaceae family and is among the most crucial crops of economic, nutritional and health significance. Chili peppers have distinctive traits that allow them to easily adapt to different environmental circumstances. [1] The chili pepper is a crop used in ancient times in numerous cultures. Its resistance to certain stresses and ability to grow in relatively polluted environments have attracted more attention in sustainable agriculture. As such, environmental impact studies using this technology have become increasingly widespread. In terms of environmental factors, the chili pepper plant is influenced by various factors like other plants, soil contamination with heavy metals, including lead (Pb), cadmium (Cd), and nickel (Ni), are also some of the most harmful ones because they have negative effects on plant growth, physiological functioning, and metabolism. Contamination of various plant tissues with certain elements results in disturbances of ionic balance, which leads to effects on plant cell membranes, enzymes, and biochemical composition. Heavy metals are one of the most deadly environmental pollutants as a result of agricultural and industrial expansion, wastewater, and industrial waste. They cannot be degraded as a result, and they remain in the soil for long periods of time. Environmental pollution with heavy metals is a serious problem nowadays due to the transfer of heavy metals to edible plants and the accumulation of heavy metals in plant tissues, in such a way that toxic level is found in both human and animal body. The movement of these metals in soil can have negative effects on plant membranes or chlorophyll and the enzyme activity [5], which causes to a great extent crop yield loss. The soil quality is the foundation of successful plant growth and agricultural crop productivity, and the heavy metal contamination results in a visible decrease in the fertility of arable land due to heavy metal accumulation and their elevated toxicity. This is especially true in the Middle East, where 17% of the world's agricultural land reaches toxic levels, including heavy metals such as lead, cadmium, and nickel as they bioaccumulate there, harming food security and public health, affecting plant growth and activity [6].

The objectives of this study were to: Evaluate the effects of lead, cadmium, and nickel contamination on growth and yield traits of chili pepper. Compare the tolerance of two chili pepper genotypes to heavy metal stress. Determine the interaction between genotype and heavy metal concentration on plant performance. Identify the genotype with superior tolerance and productivity under heavy metal-contaminated soil conditions.

Materials and Methods

The present study was conducted in the city of Kirkuk, Iraq, at a latitude of 35.5292104° N, and longitude 44.3773232 E, from March 15, 2025, to November 1, 2025, to determine the response of two genetic lines of chili pepper to soil contamination with lead, cadmium, and nickel and their effects on certain growth and yield traits. The hybrid chili pepper seeds were obtained from accredited agricultural offices and planted in plastic trays. The germination trays were filled with peat moss growing medium and then watered. The following day, three seeds were planted in each cell, and an appropriate amount of peat moss was placed over the seeds. Germination occurred after 7 days; the seeds included the Cayenne and ID15 genotypes. After germination was complete, the plants were thinned to one plant per cell, then the seedlings intended for planting were transferred to the permanent planting site after the formation of the fourth and fifth true leaves. The plants included 28 plants per variety, or 56 plants for both varieties, totaling 168 plants for three experimental units, including the control treatment. The seedlings were planted in plastic pots on April 15, 2025. Vegetative growth traits, including plant height, were measured from the base of the plant to its apex after reaching maturity using a measuring tape. The plants were measured at the end of the season for three replicates, and the average was calculated [7]. The number of branches (branches per plant) was measured, and leaf area was calculated by taking the longitudinal measurements of the leaf using the following equation: according to [8]

$$\text{Leaf Area (cm}^2\text{)} = L \times W \times K$$

L = Maximum leaf length (cm)

W = Maximum leaf width (cm)

K = Correction factor = 0.75

Leaf area was calculated using the following equation:

Leaf area = Average area of a single leaf \times Average total number of leaves per plant

The yield and its components were then calculated, with the yield per plant (g plant⁻¹) calculated using the following equation: according to [10].

Yield per plant (g plant⁻¹) = Yield of the experimental unit / Number of plants in the experimental unit.

Results and Discussion.

