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Heavy Metal Stress and Seed Germination: A Study on *Zea mays* and *Phaseolus vulgaris* under Cadmium Exposure

Anshul Mahajan and Nisha Rani*
Department of Environmental Science,
Himachal Pradesh University, Summerhill, Shimla-171005. Himachal Pradesh, India.
*Email: raninisha1@rediffmail.com

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Heavy metal pollution;
Seed germination;
Plant growth;
Cadmium stress;
Chlorophyll content;
Germination indices

Abstract

The present study evaluates the impact of cadmium (Cd) toxicity on the germination and seedling growth of *Zea mays* and *Phaseolus vulgaris* under controlled laboratory conditions. Seeds were exposed to varying Cd concentrations (0, 10, 20, 50, and 100 ppm), and key growth parameters such as germination percentage, root and shoot length, biomass accumulation, and chlorophyll content were analyzed. A significant decline in germination was observed, with *P. vulgaris* exhibiting a 94.48% reduction compared to 22.65% in *Z. mays*. Increasing Cd stress led to a statistically significant reduction ($p < 0.01$, $p < 0.05$) in root and shoot length, with *P. vulgaris* experiencing a more pronounced inhibition (99% and 97%, respectively) than *Z. mays* (53% and 37%). Biomass accumulation and growth indices including germination index, vigor index, tolerance index, and relative germination rate declined progressively with rising Cd concentrations. While total chlorophyll content increased in *Z. mays* at 100 ppm (0.325 mg/g FW), *P. vulgaris* displayed a significant reduction in pigment levels under Cd stress. Over all, *Z. mays* demonstrated higher tolerance to cadmium toxicity compared to *P. vulgaris*, suggesting its potential for cultivation in Cd-contaminated soils.

1. Introduction

A naturally occurring group of metallic elements with high molecular weight and having densities more than water are classified as heavy metals. These are characterized by metallic luster, high thermal and electric conductivity, high reflectivity, strength and ductility (Tchounwou *et al*., 2012). These normally occurring elements are essential in differentiated quantities by almost all forms of life and some metals in traces are required for vital functioning of organisms and plant life. But, as concentration of these elements in soil and water increases beyond the threshold limit it bioaccumulates in the food chain and becomes toxic to life and in higher doses they can cause a range of adverse impacts on the body including nervous system and kidney damage. Environmental contamination by various metals is a worldwide issue. From the last few years, it has become a conspicuous problem as there is an increase in industrial and modern agriculture. Human activities are the main reason behind the increased pollution. Metal based industries, smelting, mining the metal reserves, foundries, and leaching of metals from different sources such as, waste dumps, excretion, landfills, livestock and chicken manure, runoffs, roadworks and automobiles are the main cause of pollution. The use of pesticides, insecticides and fertilizers in the agricultural fields are the secondary source of heavy metal in soil and water bodies. Volcanic eruptions, corrosion, geological weathering, soil erosion and sediment re-suspension are natural causes of pollution due to heavy metal. Crops grown on polluted soil or irrigated with contaminated water having high concentration of heavy metals can accumulate in the plant`s edible parts, which when ingested by humans causes health problems like bone thinning, neoplastic growth, improper endocrine gland function, skin problems, blood pressure, impairment of sexual characteristics, asthma and other respiratory issues, heart diseases, and brain impairments. Pollution due to heavy metals is a worldwide environmental crisis. Growth and yield of various crops severely affected due heavy metals. Inhibited plant growth and reduction in biomass are the basic phenomena that occur in response to toxicity and stress (Shekhawat *et al*., 2010; Shanmugaraj *et al.,*2013).

