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Effect of Cadmium on Growth and Cadmium Accumulation, in Cadmium Tolerant and Sensitive Varieties of Chickpea (*Cicer arietinum*)

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ABSTRACT

Cadmium (Cd) is ranked seventh topmost environmental pollutants because of its high toxicity. It can be quickly absorbed by plants, where it adversely affects growth and metabolic functions. Trace metal (TM) contamination has become a major environmental issue, significantly reducing crop productivity and quality. In the current research, the effects of different cadmium concentrations (0, 25, 50, 75 and 100 μM) on the growth, accumulation, as well as tolerance capacity of four *Cicer arietinum* L cultivars namely IPC-K-13-163, GNG-1581, IPC-11-112, and IPC-K-09-145 were evaluated under hydroponic conditions. Cadmium levels were measured using AAS (Atomic Absorption Spectrophotometry). Results revealed that Cd accumulation was highest in IPC-11-112 and IPC-K-09-145, while GNG-1581 and IPC-K-13-163 exhibited comparatively lower accumulation, indicating better tolerance to Cd stress. Cadmium toxicity caused a considerable decline in every growth parameter including plant hight, root, shoot leaf length, with fresh and dry weight. The greatest reduction was seen in 100 μM Cd concentration. Among the tested cultivars, IPC-K-13-163 and GNG-1581 demonstrated superior tolerance and sustained growth under Cd stress, suggesting their potential utility in breeding programs aimed at developing Cd-tolerant chickpea varieties.

Keywords Abiotic stress, Heavy metal stress, Cadmium tolerance, Cadmium stress, Chickpea.

INTRODUCTION

Trace metal (TM) contamination of soil, primarily caused by industrial effluents and intensive agricultural activities, has emerged as a serious global environmental issue (Anjum *et al.* 2012 a). Plants naturally absorb and accumulate trace metals such as copper (Cu), cadmium (Cd), manganese (Mn), iron (Fe), and zinc (Zn) from the soil, that are required for their growth as well as development because