1- Plant height (cm) affected by different genotypes and the levels of heavy metals and their interactions:

As can be seen from the data of this study Figure (1), the genotypes have statistically significant variations in mean plant height, where Cayenne genotype showed the maximum mean (53.50 cm) compared to the lowest, ID15 genotype (45.28 cm). This might be driven by differences in the genetic performance between the two species for physiological mechanisms critical for vegetative growth, including the efficiency of photosynthesis and efficiency of cell division and elongation in the plant. Plant height is one of the basic measures of the physiological health of this plant and can be directly influenced by the degree of the plant's ability to maintain a balance of anabolic and catabolic processes after stress conditions, which are also consistent with values obtained in [11]. Regarding the effect of treatments, Figure (2) reveals substantial differences between the treatment means wherein the Control treatment (T28) (Ni0Pb0Cd0) mg kg⁻¹ soil exceeded all other treatments by using the highest average plant height (67.33 cm), whilst treatment T24 (Ni3Pb2Cd2) (80,120,6) mg kg⁻¹ soil obtained the lowest mean (34.66 cm). This variability can also be related to the direct influence of heavy metals on plant's biological and the physiological processes: heavy metals have the effect of breaking the physiological equilibrium in the plant, inhibiting enzyme activities and decreasing the process efficiency of the plant uptake of water and nutrients, with negative effects especially on chloroplasts and photosynthetic efficiency and vegetative growth. This is consistent with [12]. In terms of interaction effect of the study factors, the result of study results as seen in Figure (3) presents significant differences between means of the treatments with genotypes, as the Cayenne genotype was superior to control treatment T28 (Ni0Pb0Cd0) by producing the highest mean point of 76.00 cm. Treatment T1 (Ni1Pb1Cd1) (40,80,3) mg kg⁻¹ soil, treatment T10 (Ni2Pb1Cd1) (60,80,3) mg kg⁻¹ soil presented the highest values after control treatment, reaching 71.33 cm, while high-concentration treatments produced very clear decreases in plant height, yielding the lowest average in treatment T24 in genotype ID15 (Ni3Pb2Cd3) (80,120,6) mg kg⁻¹ soil, reaching 31.33 cm in genotype ID15 compared with control treatment, reaching 58.66 cm. This is based on different nature of the interaction and interference of heavy metals in the plant, where at low enough concentrations, an antagonistic effect is observed, where the heavy metals are not taken up and only plants thrive, at high enough concentrations, the accumulation becomes synergistic, making compounds harmful to the plant. This is similar to what was reported by [13].

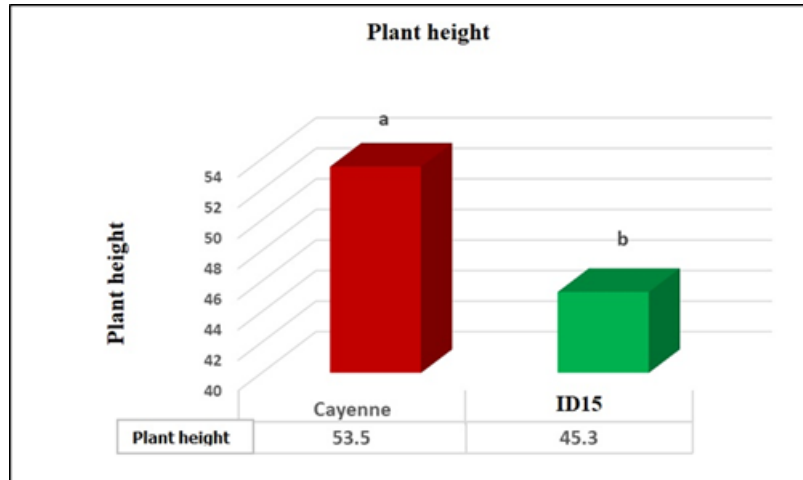


Figure (1) Effect of genetic combinations on plant height (cm).

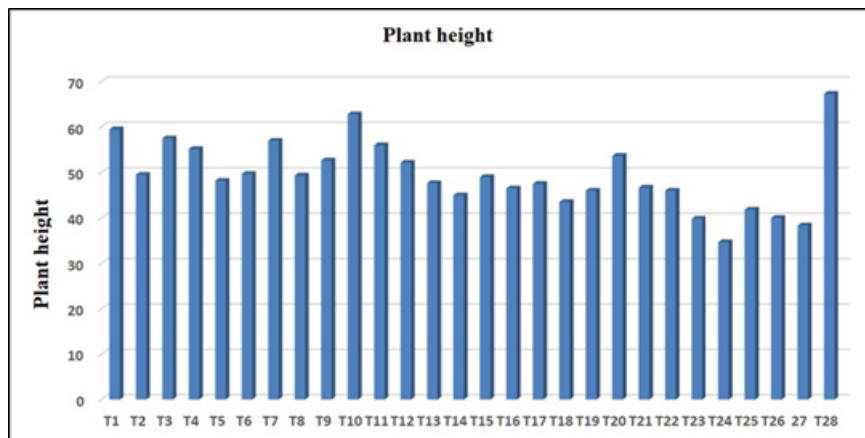


Figure (2) Effect of treatments on plant height (cm).

