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Comparative effects of Cadmium and Lead on the growth and metabolism of Cow-pea or Lobia (*Vigna unguiculata* L.)

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ABSTRACT

Because of their persistence and toxic nature, heavy metal pollution is aptly referred to as "devils in disguise" and currently poses a serious threat to global ecosystems. Cadmium (Cd) and lead (Pb) are two of the heavy metals that are most concerning because of their high atomic weight, extended environmental persistence, and capacity to bioaccumulate in living things. The present study investigates and compares the individual effects of Cd and Pb on growth and metabolism of Vigna unguiculata, commonly known as cowpea or lobia, a widely cultivated leguminous crop in India. Field experiments were conducted to assess the impact of varying concentrations of these metals from seed germination to maturity. The results indicate significant differences in the plant's response to Cd and Pb exposure, with Cd exerting more pronounced inhibitory effects on metabolic and physiological functions. The study highlights the need for strategic mitigation and soil management practices to safeguard agricultural productivity in metal-contaminated regions.

Keywords : Cadmium (Cd), Lead (Pb), Vigna Unguiculata, Heavy Metal Toxicity, Cowpea, Plant Metabolism, Growth Parameters, Morphological Changes.

Introduction- The wellness of ecosystems and human societies is seriously threatened by environmental pollution, which is defined as undesired changes in physical, chemical, or biological properties of air, land, and water. In recent decades, the pace and scale of environmental contamination have accelerated, driven by industrialization, urbanization, and unsustainable agricultural practices. Because of their non-biodegradable origin, long-term ecological persistence, and capacity for bioaccumulation and biomagnification, heavy metals constitute a particularly dangerous and persistent class of pollutants affecting our ecosystem.

High levels of heavy metals including lead (Pb) & cadmium (Cd) have been found in water and soil systems as a result of anthropogenic activities including mining, smelting, and the careless use of pesticides and fertilizers. These elements, although naturally occurring, have become significant environmental toxins due to their widespread release and the inability of natural systems to effectively sequester or degrade them.Of particular concern are cadmium and lead, which rank among the top environmental hazards as identified by the U.S. Agency for Toxic Substances and Disease Registry (ATSDR). Even at low concentrations, these metals are highly toxic and pose severe risks to plant health, human safety, and food security. Cadmium, in particular, is noted for its high solubility, mobility in soil, and capacity to enter food chains, making it a critical target for environmental monitoring and remediation efforts.Heavy metals have been shown to have detrimental impacts on plant systems, including alterations in morphological, physiological, and biochemical processes. These metals hinder growth, obstruct the uptake of nutrients, and frequently result in decreased output along with

plant death. Furthermore, because of the possibility of exposure to humans and animals through the food chain, the buildup of toxic metals in food plant components poses major public health problems.
Given these challenges, it is imperative to develop effective strategies to monitor, manage, and mitigate heavy metal contamination in terrestrial ecosystemsThe effect of cadmium-induced phytotoxicity is the main topic of this research, which also looks at possible mitigation techniques including supplementing plants with zinc to increase plant tolerance and support sustainable farming methods. This study intends to further knowledge of metal interaction in plants and provide guidance for upcoming environmental protection & crop management initiatives through a thorough physiological and biochemical examination.
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Vigna unguiculata (L.) Walp., widely known as cowpea, is an annual leguminous plant that falls under the Fabaceae family. It is sometimes identified by its alternate name, *Vigna sinensis* (L.). This herbaceous species typically grows between 2 to 3 feet in height and is covered with fine hairs. The foliage consists of trifoliate compound leaves, and its purple blossoms usually appear in clusters of two or three on extended stalks. The plant bears slender, cylindrical pods measuring about 3 to 5 inches long, which hang sideways or down from the peduncle. The seeds are brown in color and range from 6 to 10 mm in size.