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trace metal act as essential catalytic and structural elements in various proteins (Fraga 2005, Andresen *et al.* 2018). Chickpea provides essential nutrients such as protein, fats, and carbohydrates in developing regions, and is commonly employed worldwide as green manure and feed for animal (Ahmad *et al.* 2016, Ullah *et al.* 2020). However, excessive intake of these metals, particularly cadmium, disrupts normal physiological as well as biochemical processes, leading to reduced crop productivity and quality (Bajguz and Hayat 2009). Chickpea (*Cicer arietinum* L.) is an essential pulse crop that contain a high amount of protein, folate, and mineral content. Despite its nutritional and economic significance, chickpea cultivation is increasingly affected by cadmium contamination in agricultural soils. Cadmium (Cd) is ranked seventh amongst the topmost solubility in water. When absorbed by plants, Cd interferes with growth and metabolic activities, adversely impacting plant development and yield (Hasan *et al.* 2009). Cadmium accumulation in agricultural soils is mainly due to the long-term use of phosphate fertilizers, application of sewage sludge, atmospheric deposition, smelting emissions, and industrial waste disposal (Thawornchaisit and Polprasert 2009). According to Wagner (1993), Cd concentrations in soil pore water of uncontaminated soils range from 0.04 to 0.32 μM, while in highly polluted soils, levels can reach 0.32–1.00 μM. Only Cd-tolerant species can survive in soils with concentrations exceeding 35 μM in the soil solution, (Farouk *et al.* 2011). Cd is amongst most mobile and non-recyclable trace metals and is readily taken up by crops and transported to aerial tissues, where it accumulates at potentially toxic levels (Sairam *et al.* 2005). Excess Cd interferes with various chemical and different biological process, including nitrogen fixation, enzymatic activity, and microbial interactions, ultimately reducing plant productivity (Weggler-Beaton *et al.* 2000). High Cd exposure give rise to ROS (reactive oxygen species) and free radicals, and causes oxidative stress and damage to cellular macromolecules such as proteins, lipids, DNA, and carbohydrates, thereby impairing growth and metabolism (Hodges *et al*. 1999). Excessive Cd levels can induce a range of physiological and morphological symptoms, including stunted growth, chlorosis, reduced biomass accumulation, and even plant mortality (Sullivan and Ross 1979, Sairam 1994). Anthropogenic activities such as industrialization, mining, the extensive fertilizers and pesticides usage, as well as the discharge of untreated effluents have significantly contributed to increasing Cd concentrations in agricultural and aquatic systems (Chai *et al.* 2013). Once Cd enters the food chain, it poses severe health risks to both humans and animals. Similar to other heavy metals, Cd disrupts key plant processes, including respiration, photosynthesis and nutrient homeostasis, while inducing oxidative stress through the overproduction of ROS (Sandalio *et al.* 2001, Zhang *et al.* 2010, Wani and Tahir 2019). Several findings have documented the impact of cadmium toxicity over crop productivity, including production of ROS, lipid peroxidation, and possible remediation approaches. (Bashir *et al.* 2018, Baruah *et al.* 2019, Zhang *et al.* 2019, Hussain *et al.* 2021 a, b). Plant responses to increasing Cd level differ depending on species, cultivar type, soil physio-chemical characteristics, and variation in Cd uptake (Benavides *et al.* 2005). With the growing demand for food and need to ensure sustainable agricultural practices, efficient stress management is crucial, particularly for economically important crops. Chickpea is a low–cost and protein rich pulse crop that ranks among the top legumes globally, with major production concentrated in South-East Asia. (Muehlbauer and Sarker 2017, Liza *et al.* 2024). Cadmium concentrations above 5–10 μg Cd g^{-1} dry weight are toxic to most crop species, whereas Cd-hyperaccumulator plants can tolerate concentrations up to 100 μg Cd g^{-1} leaf dry weight (Reeves and Baker 2000, Verbruggen *et al.* 2009, Gill *et al*. 2011). It has harmful effect on human, animals, and plant (Kabata-Pendias 2000). Globally, several anthropogenic activities contribute to Cd pollution, including mining, industrial discharges, phosphate fertilizer use, sewage sludge application, and fossil fuel combustion. In Thailand, for instance, permissible limit of Cd and its compounds in agricultural soils is 37 mg/kg. However, the Mae Sot District in Tak Province contains the largest known Cd deposit in Thailand, with soil Cd concentrations ranging from 3.4 to 284 mg/kg, as reported by the International Water Management Institute (IWMI) in 2000 (Unhalekhaka and Kositanont 2008). Mining operations in these regions have long-term ecological consequences, including increased soil salinity and heavy metal accumulation, which further intensify metal toxicity and degrade soil and plant health (DalCorso *et al.* 2010, Chen *et al.* 2015, Jampasri *et al*. 2017).

MATERIALS AND METHODS

Chickpea seeds and growth conditions

The uniform and healthy grains of seven different varieties IPC-05-62, IPC-11-112, IPC-K-09-145, IPC-K-13-163, GNG-1581 and, JG -14, ICCV-1205, were taken from Indian Institute of Pulse Research (IIPR), Kanpur. A laboratory-based pot experiment was performed. The experiment was performed in hydroponics condition containing Hoagland Media, in five different pots, and repeated three times for each treatment. Pots were seeded with ten seeds each. These pots were kept in incubator with an average day/night temperature of 24°C/11°C. Hogland media were changed at every 48 hours. 0 µm, 25 µm, 50 µm, 75 µm, 100 µm cadmium treatment was given to seedling in different pots.

Growth measurement

Seedlings were taken on the tenth day, and then rinsed three to four times with DW to wash away the Cd from the root surface and separated into roots, shoots and leaves. The measuring tape was used to measure length of the root, shoot and leaf. An electronic balance was used to measure the Fresh weight (FW) and dry weight (DW). Samples were oven dried for 60–70°C for 72 hours in hot air oven and their dry weight was measured.