Elevated levels of cadmium (Cd) in agricultural soils of NCR Delhi, particularly in wastewater-irrigated sites was reported by Rani et al. (2021) where Cd concentrations reached up to 1.96 mg/kg—over four times the global average. The high Cd levels were primarily attributed to irrigation with sewage-contaminated drains receiving effluents from printing and chemical industries. Additional sources include Cd-containing fertilizers. These findings align with previous reports from peri-urban Delhi and regions of southwestern China, highlighting the growing concern of Cd contamination in intensively cultivated and industrially influenced areas. Cadmium (Cd) was chosen as the heavy metal of focus due to its high toxicity, environmental persistence, and classification as a priority pollutant by regulatory agencies such as the World Health Organization (WHO) and the United Nations Environment Programme (UNEP). Cd contamination primarily originates from industrial processes, mining, wastewater irrigation, and phosphate fertilizers. Cadmium is one such environmental toxicant and non-essential element, which persists and prevails as toxic heavy metal among animals and plants. Cd is the leading cause of lung, prostate and kidney cancer in human beings. (Sanita di, 1999; Raza and Shafiq, 2013). It ranked seventh among top 20 toxins and is one of the most harmful metals that adversely affect almost all biological processes of plants, humans and animal life. Acute toxic effects include malformation of the fetus and death among birds, fish and other animals (Prasad, 1995). According to UNEP (2008) about 90 % exposure of cadmium is through food intake, particularly irrigated rice. When Cd is present in high amounts in agricultural soil it does not allow the uptake of iron by plants, and they show iron deficiency symptoms (Kumar, 2016). According to WHO guidelines, cadmium levels in agricultural soils should not exceed 0.03 mg/kg, while concentrations in plant tissues must remain below 0.002 mg/kg to ensure crop safety and prevent health risks. These limits are set to safeguard food quality and support sustainable farming practices (Nungula *et al.*, 2024).

A recent study in Kanpur, India, revealed high levels of cadmium, chromium, and lead in agricultural soils, exceeding WHO limits. Using ICP-OES analysis and risk assessment models, the study found both carcinogenic and non-carcinogenic health risks, especially for children, highlighting the urgent need for remediation. (Upadhyay *et al.*, 2024). Zea mays (maize) and Phaseolus vulgaris (common bean) are two widely grown crops valued for their nutritional benefits and agricultural versatility. Maize, which originated in Central America, is now a leading cereal crop in countries like the United States, China, and Brazil, used for food, animal feed, and biofuel. Common beans, native to Latin America, are cultivated globally as a key source of plant protein and soil-enriching nutrients. In India, maize flourishes during the Kharif season in states such as

Andhra Pradesh, Karnataka, and Bihar. Beans are mostly grown in temperate regions like Himachal Pradesh and Uttarakhand, often paired with maize in intercropping systems that naturally boost soil nitrogen and improve overall yield. Their combination supports both food security and eco-friendly farming.

The present study focuses on *Zea mays* (maize) and *Phaseolus vulgaris* (common bean) due to their economic importance and differential sensitivity to heavy metal stress. *Z. mays* is one of the world's most widely cultivated cereal crops, valued for its high biomass production and potential resilience to environmental stress. In contrast, *P. vulgaris* is a crucial leguminous crop that not only serves as a rich protein source but also plays a significant role in soil nitrogen fixation. However, legumes are generally more sensitive to metal toxicity, making *P. vulgaris* a suitable model to assess cadmium-induced stress responses. A comparative study of these two crops can provide valuable insights into the mechanisms of metal tolerance and susceptibility, aiding in crop selection for contaminated agricultural lands. The objectives of this study are to examine the effects of cadmium on seed germination and early seedling growth of *Z. mays* and *P. vulgaris*, compare the tolerance levels of these two species under increasing concentrations of cadmium, evaluate the impact of Cd exposure on key physiological parameters such as chlorophyll content and biomass accumulation and assess growth indices such as germination index, vigor index, tolerance index and relative germination rate. Cadmium concentrations up to 100 ppm were selected for this study to simulate a range of possible contamination scenarios-from mild to extreme-commonly observed in polluted agricultural zones. This gradient helps to evaluate plant responses across a spectrum of stress conditions, aiding in identifying species-specific tolerance thresholds.

The present study was conducted under controlled laboratory conditions using petri dishes and filter paper setups, which do not fully replicate complex soil-plant interactions in natural field environments. Moreover, only early seedling responses were assessed, which may not represent long-term effects of cadmium stress on yield or reproductive growth. Additional studies involving soil-based systems, diverse cultivars, and longer growth periods are needed to validate and expand upon these findings.

2. Material and Methods

2.1. Plant material and treatment details

The certified seeds of maize (*Zea mays)* KANCHAN KH- 5922 and common bean (*Phaseolus vulgaris)* EC-845820 were collected from Directorate of Agriculture, Boileuganj, Shimla and ICAR- National Bureau of Plant Genetic Resources, Regional Station, Shimla, India respectively. The metal stress of Cd was created by using Cadmium sulphate. A stock solution of cadmium (1 000 ppm) was prepared and used to make different concentrations of Cadmium (10, 20, 50 and 100 ppm) using distilled water and a control (without Cadmium).

