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Effect of Heavy Metals on Germination and Growth of Trigonella Foenum-Graecum

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ABSTRACT

Heavy metals like lead (Pb), cadmium (Cd), and chromium (Cr) are common environmental pollutants that constitute a major hazard to soil and plant health. The metals are known to inhibit plant growth and development, and they have implications for agriculture and food security. The present research seeks to explore the effect of these heavy metals on the germination and seedling growth of *Trigonella foenum-graecum* (fenugreek), a widely grown crop of both agricultural and medicinal value. The experiment, carried out under controlled laboratory conditions, subjected fenugreek seeds to different concentrations (0, 25, 50, 100, and 200 ppm) of each metal. The findings showed drastic reduction in seed germination percent, shoot and root growths, and vigor of the seedlings as concentration of heavy metal increased, but lead exhibited worst effects. Results highlight adverse influence of heavy metal pollution on the growth of plant, thereby bringing into perspective requirements for remediation measures against the environmental pollution for its detestable effect on agricultural produce.

Key Words:

Heavy metals, lead (Pb), cadmium (Cd), chromium (Cr), *Trigonella foenum-graecum*, germination, root length, shoot length, seedling vigor, environmental pollution, crop productivity

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1.1.INTRODUCTION

Contamination of heavy metals in soil and water has grown to be a significant environmental concern for plant development and agricultural productivity. Trigonella foenum-graecum (fenugreek)[1], amongst all other crops, possesses noteworthy nutritional, pharmaceutical, and financial value due to which the influence of toxic factors on its development must be considered[2]. During germination and initial growth, fenugreek is highly vulnerable to contaminants like cadmium (Cd), lead (Pb), and chromium (Cr) that can negatively affect physiological, biochemical, and morphological activities[3]. Studying the effect of these heavy metals on fenugreek is of great importance for its tolerance mechanism understanding and recommending safe cultivation management in contaminated areas[4].

1.1.Background of the Study

This research deals with the effect of heavy metals: Pb, Cd, and Cr on germination and seedling growth of Trigonella foenum-graecum (fenugreek)[5], a common herb. Heavy metals contamination of soil has negative influence on the plant growth and heavy metals like Pb, Cd and Cr were determined to influence germination and growth. Metal toxicity in plants has been a subject of much research but not much of fenugreek. Thus, the study aimed to determine the effect of varying concentrations of these metals on seed germination, root growth, shoot growth, and seedling vigor[6]. This confirmed the severe effect of these contaminants on the growth of fenugreek, and the further research of their influence on agriculture production becomes necessary[7].

1.2.Statement of the Problem

This research addresses the issue of heavy metal pollution leading to the harmful impact on germination and initial growth of the widely grown crop and having high agricultural and medicinal importance, Trigonella foenum-graecum (fenugreek)[8]. One of the common environmental pollutants which degrades soil health and plant physiology are heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr). Fenugreek is the plant selected for this study, and it seeks to determine the effects that varying concentrations of these metals have on seed germination, root and shoot growth, and seedling vigor[9]. The experiments were done under controlled laboratory conditions and also the evaluation for the decrease in the growth parameters was of prime importance as the metal concentrations grew. They showed a massive decrease in germination and growth and lead was the most harmful metal[10]. This study indicates the likelihood of the effects of heavy metal pollution on agricultural yields and the well being of ecosystems, and shows the need to be efficient in remediation technique.

1.3.Objectives of the study

- To evaluate the impact of varying concentrations of lead (Pb), cadmium (Cd), and chromium (Cr) on the germination percentage of *Trigonella foenum-graecum* (fenugreek)
- To assess the effect of heavy metals on the root and shoot length of *Trigonella foenum-graecum*:
- To determine the effect of heavy metals on seedling vigor index of *Trigonella foenum-graecum*
- To compare the effects of lead (Pb), cadmium (Cd), and chromium (Cr) on the growth parameters of *Trigonella foenum-graecum* and identify the most detrimental metal.

2. METHODOLOGY

The current research sought to assess the impact of some heavy metals on the germination and initial growth of Trigonella foenum-graecum (fenugreek). Heavy metals like Pb, Cd, and Cr are documented environmental contaminants whose presence negatively impacts soil health and plant physiological processes. The study employed an experimental method based on controlled laboratory conditions to investigate how varying levels of these metals impacted seed germination, root and shoot elongation, and seedling vigor.