Estimation of Cd

Approximately 0.5 gm of the dried sample was transferred into a digestion vessel. To this, 6 ml of 65% HNO_3, 3 ml of 70% $HClO_4$, and 1 ml of 30% H_2O_2 was added. Mixture was then heated on a hot plate at 80°C for about 3 hours until complete digestion was achieved. After digestion, the resulting clear solution was filtered through Whatman filter paper No 4. The filtrate was made up to a final volume of 50 ml and stored for further analysis using AAS Abrham and Gholap (2021).

Statistical analysis

All experiments were done in triplicate under identical conditions. The data were analyzed by One-way ANOVA to measure the impact of different factor and their interactions. Statistical significance was determined at $p < .05$. The results are mean ± standard error (SE) (n=3).

RESULTS AND DISCUSSION

Effect of cadmium on plant growth

It can be seen from Table 1 that with increasing Cd

Table 1. Effect of cd stress on the length of shoot in 10 days old chickpea seedlings.

Conc.	GNG-1581 (cm)	IPC-K-13-163 (cm)	IPC-K-11-112 (cm)	IPC-K-09-145 (cm)	IPC-05-62 (cm)	JG-14 (cm)	ICCV-1205 (cm)
0 µM	13.53 ± 0.1 (100%)	17.71 ± 0.7 (100%)	16.19 ± 0.8 (100%)	170.8 ± 0.01 (100%)	12.96 ± 0.7 (100%)	12.66 ± 0.63 (100%)	3.32± 0.79 (100%)
25 µM	12.95 ± 0.80 (95%)	16.64 ± 0.58 (90%)	16.08 ± 0.36 (99%)	14.96 ± 0.36 (87.58%)	12.33 ± 0.8 (95%)	8.83 ± 0.5 (69%)	2.34± 0.60 (70%)
50 µM	12.17 ± 0.8 (89%)	12.45 ± 0.1 (70%)	14.99 ± 0.6 (92%)	12.56 ± 0.3 (73%)	10.52 ± 0.7 (81%)	9.79 ± 0.1 (77%)	1.99 ± 0.05 (59%)
75 µM	10.80 ± 0.3 (80%)	11.32 ± 0.2 (63%)	.63 ± 0.08 (53%)	6.97 ± 0.5 (40%)	7.08 ± 0.7 (54%)	6.05 ± 0.9 (47%)	1.88± 0.20 (56%)
100 µM	10.2 ± 0.5 (75%)	10.9 ± 0.5 (61%)	7.3 ± 0.0.34 (45%)	5.88 ± 0.7 (34%)	7.77 ± 0.6 (59%)	6.19± 0.7 (46%)	1.80 ± 0.1 (54%)

Note : Chickpea seedling were grown hydroponically on nutrient medium supplemented with different concentration of CdCl2 (0-100µM). Ten-day -old seedling were randomly selected for the measurement of shoot length. Value are expressed as mean ±standard error (SE) of replications and percentage value are given relative to control (0µM), which was considered as 100%. The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

Table 2. Effect of cd stress on the length of root in 10 days old chickpea seedlings.