2.2. Seed germination experiment

To assess the phytotoxicity of heavy metal most common methodology of Petri plates lined by filter paper was used following (Bae *et al*., 2014). The germination experiment was conducted in sterilized Petri plates (9 cm diameter) lined with autoclaved Whatman No.1 filter papers. The papers were moistened with respective concentration of Cd. Seeds were surface sterilized with 0.01% solution of mercuric chloride ($HgCl_2$) for two minutes before experiment, then thoroughly washed several times with distilled water to remove all traces of disinfecting solution. Seeds were then soaked in respective concentrations (0, 10, 20, 50 and 100 ppm) for 4 hours. Seven seeds were placed in each Petri plate. The moisture level of filter papers was maintained by adding 5 ml of respective concentration of Cd periodically during experiment. The experiment was replicated thrice. The germination assay was kept in BOD at a temperature of 25 ± 2^0 C for 8 days.

The seeds were observed for germination after 24 hours of experiment setup and parameters of germination were observed every day. On the 8^{th} day of the experiment, mean germination percentage, length of plumule and radicle, fresh weight of root, shoot and cotyledon and total chlorophyll content were observed. Root, shoot and cotyledon were kept for drying at 50^oC in an oven overnight to observe the dry weight.

2.3. Morphological growth parameters

The impacts of different concentrations of cadmium were studied on following morphological growth parameters-

2.3.1. Germination percentage and percent inhibition: Germination percentage of seed was calculated using equation:

$$GP = (n / N) \times 100 \quad \text{--(1)}$$

where ‘n’ is the number of grown seeds and N is the complete number of tested seeds.
Percent inhibition of germination was calculated with the following formula given by Baruah. (Baruah *et al*., 2019)

Percent inhibition of germination =100-GI of treatment/ GI of control*100 -----------------------(2)

2.3.2. Length of root and shoot: Ruler was used to measure the length of root and shoot. The roots and shoots were separated by cutting them down with the help of a sharp blade. They were laid down on white sheet of paper and a ruler was placed parallel to them to measure the length.

2.3.3. Fresh and dry weight of root, shoot and cotyledon: Fresh weight of the whole plant was done by keeping it at weighing balance. The roots, shoots and cotyledons were separated by cutting them with the help of blades. Dry weight was measured by oven drying plant material at 50^oC overnight.

2.3.4. Chlorophyll content: The amount of chlorophyll a (Chl a) and chlorophyll b (Chl b) estimated by using following equation given by (Harborne, 1973) and total chlorophyll was calculated by the formula given by (Arnon, 1949):

$$Chla\left(\frac{mg}{g}Fw\right) = \frac{12.3A_{663} - 0.86A_{645}}{a \times 1000 \times W} \times V \text{------------------------------(3)}$$

$$Chlb\left(\frac{mg}{g}Fw\right) = \frac{19.3A_{645} - 3.6A_{663}}{a \times 1000 \times W} \times V \text{ ------------------------------(4)}$$

$$Total\ chlorophyll\ (\frac{mg}{g}) = \frac{20.2A_{645} + 8.02A_{663}}{a \times 1000 \times W} \times V \quad \text{--------------------(5)}$$

Where, A_{645} and A_{663} = Absorbance at 663 and 645 nm, respectively

a = path length of light (1 cm)
V= volume of extract (ml)
FW= Fresh weight of tissue (g)
The amount of chlorophyll was expressed in terms of mg/g fresh weight.

2.3.5. Germination index: Germination index (GI) was determined by the formula given by (AOSA, 1983):

$$GI = \frac{No.of\ germinated\ seeds}{Days\ of\ first\ count} + \cdots + \frac{No.of\ germinated\ seeds}{Days\ of\ final\ count} \qquad \text{------------(6)}$$

2.3.6. Vigor index: Seed vigor index was calculated as under following (Maisuria and Patel, 2009):

$$Vigor\ index = Root\ length + Shoot\ length \times Seed\ germination\ \% \qquad \text{----------------(7)}$$

2.3.7. Tolerance index: The tolerance index (T.I.) was calculated using the formula given by (Iqbal and Rahmati, 1992).

$$T.I. = \frac{Mean\ root\ length\ in\ the\ metal\ solution}{Mean\ root\ length\ in\ control} \times 100 \qquad \text{-------------------------(8)}$$

2.3.8. Relative germination rate: The relative germination rate (RGR) and the root and shoot length was measured, as well as the ratio between them.

$$RGR = \frac{Germination\ percentage\ in\ the\ metal\ concentration}{Germination\ Percentage\ in\ the\ control} \qquad \text{--------------------(9)}$$

2.3.9. Statistical analysis: One -Way Analysis of variance (ANOVA) using SPSS software followed by Tukey's HSD test was used to analyze the experimental data. The values are the mean of three replicates.