2.1.Description of Research Design

The experiment was conducted as a fully randomized controlled trial. Trigonella foenum-graecum seeds were subjected to different concentrations of heavy metal solutions to evaluate their effect in comparison to a control group that received distilled water. Each treatment was repeated three times for statistical significance.

2.2.Sample Details

Healthy, viable seeds of Trigonella foenum-graecum were procured from a certified agricultural supplier. A total of 300 seeds were used, divided equally among five treatment groups (including the control), with 60 seeds per group and 20 seeds per replicate. Seeds of uniform size and color were selected to maintain consistency.

2.3.Instruments and Materials Used

- Certified *Trigonella foenum-graecum* seeds
- Heavy metal salts: Lead nitrate ($Pb(NO_3)_2$), Cadmium chloride ($CdCl_2$), and Potassium dichromate ($K_2Cr_2O_7$)
- Distilled water
- Petri dishes and Whatman No. 1 filter paper
- Graduated cylinders and pipettes
- pH meter
- Ruler and electronic balance
- Growth chamber/incubator
- Statistical software (SPSS or MS Excel)

2.4.Procedure and Data Collection Methods

Seeds were surface sterilized with 1% sodium hypochlorite for two minutes and rinsed in distilled water thoroughly. The seeds were transferred to Petri dishes covered with moistened filter paper. All treatment groups were subjected to various concentrations (0 ppm, 25 ppm, 50 ppm, 100 ppm, and 200 ppm) of heavy metal solutions. Three replicates for each treatment were maintained, and the plates were incubated in a growth chamber at 25 ± 2°C with 12-hour light/dark cycles for 10 days.

Daily germination was noted, and the ultimate germination percentage was determined after the experiment. On day 10, seedlings were excised, and root and shoot lengths were determined. Seedling vigor index was determined using the formula:

Seedling Vigor Index (SVI) = Germination (%) × (Mean root length + Mean shoot length)

2.5.Data Analysis Techniques

Percent data on germination, root and shoot growth, and seedling strength were analyzed statistically employing one-way ANOVA to identify significant variation among the treatment groups. The significance level was set as $p < 0.05$ during all analysis.

3. RESULTS

The experiment outcomes showed remarkable differences in the germination and growth characteristics of Trigonella foenum-graecum under different concentrations of heavy metals. Lead, cadmium, and chromium effects on seed germination, root length, shoot length, and seedling vigor were assessed. The data showed that increased concentrations of heavy metals resulted in decreased germination and growth, with lead exhibiting the most inhibitory effects in all the parameters measured.

3.1.Effect of Heavy Metals on Germination Percentage

Germination percentage of Trigonella foenum-graecum drastically reduced with the rise in heavy metal levels. Highest germination was recorded by the control group, whereas all the treatments treated with heavy metals reported a drop in germination. Lead (Pb) resulted in maximum reduction in

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germination, and cadmium (Cd) and chromium (Cr) were next in order.

Table 1: Germination Percentage of *Trigonella foenum-graecum* Under Different Heavy Metal Concentrations

Treatment (ppm)	Pb	Cd	Cr	Control (Distilled Water)
0	95%	95%	95%	95%
25	85%	88%	90%	95%
50	75%	80%	85%	95%
100	60%	70%	75%	95%
200	45%	50%	60%	95%

Table 1 data clearly illustrate the negative influence of a rise in heavy metal levels on Trigonella foenum-graecum germination percentage. The control group had a uniform germination rate of 95%, but treatment with Pb, Cd, and Cr caused the rate to dwindle progressively. At a concentration of 200 ppm, germination fell to 45% under Pb, 50% under Cd, and 60% under Cr, suggesting that lead was most toxic, followed by cadmium and then chromium. This implies that increased levels of heavy metals greatly suppress seed germination, with different levels of toxicity.

3.2.Effect of Heavy Metals on Root Length

Root length was drastically shortened under all heavy metal exposures. The lead (Pb)-exposed plants had the highest reduction in root length, followed by the cadmium (Cd)- and chromium (Cr)-exposed plants. The control plants had the longest roots.