Conc.	GNG-1581 (cm)	IPC-K-13-163 (cm)	IPC-K-11-112 (cm)	IPC-K-09-145 (cm)	IPC-05-62 (cm)	JG-14 (cm)	ICCV-1205 (cm)
0 μM	6.47 ± 0.03 (100%)	3.86± 0.1 (100%)	9.72± 0.45 (100%)	6.66 ± 0.76 (100%)	2.47 ± 0.08 (100%)	14.03 ± 0.9 (100%)	5.67 ± 0 .1 (100%)
25 μM	5.45 ± 0.3 (84%)	2.75 ± 0.3 (71%)	3.80± 0.40 (39.09%)	5.7± 0.1 (85.58%)	2.08± 0.44 (81%)	9.08 ± 0.4 (64%)	2.72 ± 0.6 (47%)
50 μM	4.1 ± 0.2 (64%)	2.84 ± 0.6 (73%)	3.85± 0.87 (39.6%)	3.53 ± 0.72 (53%)	1.43 ± 0.8 (57%)	3.9 ± 0.7 (28%)	1.57 ± 0.7 (27%)
75 μM	2.66 ± 0.02 (43%)	2.33± 0.7 (60%)	.92 ± 0.22 (9.46%)	1.42± 0.17 (21%)	.826± 0.04 (33%)	2.46 ± 0.3 (17%)	1.28 ± 0.3 (22%)
100 μM	1.83 ± 0.3 (28%)	2.10± 0.6 (54%)	.87 ± .0.8 (8.98%)	.96 ± 0.04 (14%)	.843± 0 54 (34%)	2.16 ± 0.07 (15%)	1.37 ± 0.4 (24%)

Note : Chickpea seedling were grown hydroponically on nutrient medium supplemented with different concentration of $CdCl_2$ (0–100 μM). Ten-day -old seedling were randomly selected for the measurement of root length. Value are expressed as mean ±standard error (SE) of replications and percentage value are given relative to control (0 μM), which was considered as 100%. The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

concentration there is decrease in (p<0.05) height of seven cultivars (GNG-1581, IPC-K-13-163, IPC-11-112, IPC-K-09-145, IPC-05-62, JG-14, and ICCV-1205) compared to control. A significant decrease in shoot, root and leaf length was recorded for IPC-11-112 and IPC-K-09-145 when cultivars were exposed to 0 µm, 25 µm, 50 µm, 75 µm, 100 µm., meaning that these varieties are more sensitive in comparison to others (Table 1, 2, 3 and Figs. 1, 2, 3). Highest decrease was recorded in roots followed by leaves and Shoots.

The observed reduction in root growth aligns with previous findings in chickpea, rice and tomato cultivars (Baruah *et al.* 2019, Liza *et al*. 2024). Cadmium (Cd) accumulation in plant tissues is a major stress factor that severely limits crop development and overall yield. As observed by Ashraf *et al.* 2015, Cd toxicity suppresses growth by disrupting cell division and altering plant structural integrity. Furthermore, the translocation of Cd throughout the plant impairs photosynthesis, negatively shifts nutrient profiles, and reduces enzymatic activity,

Table 3. Effect of Cd stress on the growth of leaf in 10 days old chickpea seedlings.

Conc.	GNG-1581 (cm)	IPC-K-13-163 (cm)	IPC-K-11-112 (cm)	IPC-K-09-145 (cm)	IPC-05-62 (cm)	JG-14 (cm)	ICCV-1205 (cm)
0 μM	.39 ± 0.03 (100%)	.36+ ± 0.08 (100%)	1.67 ± 0.95 (100%)	0.49 ± 0.06 (100%)	.37 ± 0.6 (100%)	.48± 0.03 (100%)	.43 ± 0.06 (100%)
25 μM	.37 ± .01 (\94%)	.31 ± 0.01 (86%)	1.56 ± 0.12 (93.4%)	0.46 ± 0.04 (93%)	.28± 0.01 (77%)	.46± 0.02 (96%)	.31 ± 0.06 (72%)
50 μM	.36 ± 0.04 (92%)	.29 ± 0.30 (80%)	0.32 ± 0.06 (19.16%)	0.45 ± 0.01 (91%)	.26± 0.08 (71%)	.46 ± 0.01 (95%)	.34 ± 0.04 (79%)
75 μM	.34 ± 0.06 (87%)	.27 ± 0.01 (75%)	0.22± 0.01 (13.17%)	0.19± 0.02 (38%)	0.23± 0.07 (62%)	0.32± 0.02 (72%)	.30 ± 0.09 (69%)
100 μM	.28 ± 0.03 (71%)	.24 ± 0.01 (66%)	0.2 ± 0.09 (11.17%)	0.18 ± 0.05 (36%)	0.24 ± 0.09 (64%)	0.28± 0.04 (58%)	.3 ± 0.05 (69%)