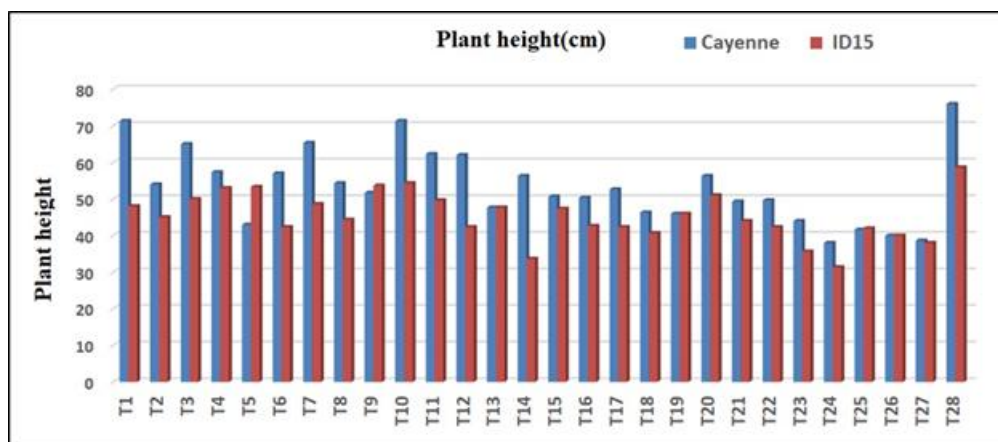


Figure (3) The effect of interaction between treatments and genetic backgrounds on plant height (cm).

2- The effect of genotypes and different levels of heavy metals, and their interactions, on the trait of number of branches (branches·plant-1):

The study results, as shown in Figure(4), indicate that there are significant differences between the means of the genetic compositions in the number of branches per plant (branch/plant-1) trait, with the Cayenne genetic composition having the highest mean of 2.38 branches/plant-1, compared to the ID15 genetic composition, which had a mean of 1.41 branches/plant-1. This variation may be attributed to genetic differences. plant-1, compared to the ID15 genotype, which had a mean of 1.41 branches. plant-1. This variation may be attributed to genetic differences among the varieties in their ability to tolerate stress caused by heavy metals, as the Cayenne genotype is more efficient at

maintaining meristematic activity and the balance of plant hormones responsible for branch formation, leading to an increase in the number of branches compared to the ID15 genotype, which is consistent with the findings reported in [14].

As for the effect of treatments, the results shown in Figure (5) indicate the presence of significant differences between the treatment means, as the Control treatment (T28) (Ni0Pb0Cd0) and treatment T6 (Ni1Pb2Cd3) (40,120,6) mg kg⁻¹ soil, yielding the highest average number of branches at 2.83 branches plant-1, whereas treatments with high concentrations of the heavy metals lead, cadmium, and nickel such as treatment T15 (Ni2Pb2Cd3) (60,120,6) mg kg⁻¹ soil and treatment T24 (Ni3Pb2Cd3) (80,120,6) mg kg⁻¹ soil and treatment T25 (Ni3Pb3Cd1) (80,160,3) mg kg⁻¹ soil, which had the lowest mean of 1.16 plants-1. This decrease may be attributed to the negative effect of heavy metals in inhibiting cell division and reducing meristematic activity in the growing tips, which is consistent with the study [15].

As for the interaction effects among the study factors, the results of the study, as shown in Figure (6), indicate the presence of significant differences between the means of the treatments and genotypes, while the three-way interaction of lead, cadmium, and nickel in treatment T13 (Ni2Pb2Cd1) (60, 120, 3) mg kg⁻¹ soil in the Cayenne genotype, the highest number of branches, which reached 4.00 branches per plant.1, while the interaction at high concentrations of heavy metals (Ni3Pb3Cd3) led to a clear decrease in the number of branches per plant. This decrease may be attributed to damage to cell membranes and disruption of cell division processes; consequently, these processes negatively affect the plant’s vegetative growth and its photosynthesis, as well as the absorption of macronutrients such as nitrogen, phosphorus, and potassium, which negatively affects the formation of lateral branches in the plant, consistent with [16].