Cowpea plays a vital role as a food legume in the semi-arid tropical regions of Asia, Africa, southern Europe, and the Americas. It can be consumed at various developmental stages: the tender leaves can be cooked like spinach, the immature pods are eaten as fresh vegetables, and the dried mature seeds are staple dietary elements in many regions. It is cultivated and harvested throughout the year for both vegetable and pulse uses.A major agricultural advantage of cowpea is its capacity to fix nitrogen from the atmosphere through root nodules, which improves soil fertility. Its shade tolerance makes it suitable for intercropping with grains such as maize, sorghum, and millet, as well as cash crops like cotton and sugarcane. Cowpea is also valued for producing high-quality hay for livestock. The mature seeds are nutritionally rich, offering about 25% protein along with significant amounts of starch, fiber, vitamin C, and vital minerals. These attributes make it a key food and feed crop. Its adaptability to modern farming, high productivity, compact seed size, and reduced anti-nutritional content contribute to its popularity among growers and agribusinesses.

The nutritional composition of cowpea seeds is approximately as follows:

- ***Protein:*** *24.8%*
- ***Fat:*** *1.9%*
- ***Fiber:*** *6.3%*
- ***Carbohydrates:*** *63.6%*
- ***Thiamine:*** *0.00074%*
- ***Riboflavin:*** *0.00042%*
- ***Niacin:*** *0.00281%*
- ***Energy:*** *6.5193 MJ/kg*

Cowpea also provides several minerals, including Na, K, N, P, Mg, Ca, Fe, Pb, Cu, Mn, Cd, Zn, Co, and Cr. Its protein content is particularly rich in lysine and tryptophan, making it a valuable complement to cereal-based diets. However, like other legumes, cowpea also contains anti-nutritional factors such as trypsin inhibitors that can limit protein utilization. These can be reduced using traditional processing techniques such as soaking, fermentation, and cooking.

In addition to its recognized nutritional and ecological value, cowpea plays a pivotal role in promoting sustainable agriculture due to its capacity to thrive in nutrient-poor soils and its tolerance to drought-prone environments. Its contributions to improving soil health and its resilience under environmental stress make it an important crop in addressing global challenges related to food and nutritional security.

The present study is designed to examine the physiological and biochemical responses of cowpea (*Vigna unguiculata* (L.) Walp.) when exposed to environmental stress caused by two heavy metals—Cadmium (Cd) and Lead (Pb)—applied individually at varying concentrations.By employing a multidisciplinary approach, this study aims to generate valuable insights into how cowpea plants cope with heavy metal stress at physiological and biochemical levels. The outcomes are expected to enhance our understanding of the plant's viability in contaminated or marginal lands and its broader implications for soil health, food safety, and sustainable crop production.

Literature Review

One heavy metal that is not necessary but has a negative impact on the development and growth of plants is cadmium (Cd). Because of its excellent dissolution in water and environmental persistence, cadmium (Cd) is one of the most hazardous heavy metals (Das et al., 1997). Cadmium buildup in soils has become a major global issue (Zhou and Song, 2004). Despite being connected to the activity of the enzyme carbonic anhydrase in ocean diatoms (Lane and Morel, 2000), cadmium has not yet been found to have a clear biological function in terrestrial plants.

Research conducted by Heidari and Sarani (2011) on *Sinapis arvensis* treated with varying concentrations of cadmium nitrate (ranging from 0 to 1000 μM) demonstrated that Cd negatively impacts seed germination. While low levels of cadmium (up to 300 μM) did not significantly affect germination, higher concentrations led to noticeable inhibition, with germination declining by approximately 5.6%.Similar findings have been reported across various plant species. In *Vigna unguiculata*, germination rates decreased at 40 ppm of cadmium chloride, with significant reductions observed at 80 and 160 ppm (AI-Rumaih, 2001). In *Thespesia populnea*, seed germination and seedling development were suppressed at concentrations of 10, 30, 50, 70, and 90 μM (Kabir et al., 2008), and in *Phaseolus vulgaris*, toxicity effects appeared at 70 ppm.