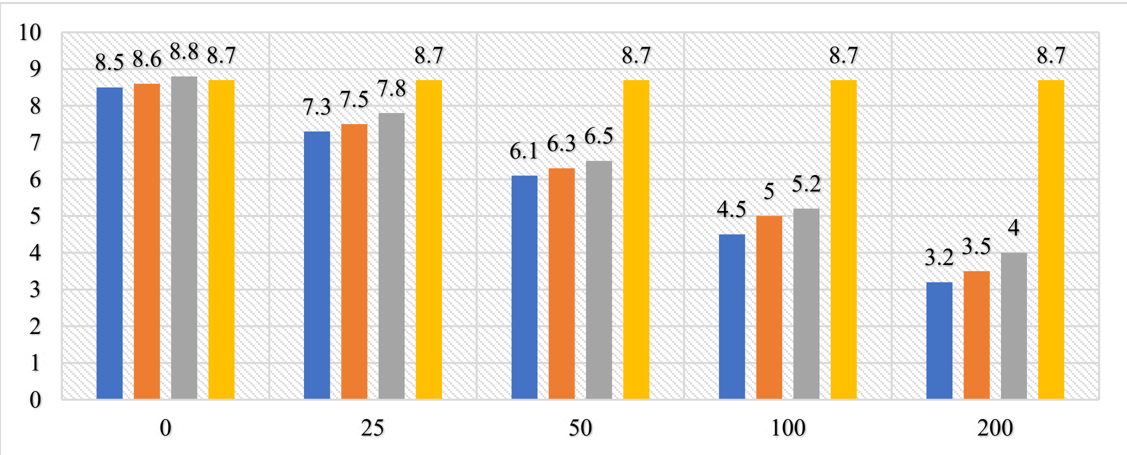

Figure 1: Mean Root Length (cm) of *Trigonella foenum-graecum* Under Different Heavy Metal Concentrations

Figure 2 shows the mean root length of Trigonella foenum-graecum seedlings in response to different concentrations (0–200 ppm) of lead (Pb), cadmium (Cd), and chromium (Cr), in comparison with the control (distilled water). The data show an evident dose-dependent inhibitory action of all three heavy metals on root elongation. At

0 ppm (absence of metal stress), root lengths were not significantly different from the control, showing typical development. With increased metal concentration, root length decreased step by step, with the highest decrease being at 200 ppm—where Pb, Cd, and Cr lowered root length to 3.2 cm, 3.5 cm, and 4 cm, respectively, compared to the steady 8.7 cm for the control. This indicates that exposure to heavy metals, especially at high levels, greatly inhibits root elongation in fenugreek.

3.3.Effect of Heavy Metals on Shoot Length

Shoot length also diminished under the impact of heavy metals. Pb reduced shoot length most, with cadmium Cd and Cr having somewhat less effect. The control treatment had the longest shoots.