3. Results and Discussion:

3.1. Germination percentage (%) and percent inhibition

Seedling germination was adversely affected by different Cd concentrations (10, 20, 50, 100 ppm) in both *Zea mays* and *Phaseolus vulgaris* (Table 1). In *Z. mays*, reduction in germination from 1.64%-22.65% with increase in concentration and adverse effects of Cd was more pronounced in *P. vulgaris* as seeds were failed to germinate at 100ppm concentration and a reduction of 29.85% - 94.48% was recorded. Decreased rate of Seed germination may be due to accelerated breakdown of stored nutrients in seed and alternations of selection permeability properties of cell membrane, in the presence of high concentrations of heavy metal. Similar observations were recorded in seed germination percentage of *Leucaena leucocephala* and bean (*Phaseolus vulgaris L.*) due to Cd (Shafiq *et al.*, 2008, Bahmani *et al.*, 2012). Dubey (1997) also noticed that Cd toxicity adversely affected germination of seeds and seedling vigor in rice by limiting water transport to growing tissues. The negative effect of cadmium on germination rate has been reported in wheat, barley and rice (Titov *et al.*, 1996) (Rascio *et al.*, 2008). In peanuts similar results were obtained by (Shan *et al.*, 2012). Cadmium (Cd) decreased germination in pea seed by inhibiting respiration in cotyledons and altering mitochondrial enzyme activities (Smiri *et al.*, 2010; Gangwar *et al.*, 2012).

Table 1. Effect of different concentrations of Cd on Germination Percentage (%) of *Zea mays* and *Phaseolus vulgaris*

Treatments	Germination (%)			
	Zea mays	Decrease (%)	*Phaseolus vulgaris*	Decrease (%)
Control	$96.7^{a}\pm0.9$		$86.7^{a}\pm2.6$	
Cd_{10}	$95.5^{a}\pm1.2$	1.64%	$61.0^{b}\pm0.5$	29.85%
Cd_{20}	$95.1^{a}\pm1.4$	2.05%	$54.3^{c}\pm1.3$	37.56%
Cd_{50}	$75.5^{b}\pm1.5$	22.24%	$33.3^{d}\pm1.0$	61.70%
Cd_{100}	$75.1^{b}\pm1.6$	22.65%	$4.8^{e}\pm0.2$	94.48%
HSD	4.057		5.129	
p values of one - way ANOVA				
Concentration	0.000		0.000	

Data shown are mean ± S.E. (n = 3). Treatments Cd indicate cadmium and Subscript numbers 10, 20, 50 and 100 are levels of applied metal concentration in ppm. Different letters (a, b, c, d, e) indicate significant difference between means at $P \leq 0.05$ based on Tukey HSD.

3.2. Root and shoot length

Morphological parameters of both the plant viz., *Z. mays* and *P. vulgaris* were adversely affected with increase in concentration of Cd (Fig 1 and 2). The root length in *Z. mays* decreased 53% with increased Cd concentration (0-100 ppm) and shoot length decreased 37% as compared to control. The reduction in both shoot length and root length with increase in Cd concentration was statistically significant ($P\leq0.05$, $P\leq0.01$; F= 12.25**; F= 3.53*one way ANOVA). The impact of Cd was more pronounced and statistically significant at each concentration with *P. vulgaris*. After germination the root length were decreased to 99% and shoot length decreased to 97% as compared to control ($P\leq0.05$, $P\leq0.01$; F= 60.47**; F= 46.56**one way ANOVA). Browning of root tips was also noticed in case of *P. vulgaris*. The application of Cd reduced the shoot length in bean, wheat and alfalfa (Chaoui *et al*., 1997; Bhardwaj *et al*., 2009; Aydinalp, 2009). A similar opinion that the reduction in root length and height of the plant was due to Cd accumulation in *Z. mays* and *P. vulgaris* was also observed (Mihalescu *et al*., 2010). The decrease in root length in *Solanum melongena* and alfalfa was recorded by Cd treatment (Aydinalp, 2009; Siddhu *et al*., 2008).