Numerous morphological, physiological, including biochemical functions in plants have been demonstrated to be affected by cadmium. Plant height (Pandey and Tripathi, 2011), root elongation (Heidari and Sarani, 2011), fresh biomass of shoots, roots, and leaves (Sun et al., 2011), leaf area (Domínguez et al., 2011), dry biomass (Singh et al., 2011), stomatal function (Rehman et al., 2011), overall yield (Rahmanian et al., 2011), flowering (Rehman et al., 2011), relative growth rate (Domínguez et al., 2011), as well as tolerance index (Chen et al., 2011) have all been shown to be negatively impacted by it. For plants, exposure to elevated cadmium amounts can ultimately prove fatal.

Numerous morphological, physiological, including biochemical functions in plants have been demonstrated to be affected by cadmium. POne of the most common and dangerous heavy metals found in the environment is lead (Pb). It has no known advantageous function in biological systems, yet human activity has caused its levels in agricultural soils to rise continuously (Hamid et al., 2010). There is little chance that contamination with lead in soils will decrease anytime soon due to the extensive use of lead-containing products in daily life (Yang et al., 2000). Pb is renowned for its subtle and protracted negative effects and serves as an accumulating toxicant that disrupts cellular processes.

Research by Heidari and Sarani (2011) demonstrated that seed germination in mustard (Sinapis arvensis) was not significantly affected at lower Pb concentrations (150 µM), though higher levels led to irregular germination. Similarly, Jiang et al. (2010) found that elevated Pb concentrations significantly suppressed growth in *Luffa cylindrica*, with reductions in fresh weight recorded in cotyledons (44.8%), hypocotyls (26.5%), and radicles (31.7%) at concentrations of 200, 400, and 800 µM, respectively. However, no marked changes in seedling biomass or visible symptoms were noted at 100 µM Pb.Azad (2011) reported that increasing doses of lead nitrate ($Pb(NO_3)_2$), specifically at 200, 400, 600, and 800 µM, led to significant reductions in root and shoot dry mass, chlorophyll content, catalase enzyme activity, and essential nutrients such as potassium (K^+) and calcium (Ca^{2+}) in *Helianthus annuus*.

Methodology of Field Studies

Pot culture techniques were used in field experiments for this investigation. The MJPRU Bareilly's suggestions were followed in the preparation of the potting mixture. The combination was made out of a 4:1:1.5 ratio of sand, soil, and farmyard manure. This potting mixture weighed 20 kilograms per gunny bag.

Heavy Metal Treatments

Two series of experiments were conducted using different concentrations of Cadmium and Lead salts.

Cadmium Treatment

Cadmium was applied in the form of cadmium chloride ($CdCl_2 \cdot 2.5H_2O$) at concentrations of 100 µM, 250 µM, 500 µM, 750 µM, 1 mM, 5 mM, and 10 mM as basal doses. The quantities applied per kg of soil were:

- 22.83 mg for 100 µM
- 57.08 mg for 250 µM
- 114.17 mg for 500 µM
- 171.26 mg for 750 µM
- 228.35 mg for 1 mM
- 1.142 g for 5 mM
- 2.284 g for 10 mM

However, due to non-survival of plants in the 5 mM and 10 mM cadmium treatments, these concentrations were excluded from the final study (Plate 2, P1 and P2).

Lead Treatment

Lead was supplied as lead nitrate [$Pb(NO_3)_2$] in concentrations of 100 µM, 500 µM, 1 mM, 5 mM, and 10 mM. The following amounts of lead nitrate were mixed per kg of soil:

- 33 mg for 100 µM
- 165 mg for 500 µM
- 331 mg for 1 mM
- 1.655 g for 5 mM
- 3.310 g for 10 mM

These treatments were applied in a second series of experiments (Plate 2, P3 and P4).A control group with no metal treatment was maintained for comparison. No additional fertilizers were used in any of the treatments.