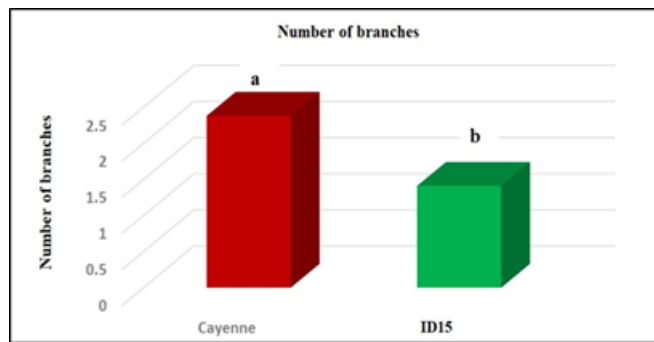


Figure (4) Effect of genetic combinations on the trait of number of branches (branches per plant-1)

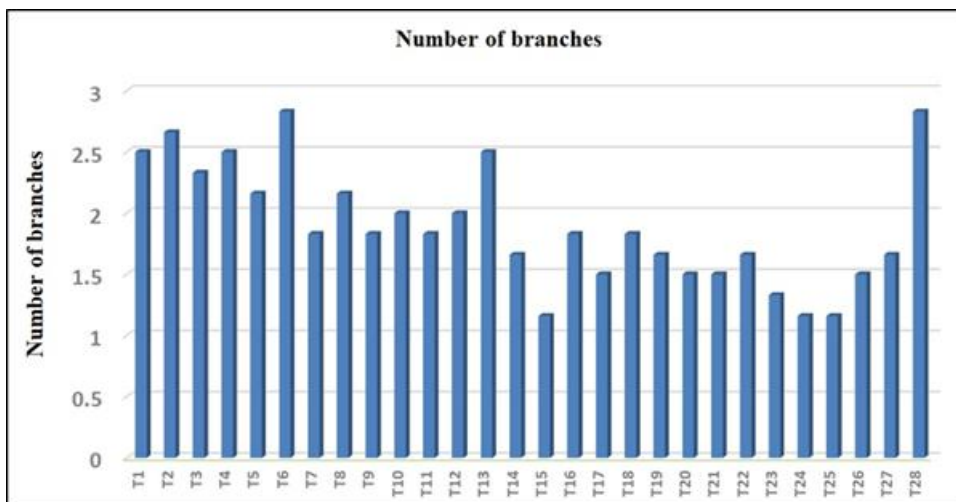


Figure (5) Effect of treatments on the number of branches (branches per plant-1)

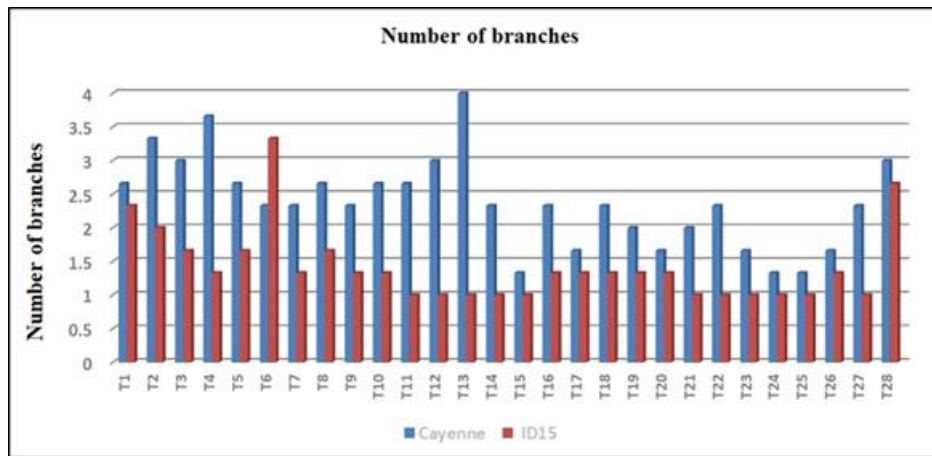


Figure (6) The effect of interaction between treatments and genetic backgrounds on the trait of number of branches (branches per plant-1).

3- The effect of genotypes and different levels of heavy metals, and their interactions, on leaf area (cm²):

The study results showed, as illustrated in Figure (7), that there are significant differences between the means of genotypes in leaf area, as the ID15 genotype significantly outperformed the others and yielded the highest mean of (18.77 cm²) compared to the Cayenne genotype, which yielded the lowest mean of (10.26 cm²). This may be attributed to differences among the genotypes in physiological activity efficiency under mineral stress conditions, as leaf area is a direct reflection of photosynthetic efficiency and the continued formation of dry matter. This result is consistent with what was noted by [17].