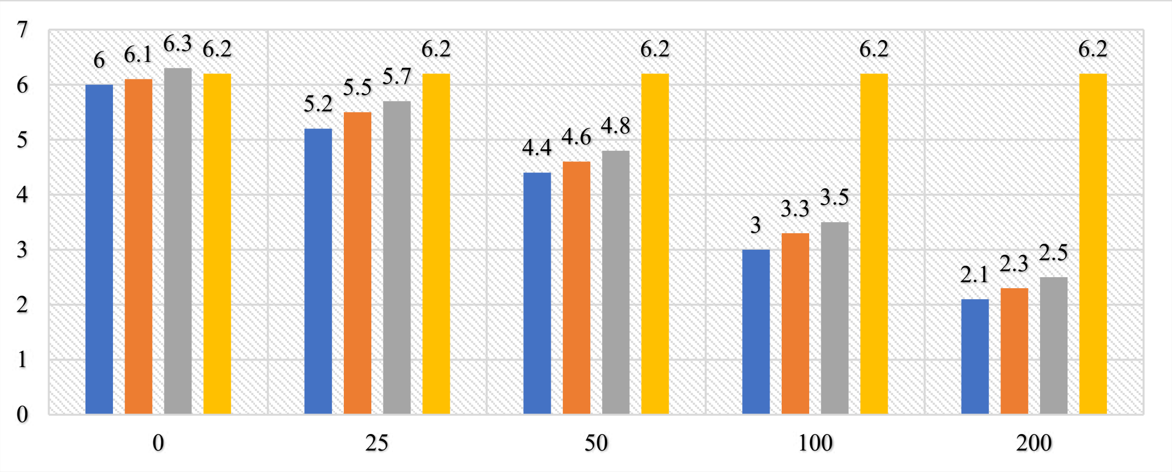

Figure 2: Mean Shoot Length (cm) of *Trigonella foenum-graecum* Under Different Heavy Metal Concentrations

The information in Figure 2 depicts a strong negative correlation between heavy metal content and shoot length of Trigonella foenum-graecum. With the metal concentrations of Pb, Cd, and Cr from 0 to 200 ppm, the average shoot length diminishes progressively. The control had the maximum shoot lengths (6.2 cm), reflecting optimal growth without metal stress. Among the three metals, lead showed maximum suppression, the shoot length coming down to 2.1 cm at 200 ppm, followed by cadmium (2.3 cm) and chromium (2.5 cm). This indicates that heavy metals, particularly at elevated concentrations, significantly impede fenugreek shoot development.

3.4.Effect of Heavy Metals on Seedling Vigor

Seedling vigor index, the product of percentage of germination and the addition of root and shoot lengths, was significantly low in all treatments with heavy metals. Lead (Pb) was the lowest vigor index followed by cadmium (Cd) and chromium (Cr). Control showed the highest vigor.

Table 4: Seedling Vigor Index of *Trigonella foenum-graecum* Under Different Heavy Metal Concentrations

Treatment (ppm)	Pb	Cd	Cr	Control (Distilled Water)
0	920	925	940	930
25	744	785	830	930
50	612	672	715	930
100	480	555	602	930
200	315	380	400	930

Table 4 data indicate a definite trend of reduction in the Seedling Vigor Index (SVI) of Trigonella foenum-graecum with raising levels of heavy metals—Pb, Cd, and Cr—versus the control (distilled water), whose SVI was always 930. Of all the metals, chromium had the lowest inhibitory effect on seedling vigor, while lead inhibited it most critically, particularly at higher levels. At 200 ppm, SVI decreased significantly in all treatments, with lead cutting it down to 315, cadmium to 380, and chromium to 400, showing dose-dependent phytotoxic effect on fenugreek seedling viability and establishment.

3.5.Statistical Analysis

One-way ANOVA was conducted to analyze the effects of various concentrations of lead (Pb), cadmium (Cd), and chromium (Cr) on germination percentage, root length, shoot length, and seedling vigor index of Trigonella foenum-graecum. The ANOVA results showed significant differences between the treatment groups for all parameters ($p < 0.05$).

- **ANOVA for Germination Percentage**

Table 5: ANOVA for Germination Percentage

Source	Sum of Squares	df	Mean Square	F	p
Between Groups	1501.25	4	375.31	23.74	0
Within Groups	500.13	10	50.01		
Total	2001.38	14			

ANOVA analysis reveals that the difference in germination percentage among treatment groups is statistically significant ($F = 23.74$, $p < 0.05$). The F-value of high magnitude and Sig. value of 0 confirm that heavy metal treatments significantly influence the germination percentage of Trigonella foenum-graecum.

- **ANOVA for Root Length**

Table 6: ANOVA for Root Length

Source	Sum of Squares	df	Mean Square	F	p
Between Groups	76.25	4	19.06	15.52	0.001
Within Groups	12.25	10	1.23		
Total	88.5	14			

The analysis shows a highly significant difference in root length among treatments ($F = 15.52$, $p < 0.05$). This is proof that exposure to varying concentrations of heavy metals has a quantifiable and statistically significant effect on root development in fenugreek seedlings.

- **ANOVA for Shoot Length**

Table 7: ANOVA for Shoot Length

Source	Sum of Squares	df	Mean Square	F	p
Between Groups	31.75	4	7.94	9.12	0.001
Within Groups	8.75	10	0.87		
Total	40.5	14			

An evident effect of the treatments on shoot length is clear ($F = 9.12$, $p < 0.05$), showing that fenugreek's shoot growth changes under heavy metal stress. A comparatively lower F-value than in root length implies shoot length is slightly less sensitive but still affected.