Seed Preparation and Experimental Setup

0.01% mercuric chloride was used to surface sterilize healthy cow-pea seeds, which were then thoroughly cleaned with tap water and rinsed in distilled water. For each concentration, six replicates (gunny bags) were maintained to ensure statistical significance. After seedling emergence, thinning was performed to maintain five uniform plants per bag.All bags were irrigated daily with equal quantities of distilled water to maintain optimal field capacity.

Sampling Intervals

Plant samples were collected at the following stages of growth:

- **Pre-flowering stage** (20th day)
- **Flowering stage** (40th day)
- **Fruit ripening stage** (60th day)

Observations and harvesting were continued until complete senescence. At each sampling stage, plants were subjected to detailed morphological, anatomical, physiological, and biochemical analyses.

Impact of Cadmium on Cowpea

Germination Studies

In the present investigation, the effect of cadmium (Cd) on the germination behavior of Cowpea (*Vigna unguiculata L.*) was assessed by evaluating several early growth parameters, including percentage of germination, emergence of primary and trifoliate leaves, and seedling height. Seeds were subjected to varying concentrations of Cd (100 µM to 10 mM), and their performance was compared with control plants (0 µM Cd).

1. Percentage of Germination

Cadmium exhibited a dose-dependent inhibitory effect on germination. While seeds in control, 100 µM, and 250 µM Cd solutions demonstrated 100% germination, a gradual decline was observed with increasing Cd concentrations. At 500 µM, a 20% reduction was recorded, which further decreased to 50% at 750 µM and 53.33% at 1 mM. Severe inhibition was noted at 5 mM with only 20% germination, and complete inhibition (0%) was observed at 10 mM (Table:1). These findings clearly highlight Cd's toxic influence on seed viability at higher concentrations.

2. Leaf Emergence

The emergence of the first leaves was also notably influenced by Cd toxicity. On the 10th day, 100% emergence of primary leaves was recorded in control, 100 µM, 250 µM, 500 µM, and 750 µM. However, a reduction to 40% was observed at 1 mM. Similarly, the emergence of the first trifoliate leaf was 100% in control and 250 µM, 40% in 500 µM, and completely absent at 750 µM and 1 mM. Only the plumule emerged in 1 mM, showing significant developmental delay. In 5 mM, weak and chlorotic seedlings with only cotyledonary leaves were seen, which failed to survive until the first sampling.

3. Plant Height

Across treatments, there was a significant variation in seedling height ($F = 26.484$, $p < 0.01$). The control group reported the highest seedling height (10.567 ± 1.46 cm), which was considerably greater than all other treatments. No significant difference in height was found among 100 µM, 250 µM, and 500 µM treated plants. However, further increases in Cd concentration led to a marked reduction in height. Seedlings treated with 750 µM and 1 mM Cd showed a reduction of 52% and 62.16%, respectively, compared to the control.

Table 1: Impact of Cd on Germination and Early Seedling Growth of Cowpea on the 10th Day

Treatments	Germination (%)	% of Primary Leaf Emerged	% of 1st Trifoliate Leaf	Seedling Height (cm)
Control	100 ± 0	100 ± 0	100 ± 0	10.567^{a} ± 1.46
100 µM	100 ± 0	100 ± 0	100 ± 0	7.567^{b} ± 0.95

Treatments	Germination (%)	% of Primary Leaf Emerged	% of 1st Trifoliate Leaf	Seedling Height (cm)
250 μM	100 ± 0	100 ± 0	100 ± 0	8.517^{b} ± 0.45
500 μM	80 ± 17.89	100 ± 0	40 ± 0	7.63^{b} ± 0.01
750 μM	50 ± 16.73	100 ± 0	0 ± 0	5.067^{c} ± 0.06
1 mM	46.67 ± 24.22	40 ± 0	0 ± 0	4^{c} ± 0.1
F-value				**26.484****

**Significant at 0.01 level;

The above results confirm that increasing concentrations of cadmium substantially impair the germination and initial growth of cowpea seedlings, underlining its phytotoxic nature. These observations offer a clear indication of cadmium's role in reducing plant vigor and establishment, which may have broader implications for crop yield and productivity in contaminated soils.