As for the effect of the treatments, the study results, as shown in Figure (8), revealed significant differences between the treatment means. The control treatment T28 (Ni0Pb0Cd0) at 0.01 mg kg⁻¹ soil outperformed the others, yielding the highest mean leaf area of 24.51 cm², while treatment T21 (Ni3Pb1Cd3) (80,80,6) mg kg⁻¹ soil the lowest mean of 8.90 cm². This is attributed to the negative effect of heavy metals at high concentrations of lead, cadmium, and nickel, particularly at concentrations of (Ni80,Pb160,Cd6) mg kg⁻¹ soil, as these elements inhibit cell division, reduce chlorophyll content, and increase oxidative stress, leading to decreased photosynthetic efficiency and consequently a reduction in the plant's leaf area. This result is consistent with the study [18], which showed that cadmium stress causes a clear reduction in plant vegetative growth.

As for the interaction effects among the study factors, the results of the study, as shown in Figure (9), indicate that there are significant differences between the means of the treatments and genotypes. Treatment T1 in the ID15 (Ni1Pb1Cd1) (40,80,3) mg kg⁻¹ soil yielded the highest mean of (31.20 cm²), whereas interactions with high concentrations, such as treatment T18 in the Cayenne (Ni2Pb3Cd3) (60,160,6) mg kg⁻¹ soil, which yielded the lowest average of 4.70 cm². As for treatments T21 (Ni3Pb1Cd3) (80,80,6) mg kg⁻¹ soil and treatment T27 (Ni3Pb3Cd3) (80,160,6) mg kg⁻¹ soil, respectively, recorded a clear decrease in leaf area, reaching 5.33 cm² and 7.36 cm² in the Cayenne genotype. It is noted from the results of the current study that high nickel concentrations cause a decrease in plant biomass, as nickel is involved in photosynthetic processes and inhibits chlorophyll synthesis enzymes, leading to the displacement of Mg⁺² from the chlorophyll molecule, which results in reduced light absorption, affects stomatal opening and closing, and leads to necrosis of the cuticle layer. This is consistent with a study [11].

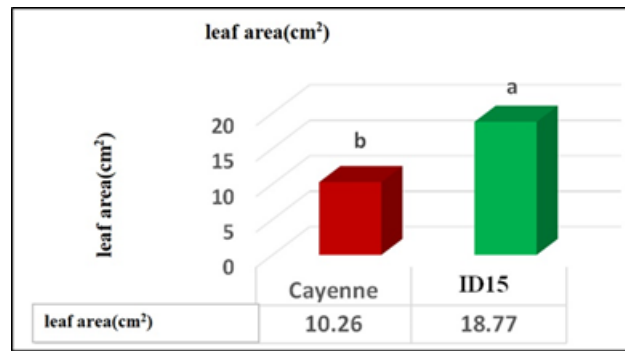


Figure (7) Effect of genetic compositions on leaf area (cm²).

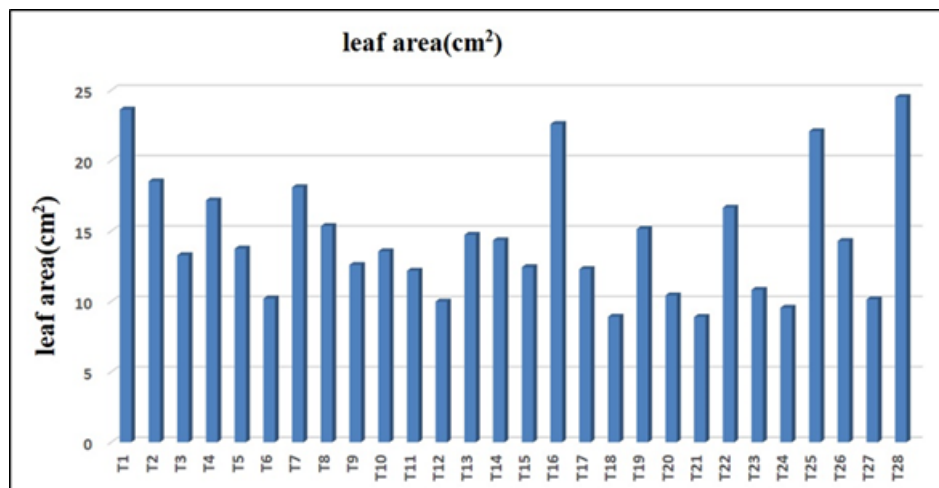


Figure (8) Effect of factors on paper area (cm²)