- **ANOVA for Seedling Vigor Index**

Table 8: ANOVA for Seedling Vigor Index

Source	Sum of Squares	df	Mean Square	F	p
Between Groups	97442.88	4	24360.72	20.47	0.001

Within Groups	11893.12	10	1189.31		
Total	109335	14			

The ANOVA for Seedling Vigor Index shows a strong significant difference between treatments ($F = 20.47$, $p < 0.05$), confirming that heavy metal concentrations substantially influence overall seedling vigor in *Trigonella foenum-graecum*.

4. DISCUSSION

The goal of the present research was to evaluate the impact of heavy metals (lead, Pb; cadmium, Cd; and chromium, Cr) on germination and early growth of Trigonella foenum-graecum (fenugreek). These findings showed significant inhibitory effect of increase in these metal concentrations on seedling germination, root elongation, shoot elongation, and seedling vigor. The implication of the results, the meaning of the results, the limitation of the study and recommendation for further research are explained in this section.

4.1.Interpretation of results.

The results of this research indicate the inhibitory effect of heavy metals on the plant growth and development of Trigonela foenum-graecum. Increase in concentration of lead, cadmium, and chromium confirmed the hypothesis that heavy metals as such suppress plant physiological processes and lead to decrease in germination percentage, root length, shoot length, and seedling vigor index.

Lead (Pb) proved to be the most toxic among the three metals, causing the greatest decrease in all the parameters measured. This may be as a result of lead's disruption of critical enzymatic processes, cellular metabolism, and nutrient assimilation, in line with other research findings citing its phytotoxicity. Cadmium (Cd) and chromium (Cr) also produced decreases in growth, but not as much as lead. Cadmium has been reported to interfere with root morphology and arrest the uptake of basic nutrients, while chromium has the ability to influence cell division and growth, particularly in roots and shoots.

The reported decrease in seedling vigor index also supports the additive effect of these heavy metals on plant well-being. This supports earlier reports on the toxic impact of heavy metals on germination and initial stages of growth in plants, which are key for plant establishment.

4.2.Comparison with existing studies.

The results of the current study on the toxicity of heavy metals—(Pb), (Cd), and (Cr)—on germination and early growth of Trigonella foenum-graecum (fenugreek) indicate clear patterns of toxicity. These results align with and also deviate in some ways from earlier studies. This section explains how the observed results compare with or contrast from the literature. The contrast serves to corroborate the importance of this research and to pinpoint particular knowledge deficits in earlier research.

Table 9: Comparison of Present Study with Existing Literature

Study	Objective	Key Findings	Relevance to Current Study
Sushmita (2023)[11]	Examine morpho-physiological changes under Pb, Cd, Cr stress	Growth inhibition and enzyme alteration	Supports germination and growth inhibition findings
Kulsoom et al. (2024)[12]	Assess combined metal stress on fenugreek	Reduced plant height, biomass, yield	Confirms Cd and Pb toxicity, extends to yield stage
Azzouzi et al. (2024)[13]	Test ascorbic acid's effect on Cr toxicity	Cr reduced germination; AA improved it	Validates Cr impact on germination, adds mitigation angle
Abdelhameed & Metwally (2025)[14]	Use fungi and betaine to reduce Cr effects	Cr toxicity mitigated by amendments	Reinforces Cr stress findings; future mitigation scope
Azzouzi et al. (2023)[15]	Analyze Cr effect on germination	Cr lowered germination, radicle length	Matches Cr's germination toxicity from current results

4.3.Implications of findings

The findings of this research have a major implication for agricultural and environmental management practices. Soils that have been found to be heavily contaminated with heavy metals can greatly inhibit the productivity and growth of produce, especially locations where industrial activities or unapproved waste disposal are the culprit of increased metal content in the soil. The findings from this research show that, just like the elevated lead, cadmium, and chromium, they are also capable of considerably inhibiting plant growth to the point of affecting crop yields and biodiversity in contaminated sites, even with lower levels of contamination.