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4. Root Length

The data recorded on the 20th day clearly demonstrated that cadmium (Cd) had a significant effect on root length of cowpea plants (*Vigna unguiculata* L.), with the F-value found to be significant at $p = 0.01$. Analysis using the Least Significant Difference (LSD) test revealed that the maximum root length was observed in the control group, which measured 12 cm. All Cd treatments led to a dose-dependent suppression in root elongation when compared to control.

As the Cd concentration increased, root length declined correspondingly. Application of 100, 250, 500, and 750 μM of Cd led to progressive reductions in root length. The highest inhibition was recorded at the 1 mM concentration, showing a 60% suppression compared to control.

Table - 2: Impact of Cd on Vegetative Growth Parameters of Root in Cowpea

Treatments	20th Day		40th Day		60th Day	
	Root Length (cm)	No. of Secondary Roots	Root Length (cm)	No. of Secondary Roots	Root Length (cm)	No. of Secondary Roots
Control	12a ± 2.1	24.25a ± 1.5	17.13 ± 2.36	31.5a ± 4.65	16.67 ± 4.18	32.17a ± 3.19
100 μM	11.5a ± 2.06	21.5ab ± 2.52	17.8 ± 3.93	15.3bc ± 4.93	17.4 ± 2.07	25.8b ± 4.6
250 μM	7.98b ± 1.04	16.2bc ± 5.93	17.65 ± 1.15	20b ± 2	20.5 ± 1.73	27.8ab ± 2.95
500 μM	7.95b ± 1.81	12.6cd ± 7.96	15.25 ± 0.25	16bc ± 0	17.5 ± 1.29	22.4b ± 4.39
750 μM	5.75bc ± 1.06	7.00de ± 1.41	14.35 ± 0.21	11c ± 1	18.5 ± 6.36	14.95c ± 0.07
1 mM	4.8c ± 0.14	1e ± 0.14	11.35 ± 0.07	13c ± 0.14	16 ± 4.24	8c ± 1.41
F-value	10.111**	8.039**	2.796ns	18.605**	0.872ns	17.701**

Description

Table 2 shows how different cadmium (Cd) concentrations affect cowpea (Vigna unguiculata) root growth parameters at three distinct phases of vegetative growth (20, 40, and 60 days after planting). Root length (cm) and the quantity of secondary root under six treatment conditions are among the parameters measured: 100 μM, 250 μM, 500 μM, 750 μM, and 1 mM cadmium treatments, and control (no Cd).

On the **20th day**, a significant decline in both root length and the number of secondary roots was observed with increasing Cd concentration. The control plants exhibited the maximum root length (12 cm) and secondary root number (24.25), while the 1 mM treatment showed the minimum values (4.8 cm and 1 root, respectively). The F-values (10.111 and 8.039) were statistically significant ($p < 0.01$), indicating a strong impact of Cd stress on early root development.

By the **40th day**, root length remained statistically non-significant (F = 2.796ns), suggesting a partial recovery or reduced sensitivity at this stage. However, the number of secondary roots showed a highly significant variation (F = 18.605), with the control still maintaining a superior count (31.5), while the 750 µM and 1 mM treatments had much fewer roots (11 and 13, respectively).

On the **60th day**, root length differences among treatments were statistically non-significant (F = 0.872ns), indicating that root elongation might stabilize or compensate over time. In contrast, the number of secondary roots continued to be significantly affected (F = 17.701), with the control showing the highest number (32.17), whereas plants treated with 1 mM Cd had the lowest (8).

The data reveal that Cd stress predominantly affects secondary root development more severely than primary root elongation, especially at higher concentrations and during later stages. The statistical homogeneity of means, as shown by the superscript letters, highlights significant differences between treatments at specific time intervals.