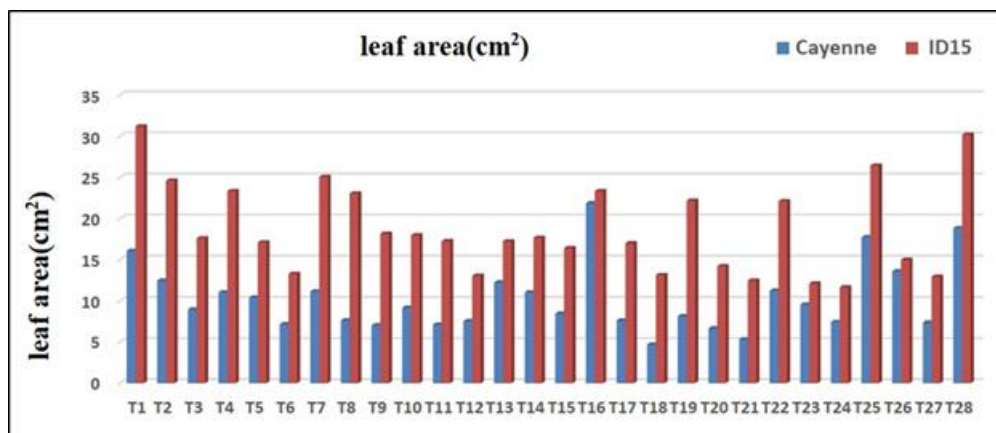


Figure (9) The effect of interaction between treatments and genotypes on leaf area (cm²).

4- The effect of genotypes and different levels of heavy metals, and their interactions, on the yield per plant (g plant-1):

The study results and Figure (10) clearly show significant differences between the means of genetic compositions in terms of yield per plant, with the Cayenne genetic composition significantly outperforming the others with a mean of 78.16 g. plant-1 compared to the ID15 genotype, which yielded an average of 51.46 g. plant-1 This variation may be attributed to differences in physiological responses among the genotypes, as the results indicate that the Cayenne genotype possesses higher efficiency in carbon allocation toward fruits and a better ability to maintain photosynthesis under stress conditions, and the ability to mitigate the negative effects of heavy metals by regulating their transport or reducing their impact within plant cells, thereby maintaining the continuity of dry matter formation in the plant and consequently increasing yield. This is consistent with a study [21].

As for the effect of treatments, the study results, as shown in Figure (11), indicate that there are significant differences between the treatment means. Treatment T22 (Ni₃Pb₂Cd₁) (80,120,3) mg kg⁻¹ soil outperformed the others, recording the highest yield of 125.85 g. plant⁻¹, while treatment T27 (Ni₃Pb₃Cd₃) (80,160,6) mg kg⁻¹ soil recorded the lowest yield of 16.61 g. plant⁻¹. This reflects the negative impact of heavy metals at high levels, as metal stress redirects metabolism toward survival mechanisms rather than production. However, some high concentrations of heavy metals did not result in a decrease in yield but maintained good production levels, This behavior may be attributed to the actual effect of heavy metals and depends on the degree of accumulation within the tissues whether in the roots, leaves, or fruits as well as on competition and interactions between the elements. This is consistent with study [21].

As for the effect of interactions between the study factors, the results of the study, as shown in Figure (12), it was shown that there were significant differences between the means of the treatments and genotypes, with the Cayenne genotype outperforming the others, recording the highest yield value in treatment T22 (Ni₃Pb₂Cd₁) (80,120,3) mg g⁻¹ soil, reaching 150.26 g. plant⁻¹, whereas the yield decreased significantly in treatment T27 (Ni₃Pb₃Cd₃) (80,160.6) mg kg⁻¹ soil to 5.23 g. plant⁻¹, whereas the ID15 genotype showed a less variable response, with a maximum yield of 101.43 g. plant⁻¹, indicating that this genotype possesses physiological stability but is less productive. This variation in response among genotypes depends on the presence of heavy metals in the soil, competition among ions for absorption sites, and synergistic effects that exacerbate the negative impact of heavy metals, which is consistent with the findings reported by [22].

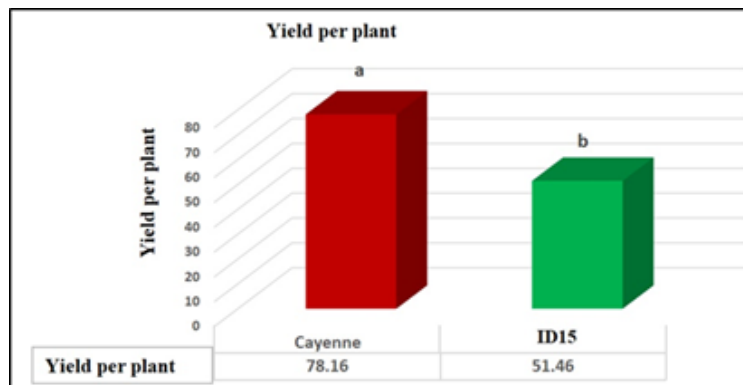


Figure (10) Effect of genetic combinations on the yield per plant (g plant-1)