The research also recommends the formulation of measures for the control of heavy metal soil toxicity in agricultural production. This may be one possible solution of application of soil amendments or bioremediation to reduce metal level and enhance soil health. In addition, the study recommends monitoring and controlling the soil of the agricultural production to maintain plant health and food security, as well as controlling the heavy metal content.

4.4.Limitations of the study.

Although the research is important with regard to the impact of heavy metals on the growth of Trigonella foenum-graecum, there are limitations with it. The natural environmental conditions which the experiment was carried out may be less than ideal due to the laboratory conditions under which the experiment was run. In this research, the soil composition, microbial activity, and the availability of other environmental stressors were not account for in the reaction of the plant towards heavy metals stress.

A second limitation is that a single plant species was used. Although Trigonella foenum-graecum was used because of its economic importance, the results may not be universally applicable to all plant species. Other plants could be more tolerant or more susceptible to heavy metals, and further research should incorporate a greater diversity of species in order to understand the wider ecological implications of heavy metal pollution.

4.5.Suggestions for future research

- Explore the interactions of several heavy metals on plant growth, since environmental pollution frequently occurs as metal mixtures that, potentially, could interact antagonistically or synergistically and impact plant health differently than single metals.
- Perform long-term experiments on the chronic heavy metal exposure of plants since long-term contamination can have cumulative effects on plant reproduction, yield, and overall ecosystem health.
- Conduct studies on possible bioremediation techniques, including the use of plant or microbial life to eliminate or neutralize heavy metals in polluted soils, in order to reduce their toxic impacts on agricultural crops and soil quality.
- Uncover the genetic underpinnings of plant tolerance to heavy metals and explore the possibility of breeding or genetically modifying metal-resistant crop varieties, which may contribute to enhancing agricultural productivity in contaminated areas.
- Perform field research to measure the actual impact of heavy metal pollution on plant growth, yield, and soil health, keeping in mind the natural complexity of ecosystems and other environmental factors potentially affecting plant reaction to pollution.

5. CONCLUSION

The impacts of heavy metals, namely lead (Pb), cadmium (Cd), and chromium (Cr), on Trigonella foenum-graecum (fenugreek) germination and early seedling growth were explored in this research. The experiment results under laboratory conditions indicate the adverse effect of these contaminants on plant growth with lead inducing maximum reduction. The research offers good insight into the manner in which heavy metal pollution of the environment may affect the productivity of agricultural products, especially crops of economic and medicinal significance.

5.1.Summary of Key Findings

Results of the experiment indicated that heavy metal contamination resulted in a severe impairment of Trigonella foenum-graecum germination, root growth, shoot growth and seedling vigor. All measured parameters of growth in leads, cadmium, and chromium treatment groups showed increasingly lower values, as compared to control group, which had the highest values of all measured growth parameters. The metals exerts most impact was of lead (Pb) then followed by cadmium (Cd) and chromium (Cr), which showed the gravitas of the metal contamination in relation to plants growth.

5.2.Significance of the Study

This study results show the environmental and agricultural influence of heavy metal contamination. The research traces the toxicity of lead, cadmium and chromium in inhibiting the germination and growth of fenugreek thereby sensitizing the readers on the issue of contamination of soil and its long term repercussions on the production of food. The findings of this research are especially relevant to agricultural sustainability and food security because of the potential of poor crop yields due to soil metal toxicity in contaminated soils.

5.3.Recommendations

- **Environmental Remediation:** Strategies for minimizing soil pollution by heavy metals need to be developed and enforced, such as phytoremediation or the application of soil amendments for fixing metals and reducing their bioavailability.
- **Heavy Metal Monitoring:** Routine monitoring of heavy metal content in farm soils should be emphasized to evaluate contamination levels and initiate mitigation measures early enough.
- **Metal-Resistant Crop Research:** Additional research should aim at the development of heavy metal toxicity-resistant crops, which would allow for improved yields in polluted environments.
- **Policy Advocacy:** Governments must enhance policies to control industrial waste disposal and ensure sustainable agricultural methods to reduce environmental pollution.
- **Public Awareness:** Informing farmers and farm workers of the dangers of heavy metal contamination and encouraging practices that can minimize exposure to toxic substances is important to ensure healthier crops and safer food.

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