3.3. Fresh and dry weight of root shoot and cotyledon

Table 2 describes the fresh and dry weight of root, shoot and cotyledon of *Zea mays* at different concentrations of Cd. Statistically significant reduction ($P \leq 0.05$, $P \leq 0.01$; F=6.11**; F=4.16*; F=14.68** One way ANOVA) was observed in the fresh weight of root (64%) shoot weight (57%) and cotyledon weight (39%) as compared to control. The dry weight of root was decreased to 69%, dry shoot weight decreased to 30% and cotyledon weight also decreased to 30% which was statistically significant ($P \leq 0.05$; $P \leq 0.01$; F= 1.68; F= .795; F= 3.94* one way ANOVA) as compared to control.

In *Phaseolus vulgaris* the fresh weight of the root was decreased to 97% and no roots emerged at 100 ppm. Fresh shoot and cotyledon weight decreased to 97% and 27% at 100 ppm as compared to control respectively (Table 3). The decrease in root weight and shoot weight was statistically significant at ($P \leq 0.05$; $P \leq 0.01$; F= 30.59**; F= 21.34**; F= .655 one-way ANOVA).

Statistically significant reduction in the dry root (70%) and shoot weight (61%) was recorded in *Phaseolus vulgaris* ($P \leq 0.05$; F=3.19*) and ($P \leq 0.01$; F= 87.24**). Cotyledon weight was also decreased to 13% (F= .289) at 100 ppm as compared to control. Bahmani reported that mean fresh weight under Cd treatment was reduced as compared with control in *Phaseolus vulgaris* (Bahmani *et al*.,2012). Similar results were obtained in *Cassia siamea* (Shafiq,2005). Reduction in fresh and dry weight of seedling in *Atriplex halimus* with increased cadmium concentration was also observed (Mesnoua and Lotmani,2015).

Table 2. Effect of different concentrations of Cd on fresh and dry biomass of *Zea mays*

Concentration (ppm)	Fresh Root Weight (g)	Fresh Shoot Weight (g)	Fresh Cotyledon Weight (g)	Dry Root Weight (g)	Dry Shoot Weight (g)	Dry Cotyledon Weight (g)
Control	0.22^{a} (100)	0.23^{a} (100)	0.49^{a} (100)	0.048^{a} (100)	0.020^{a} (100)	0.307^{a} (100)
Cd_{10}	0.17^{ab} (77)	0.15^{ab} (65)	0.40^{b} (81)	0.038^{a} (79)	0.018^{a} (90)	0.270^{ab} (88)
Cd_{20}	0.17^{ab} (77)	0.14^{ab} (60)	0.36^{bc} (73)	0.037^{a} (77)	0.017^{a} (85)	0.263^{ab} (85)
Cd_{50}	0.12^{ab} (54)	0.11^{ab} (47)	0.34^{bc} (69)	0.021^{a} (43)	0.016^{a} (80)	0.257^{ab} (83)
Cd_{100}	0.08^{b} (36)	0.10^{b} (43)	0.30^{c} (61)	0.015^{a} (31)	0.014^{a} (70)	0.217^{b} (70)

Different letters (a, b, c,) in columns indicate significant difference between means at $P \leq 0.05$ based on Tukey HSD. Values in parentheses represent relative values, control taken as 100.

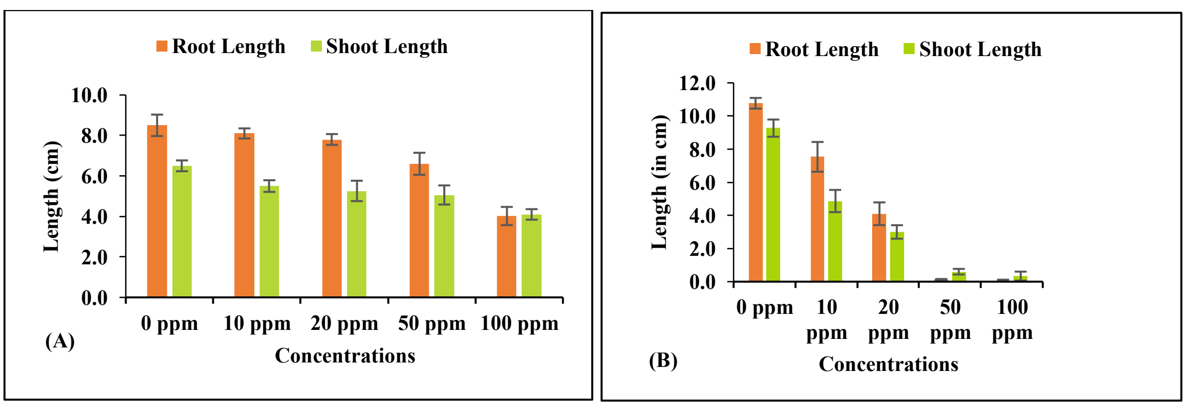

Fig 1. Effect of different concentrations of Cd on root and shoot length of *Zea mays* (A) and *Phaseolus vulgaris* (B). Values are mean (n=3) with SE (±).