Note : Chickpea seedling were grown hydroponically on nutrient medium supplemented with different concentration of $CdCl_2$ (0-100 μM). Ten-day-old seedling were randomly selected for the measurement of leaf length. Value are expressed as mean±standard error (SE) of replications and percentage value are given relative to control (0 μM), which was considered as 100%. The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

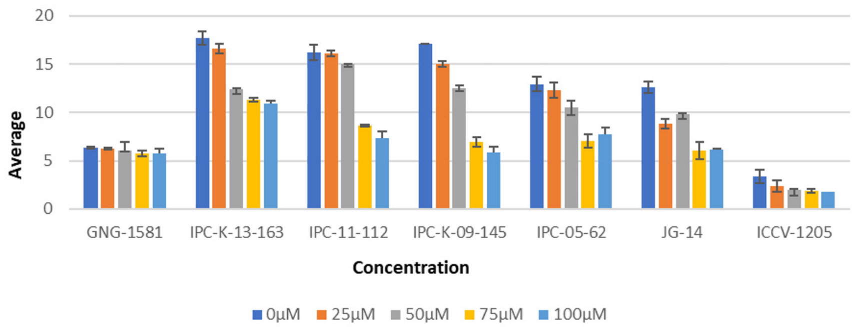

Fig. 1. The comparative study of shoot length in chickpea cultivars (GNG-1581, IPC-K-13-163, IPC-11-112, IPC-K-09-145, IPC-05-62, JG-14, ICCV-1205) grown under various concentration of Cd (0, 25, 50, 75, 100 µM. Data are presented as mean ± standard error (SE, n=3). The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

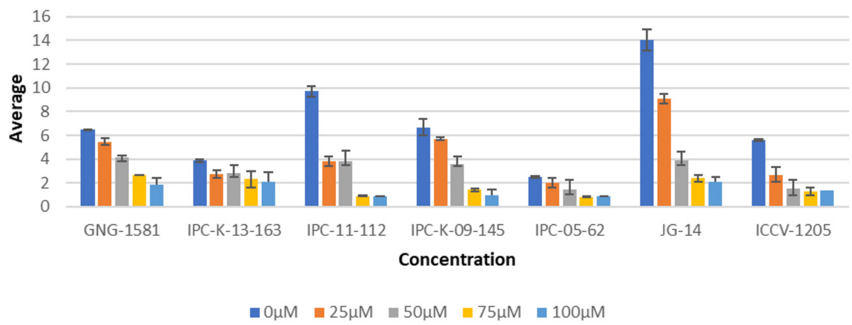

Fig. 2. The comparative study of root length in chickpea cultivars (GNG-1581, IPC-K-13-163, IPC-11-112, IPC-K-09-145, IPC-05-62, JG-14, ICCV-1205) grown under various concentration of Cd (0, 25, 50, 75, 100 µM. Data are presented as mean ± standard error (SE, n=3). The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

Table 4. Effect of Cd stress on fresh weight in 10 days old chickpea seedlings.