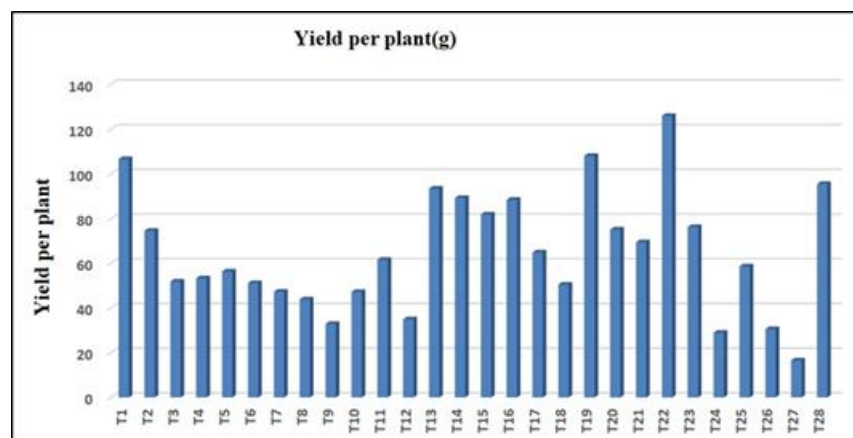


Figure (11) Effect of treatments on the yield per plant (g plant-1)

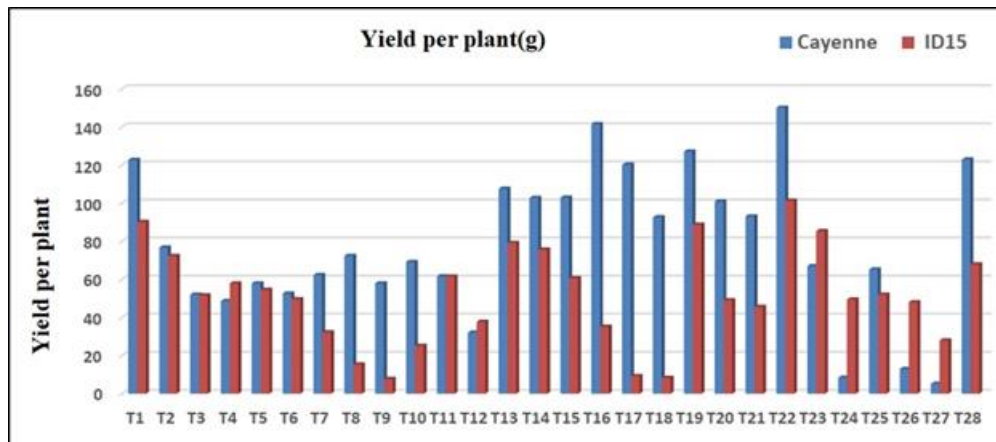


Figure 12: Effect of the interaction between treatments and genotypes on the yield per plant (g plant⁻¹)

Conclusion

The results of the study showed that there were significant differences between the means of the genetic lines in terms of plant height, with the Cayenne line outperforming the others in most of the traits studied, including plant height, number of branches, and yield per plant, indicating that the plant possesses greater capacity and higher efficiency in tolerating heavy metal stress, while the ID15 genotype outperformed others in average leaf area. The Control treatment yielded the best results for most of the studied traits, whereas the T27 (Ni3Pb3Cd3) with high concentrations (80, 160, 6) mg kg⁻¹ soil to a significant decrease in all growth and yield traits, confirming the significant negative impact of high heavy metal concentrations. The interaction between low concentrations of heavy metals produced an antagonistic effect that reduced the severity of damage and allowed growth to continue, whereas high concentrations resulted in synergistic toxicity, which led to widespread physiological and biochemical disturbances in the plant.