Fig 2. Root and Shoot length of *Zea mays* (A) and *Phaseolus vulgaris* (B) at different concentrations of Cd.

3.4. Chlorophyll content

Figure 3 illustrates the chlorophyll content in *Zea mays* and *Phaseolus vulgaris*. Total chlorophyll content increased (0.279mg/g FW) up to 20 ppm of Cd in case of *Zea mays* seeds with slight reduction at 50 ppm (0.220mg/g FW) while highest chlorophyll content was recorded at 100 ppm Cd (0.325mg/g FW). In *Phaseolus vulgaris*, there is a significant reduction in chlorophyll content with increased Cd concentration. Since no shoot growth was observed beyond 20 ppm therefore chlorophyll content was observed only up to 20 ppm (0.122mg/g FW,0.098 mg/g FW and 0.059mg/g FW). ($P \leq 0.05$; $P \leq 0.01$; F= 2.479; F= 5.477*). Chlorophyll is the main pigment which helps plants in photosynthesis. When plants are exposed to stress, their photosynthesis is inhibited and the concentrations of chlorophyll directly indicate the extent of stress-induced damage in plants (Lin *et al*., 2012). A decreased amount of chlorophyll a, chlorophyll b and carotenoids in *Lemna minor* after the application of a Cd treatment was noticed (Hou *et al*.,2007) (Malinowska and Smolik,2011). A higher decrease in the content of chlorophyll was recorded in barley after the application of cadmium (Erdei *et al*.,2002).

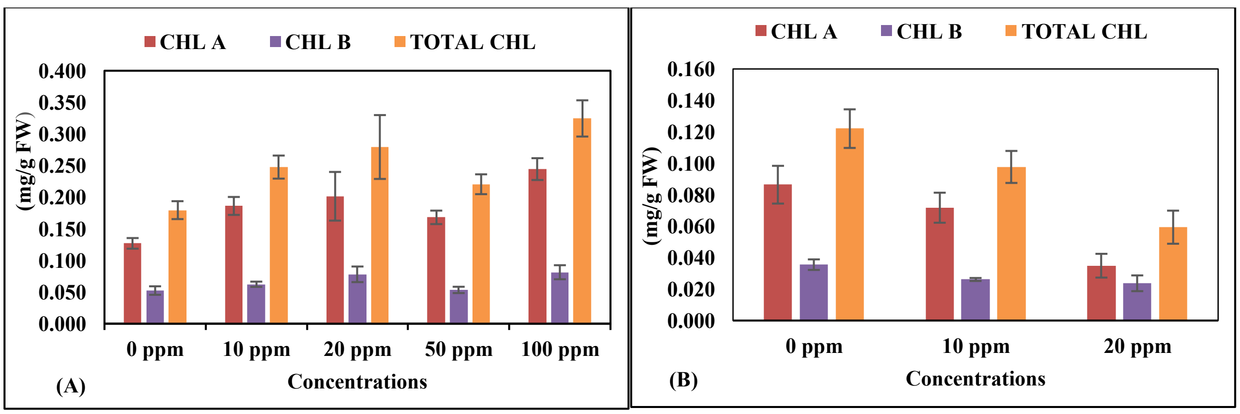

Fig 3. Effect of different concentrations of Cd on pigments Chlorophyll a, Chlorophyll b and Total Chlorophyll content of *Zea mays* (A) and *Phaseolus vulgaris* (B). Values are mean (n=3).