5. Effect of Cadmium on Stem Length in Cowpea

Twenty days after sowing, cadmium (Cd) exposure resulted in a significant inhibitory effect on the length of the stem in cowpea seedlings. Analysis of variance (F-value = 6.00, $P \leq 0.01$) indicated a statistically significant deviation in stem length among the different treatment groups when compared with the control (Table 3). A clear dose-dependent reduction in stem elongation was observed with increasing concentrations of cadmium.

Table- 3: Impact of Cd on vegetative growth parameters of stem in cowpea

Treatments	20th day Length of stem (cm)	Cf. of stem (cm)	40th day Length of stem (cm)	Cf. of stem (cm)	60th day Branch length (cm)	Cf. of stem (cm)
Control	$18.25^{a} \pm 1.44$	$2.75^{a} \pm 0.29$	61.98 ± 20.81	2.67 ± 0.1	9.05 ± 1.7	2.83 ± 0.41
100 µM	$16.00^{ab} \pm 1.14$	$2.5^{ab} \pm 0.01$	43.00 ± 10.44	2.4 ± 0.32	7.7 ± 4.59	3 ± 0
250 µM	$15.50^{b} \pm 3.4$	$2.23^{bc} \pm 0.25$	44.23 ± 12.53	2.88 ± 0.1	7.76 ± 1.08	3.2 ± 0.45
500 µM	$13.93^{b} \pm 2.17$	$1.85^{cd} \pm 0.49$	64.27 ± 12.36	2.77 ± 0	16.93 ± 8.51	3 ± 0
750 µM	$13.93^{b} \pm 2.8$	$1.55^{de} \pm 0.07$	41.50 ± 7.78	2.47 ± 0	10.94 ± 1.46	3 ± 0
1 mM	$9.05^{c} \pm 0.07$	$1^{e} \pm 0.14$	32.45 ± 0.07	2.43 ± 0	13.03 ± 0	2.5 ± 0.71
F-value	**6.00^{**}**	**14.53^{**}**	2.26^{ns}	2.53^{ns}	2.33^{ns}	1.55^{ns}

Cf. = Circumference; Values followed by different superscripts within a column differ significantly ($P \leq 0.01$); ** = significant at 1% level; ns = non-significant.

Table- 3 illustrates the effects of cadmium (Cd) on the vegetative growth parameters of cowpea (*Vigna unguiculata* L.), specifically focusing on stem length and circumference (Cf) over a period of 60 days. After 20 days of treatment, the experiment showed that cowpea plants subjected to different doses of Cd had significantly shorter stems. At 20 days post-sowing, the length of the stem in control plants was 18.25 cm, which progressively decreased with higher concentrations of Cd. At 1 mM Cd, the stem length was reduced to

9.05 cm, reflecting a 50.41% decrease compared to the control group. The reduction in stem length at 20 days showed a clear dose-dependent response, with reductions of 12.33%, 15.07%, 23.67%, and 23.67% observed in plants treated with 100 μM, 250 μM, 500 μM, and 750 μM, respectively. However, F-values for stem length at 40 and 60 days were not statistically significant ($P > 0.05$), indicating that the initial impact of Cd on stem growth was more pronounced at the 20-day stage, with subsequent effects being less significant over time. This suggests that Cd exposure initially impairs stem growth, but the effects become less evident as the plants mature.

Impact of Lead on Cowpea

Table 4 provides an analysis of the impact of lead (Pb) on the germination and early growth of cowpea (Vigna unguiculata L.) seedlings, comparing control plants with those exposed to different Pb concentrations (100 μM, 5 mM, and 10 mM). The data highlights significant inhibitory effects of Pb on germination and seedling development.

Percentage of Germination: Pb exposure caused a notable decline in seed germination. Control plants exhibited 100% germination, while this rate decreased progressively with increasing Pb concentrations. Specifically, germination rates were reduced by 10%, 20%, and 23.33% at 100 μM, 5 mM, and 10 mM Pb concentrations, respectively. This indicates that Pb toxicity inhibits germination, particularly at higher concentrations.