References

1. Barboza, G. E., Carrizo García, C., Bianchetti, L. D. B., Romero, M. V., & Scaldaferrro, M. (2022). Monograph of wild and cultivated chili peppers (*Capsicum* L., Solanaceae). *PhytoKeys*, 200, 1–423. <https://doi.org/10.3897/phytokeys.200.71667>.
2. Sharma, P., Kumar, A., and Sharma, S. (2023). Physiological and biochemical responses of *Capsicum* species under abiotic stress: A review. *Environmental and Experimental Botany*, 208, 105211.
3. Mahdavian, K., Ghaderian, S. M., & Schat, H. (2021). Effect of cadmium and lead on growth and physiology of *Capsicum annuum*. *Environmental Science and Pollution Research*, 28(2), 1582–1590.
4. Sharma, P., Dubey, R. S., and Sharma, S. (2020). Heavy metals as inorganic pollutants: Sources, impacts, and biotransformation in the environment. *Environmental Chemistry Letters*, 18(1), 203–216.
5. Tiwari, S., Kumar, S., and Tripathi, R. D. (2018). Heavy metal pollution in soil and plants: Physiological, biochemical, and molecular responses and remediation strategies. *Environmental Science and Pollution Research*, 25(12), 11469–11481.
6. Hou, D., Jia, X., Wang, L., McGrath, S. P., Zhu, Y.-G., Hu, Q., Zhao, F.-J., Bank, M. S., O'Connor, D., & Nriagu, J. (2025). Global soil pollution by toxic metals threatens agriculture and human health. *Science*, 388(6744), 316–321. <https://doi.org/10.1126/science.adr5214>
7. Shaaban, M. M. (2010). Role of boron in plant nutrition and human health. *American Journal of Plant Physiology*, 5(5), 224–240.
8. Mokhtarpour, H., Lotfollah, A., Sanavi, S. A. M. M., Rad, A. S., and Ghasemi-Golezani, K. (2010).

Comparison of different methods to estimate leaf area of maize (*Zea mays* L.). *Research Journal of Agriculture and Biological Sciences*, 6(5), 565–569.

9. Al-Dahami, A. S. M. (2013). Effect of organic nutrients on the growth and yield of hot pepper (*Capsicum annuum* L.). Master's thesis, College of Agriculture, University of Baghdad, Iraq.
10. Altaf Muhammad Ahsan, Y., Yuanyuan, H., Chengyao, H., Muhammad Ali, M., Huangying, S., Huizhen, F., and Zhiwei, W. (2022). Physiological and Biochemical Responses of Pepper (*Capsicum annuum* L.) Seedlings to Nickel Toxicity. *Frontiers in Plant Science*, 13, 950392. <https://doi.org/10.3389/fpls.2022.950392>.
11. Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals. *Journal of Chemistry*, 2019, 6730305. <https://doi.org/10.1155/2019/6730305>.
12. Altaf, M. A., Shahid, R., Ren, M. X., Altaf, M. M., Jahan, M. S., and Khan, L. U. (2021)a. Melatonin mitigates nickel toxicity by improving nutrient uptake fluxes, root architecture system, photosynthesis, and antioxidant potential in tomato seedling. *Journal of Soil Science and Plant Nutrition*, 21(6), 1842–1855.
13. Ashraf, A., Bhardwaj, S., and Ishtiaq, H. (2021). Lead uptake, toxicity and mitigation strategies in plants. *Plant Archives*, 21(1), 122–129. <https://doi.org/10.51470/PLANTARCHIVES.2021.v21.no1.099>.
14. Badawy, I. H., Eid, E. M., Al-Huqail, A. A., Ibrahim, M. M., & Elkelish, A. (2022). Alleviation of cadmium and nickel toxicity in tomato plants. *Plants*, 11(15), 2018. <https://doi.org/10.3390/plants11152018>
15. Buendía-Valverde, M. d. I. L., Gómez-Merino, F. C., Corona-Torres, T., Mateos-Nava, R. A., & Trejo-Téllez, L. I. (2023). Effects of cadmium, thallium, and vanadium on photosynthetic parameters of three chili pepper (*Capsicum annuum* L.) varieties. *Plants*, 12(20), 3563. <https://doi.org/10.3390/plants12203563>
16. Tu, D., Tian, X., Liang, C., Zhou, P., Wang, Y., Xing, D., & Liu, Y. (2025). Physiological and biochemical responses of pepper (*Capsicum annuum*) to cadmium stress. *Ecotoxicology and Environmental Safety*, 290, 118370. <https://doi.org/10.1016/j.ecoenv.2025.118370>
17. Sana, S., Zhang, M., Khan, I., Ali, B., Wang, J., & Zhou, Q. (2024). Differential responses of chili (*Capsicum annuum* L.) varieties under cadmium stress. *Scientific Reports*, 14, 10759427. <https://pmc.ncbi.nlm.nih.gov/articles/PMC10759427/>
18. Shen, C., Liu, M., Yang, Z., Zhang, X., & Wang, H. (2023). Characterization of cadmium accumulation mechanism in eggplant cultivars. *Frontiers in Plant Science*. <https://pubmed.ncbi.nlm.nih.gov/36699861/>