Table 3: Effect of different concentrations of Cd on fresh and dry biomass of *Phaseolus vulgaris*

Concentration (ppm)	Fresh Root Weight (g)	Fresh Shoot Weight (g)	Fresh Cotyledon Weight (g)	Dry Root Weight (g)	Dry Shoot Weight (g)	Dry Cotyledon Weight (g)
Control	0.28 ^{a} (100)	0.61 ^{a} (100)	0.94 ^{a} (100)	0.049 ^{a} (100)	0.053 ^{a} (100)	0.282 ^{a} (100)
Cd_{10}	0.18 ^{ab} (64)	0.34 ^{b} (56)	0.82 ^{a} (87)	0.019 ^{a} (39)	0.050 ^{a} (94)	0.266 ^{a} (94)
Cd_{20}	0.09 ^{bc} (32)	0.24 ^{bc} (39)	0.80 ^{a} (85)	0.015 ^{a} (30)	0.021 ^{b} (39)	0.247 ^{a} (87)
Cd_{50}	0.01 ^{c} (3)	0.06 ^{c} (10)	0.78 ^{a} (83)	0.000 ^{a}	0.000 ^{c}	0.271 ^{a}
Cd_{100}	0.01 ^{c} (3)	0.03 ^{c} (5)	0.76 ^{a} (81)	0.000 ^{a}	0.000 ^{c}	0.281 ^{a}

Different letters (a, b, c) in columns indicate significant difference between means at $P \leq 0.05$ based on Tukey HSD. Values in parentheses represent relative values, control taken as 100.

3.5. Growth indices

Figure 4 represents the growth indices that are Germination Index (GI), Vigor Index (VI), Tolerance Index (TI) and Relative Germination Rate (RGR) of *Zea mays* and *Phaseolus vulgaris*. All these growth indices showed a general trend of reduction with increased cadmium concentration. At 100 ppm Cd concentration germination index (Fig 4 (A)) was 58.86 in *Zea mays* and 1.09 in *Phaseolus vulgaris*. Cd stress reduced seed germination, germination index and vigor index of different crops (Raziuddin *et al*., 2011). Seed vigor, an important index of seed quality, determines the potential for rapid and uniform emergence of plants. The seedlings of *A. lebbeck* also showed a gradual decrease in seedling vigor and dry biomass as concentrations of lead and cadmium increased (Farooqi *et al*., 2009). Vigor index, tolerance index and relative germination rate was much higher in case of *Zea mays* as compared to *Phaseolus vulgaris*. In the present study, tolerance index was noticed to decrease with increased cadmium concentration. In *Albizia lebbeck* cadmium treatments at 90 µmol/L exhibited the lowest percentage of tolerance in seedlings (Farooqi *et al*., 2009). Similar results were observed in *L. leucocephala* where the lowest percentage of tolerance was found at 100 ppm cadmium treatment (Shafiq *et al*., 2008). Tolerance index in four wheat cultivars was observed, maximum tolerance was observed in Sehar-06 followed by Fareed-06, Chakwal-50 and Inqlab-91 to various concentrations of Cd (Ahmad *et al*., 2012). The germination rate decreased with increase in Cd concentration in case of *Rhus typhina* (Qu *et al*., 2021). A strong positive correlation between germination index and vigor index ($r = 0.87^*$, $f = 3$, $P \le 0.05$); between tolerance index and vigor index ($r = 0.93^*$, $df = 3$, $P \le 0.05$); between germination index and relative germination rate ($r = 0.99^{**}$, $df = 3$, $P \le 0.01$) and heavy metal concentrations (0, 10, 20, 50, 100 ppm) was found in *Zea mays* (Table 4)