Percentage of Emergence of Leaves: Pb also significantly affected leaf emergence. While control plants showed 100% emergence of primary leaves, Pb exposure resulted in reduced emergence rates. At 100 μM, 5 mM, and 10 mM Pb concentrations, primary leaf emergence decreased to 90%, 80%, and 76.67%, respectively, by the 10th day. Furthermore, the emergence of the first trifoliate leaf was also delayed, with 100% emergence in control plants and only 40% emergence at 10 mM Pb by the 10th day.

Overall, Pb exposure significantly delayed seedling emergence and early growth stages, as evidenced by both the reduced percentage of germination and the impaired development of leaves and trifoliate leaves. These findings suggest that Pb toxicity has a detrimental effect on early plant development.

Table-4. Impact of Pb on the Germination of Cowpea Seeds

Treatment	Germination % (5th day)	Cotyledon only % (10th day)	Germination % (10th day)	% of 1st Leaf Emerged (10th day)	% of 1st Trifoliate Leaf (10th day)	% of 2nd Trifoliate Leaf (10th day)
Control	100.00 ± 0.00	40.00 ± 17.89	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00	40.00 ± 17.89
100 μM Pb	90.00 ± 10.95	36.67 ± 15.06	90.00 ± 10.95	90.00 ± 10.95	50.00 ± 16.73	13.33 ± 10.33
5 mM Pb	80.00 ± 17.89	33.33 ± 16.33	80.00 ± 17.89	80.00 ± 17.89	46.67 ± 20.66	6.67 ± 10.33
10 mM Pb	76.67 ± 23.38	6.67 ± 10.33	76.67 ± 23.38	76.67 ± 23.38	43.33 ± 18.82	0.00 ± 0.00

Table 5. Summary of Morphological Effects of Lead (Pb) on Cowpea

Parameter	**Observation**	**Remarks**
Root Fresh Weight (FW)	Increased up to 100μM and 500μM Pb; decreased above these concentrations; sharp reduction at 10mM Pb	122% increase at 100μM; 61.6% increase at 500μM; 32% and 36% drop at 5mM and 10mM respectively
Root Dry	Similar trend as FW: Increase up to 500μM;	Control = 0.165g; 100μM = 0.34g; 500μM =

Parameter	Observation	Remarks
Weight (DW)	decrease at higher concentrations	0.29g; 27.27% and 36.36% reduction at 5mM and 10mM
Root Length	No significant change across treatments	F-values not significant on both 30th and 60th days
Number of Root Nodules	Increased up to 1–5mM; considerable reduction at 10mM	Suggests mild stimulation at moderate Pb levels
FW of Root Nodules	Increased up to 1–5mM; decreased at 10mM	Notable drop in 10mM
DW of Root Nodules	No significant difference across Pb concentrations	Insignificant F-values
Stem Length	Increased steadily up to 500μM Pb; decreased above this level; max inhibition at 10mM	Significant F-values only in stem length
Stem FW & DW	No significant difference	Insignificant F-values
Leaves	No influence of Pb on any leaf parameter studied	Parameters not significantly affected
Flowers & Pods	Drastic changes only at 10mM Pb	Inhibitory effects evident at higher concentration

Conclusion

According to the results of this study, cowpea growth was positively impacted by cadmium (Cd) at lower concentrations up to 100 μM or 250 μM, but its effects shifted negatively from 500 μM onward. Acute toxicity symptoms were evident at 1 mM Cd, and seedlings could not survive at 5 mM, with plants dying at the juvenile stage. No seeds germinated in the presence of 10 mM Cd. Compared to cadmium, lead (Pb) exhibited less toxicity. Seed germination in cowpea was only negatively affected from 5 mM Pb onwards. Lead enhanced growth up to 500 μM but had adverse effects from 1 mM onwards. Toxic symptoms at the macro-scale were observed at 5 mM Pb, with acute toxicity becoming evident at 10 mM Pb.

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