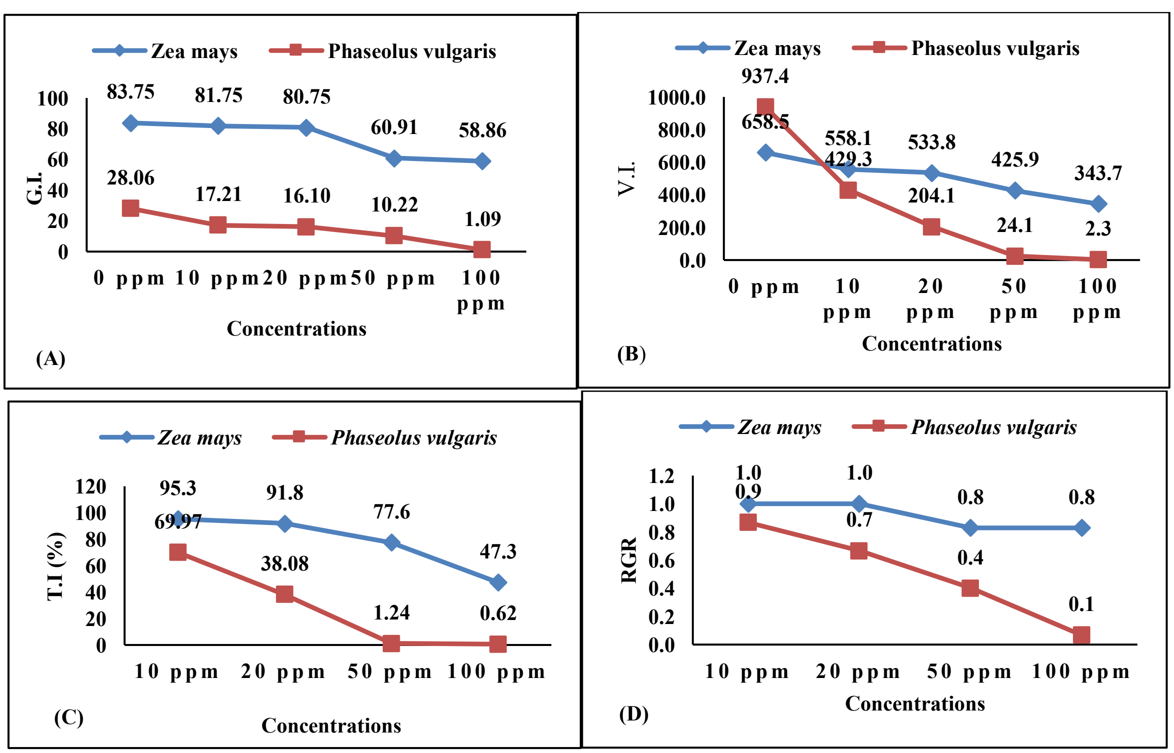

Fig 4. Effect of different concentrations of Cd on germination index(A), vigor index(B), tolerance index(C) and relative germination rate (D) of *Zea mays* and *Phaseolus vulgaris.*

A strong positive correlation between germination index and vigor index ($r = 0.84^{**}$, $f = 3$, $P \leq 0.01$); between tolerance index and vigor index ($r = 0.99^{***}$, $f = 3$, $P \leq 0.001$); between germination index and relative germination rate ($r = 0.96^{**}$, $f = 3$, $P \leq 0.01$)); between tolerance index and relative germination rate ($r = 0.85^{*}$, $f = 3$, $P \leq 0.05$); between vigor index and relative germination rate ($r = 0.85^{*}$, $f = 3$, $P \leq 0.05$) and heavy metal concentrations (0, 10, 20, 50, 100 ppm) were found in *Phaseolus vulgaris* (Table 5).

Table 4: Co-relation matrix between different Growth Indices of *Zea mays* with different concentrations of Cd (0, 10, 20, 50, 100 ppm).

Growth Indices	Germination Index	Tolerance Index	Vigor Index	Relative Germination Rate
Germination Index	1.0	-	-	-
Tolerance Index	0.73	1.0	-	-
Vigor Index	0.87*	0.93*	1.0	-
Relative Germination Rate	0.99**	0.67	0.87	1.0

P* ≤ 0.05 and P** ≤ 0.01

Table 5: Co- relation matrix between different Growth Indices of *Phaseolus vulgaris* with different concentrations of Cd (0, 10, 20, 50, 100 ppm).

Growth Indices	Germination Index	Tolerance Index	Vigor Index	Relative Germination Rate
Germination Index	1.0	-	-	-
Tolerance Index	0.71	1.0	-	-
Vigor Index	0.84**	0.99***	1.0	-
Relative Germination Rate	0.96**	0.85*	0.85*	1.0

P* ≤ 0.05, P** ≤ 0.01 and P*** ≤ 0.001

4. Conclusion

The concentration of cadmium in the environment is producing toxic effects in crops which will further lead to impairment in human health. In this study tolerance of two major food crops *Zea mays* and *Phaseolus vulgaris* was observed at different cadmium concentration and a significant reduction with increased concentration of Cd was recorded in germination indices. The seedling growth of *Z. mays* showed more tolerance as compared to *P. vulgaris*. Therefore, *Z. mays* can grow on such contaminated soil and further be used as crop for phytoremediation of degraded land affected by Cd heavy metal pollution.

5. Author's Contributions- Dr. Nisha Rani (NR) was the project leader and was responsible for experimental and project design. Ms. Anshul Mahajan (AM) performed the experiments, prepared the samples, performed the calculations and wrote the manuscript. Dr. Nisha Rani (NR) is corresponding author.

Conflict of interest: The authors declare that they have no conflict of interest.

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