Conc.	GNG-1581 (g/plant)	IPC-K-13-163 (g/plant)	IPC-K-11-112 (g/plant)	IPC-K-09-145 (g/plant)	IPC-05-62 (g/plant)	JG-14 (g/plant)	ICCV-1205 (g/plant)
0 µM	6.39 ± 0.02 (100%)	12.21 ± 0.6 (100%)	9.48 ± 0.9 (100%)	15.58 ± 0.9 (100%)	5.28 ± 0.01 (100%)	13.71 ± 001 (100%)	.211 ± 0.06 (100%)
25 µM	6.21 ± .2 (98%)	8.17 ± 0.09 (66%)	7.73 ± .9 (81%)	12.41 ± 0.05 (79%)	5.6 ± 0.1 (106%)	11.23 ± 0.06 (81%)	.177 ± 0.06 (83%)
50 µM	6.10 ± 0.3 (90%)	8.08 ± 0.6 (66%)	7.4 ± 0.8 (78%)	11.41 ± 0.05 (73%)	5.9 ± 0.4 (113%)	11.87 ± 0.03 (86%)	.175 ± 0.04 (82%)
75 µM	5.80 ± 0.6 (90%)	8.66 ± 0.7 (70%)	7.81 ± 0.2 (82%)	10.60 ± 0.5 (68%)	4.9 ± 0.10 (95%)	8.24± 0.12 (60%)	.16 ± 0.02 (78%)
100 µM	5.73 ± 0.6 (89%)	8.3± 0.8 (68%)	6.69 ± 0.3 (70%)	10.66 ± 0.6 (68%)	5.25 ± 0.58 (99%)	8.06 ± 0.04 (58%)	.15 ± 0.02 (72%)

Note : Chickpea seedling were grown hydroponically on nutrient medium supplemented with different concentration of $CdCl_2$ (0–100 µM). Ten-day -old seedling were randomly selected for the measurement of fresh weight. Value are expressed as mean ±standard error (SE) of replications and percentage value are given relative to control (0 µM), which was considered as 100%. The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

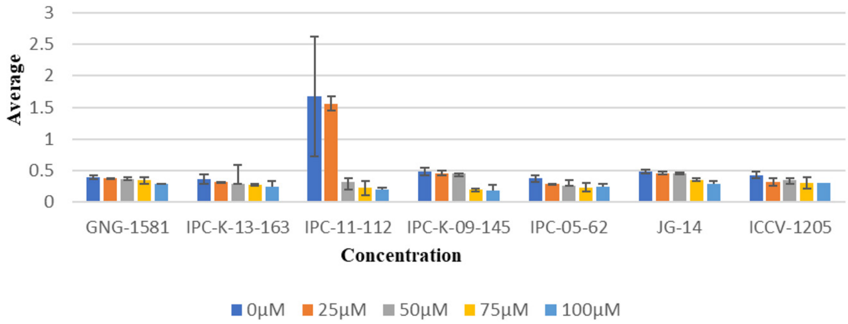

Fig. 3. The comparative study of leaves length in chickpea cultivars (GNG-1581, IPC-K-13-163, IPC-11-112, IPC-K-09-145, IPC-05-62, JG-14, ICCV-1205) grown under various concentration of Cd (0, 25, 50, 75, 100 µM. Data are presented as mean ± standard error (SE, n=3). The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

leading to a significant decline in both crop quality and productivity (Faizan *et al.* 2021, Nazir *et al.* 2024, Elhakem *et al.* 2025).

Fresh weight and dry weight

It can be seen from our results (Table 4 and Fig. 4) that fresh weight of all cultivars decreases with increasing concentration of cadmium. It shows that cultivars IPC-05-62 and GNG 1581 has less fresh biomass reduction under Cd toxicity as compared with control condition. There is highest reduction in dry weight of IPC-K-09-145 followed by IPC-K-11-112 and IPC-K-13-163, but not much change is observed in other varieties (Table 5, Fig. 5).

The current findings reveal that heavy metal toxicity negatively impact the morphological development of chickpea cultivars, as evidenced by a marked reduction in shoot, root and leaf length, as well as significant decline in fresh and dry biomass. These results aligned with prior research on *Pisum sativum*, which reported similar growth inhibition under heavy metal stress. This observed growth suppression can be attributed to cadmium-induced disruption of the glycolytic pathway. By impairing

Table 5. Effect of Cd stress on dry weight in 10 days old chickpea seedlings.

Conc.	GNG-1581 (g/plant)	IPC-K-13-163 (g/plant)	IPC-K-11-112 (g/plant)	IPC-K-09-145 (g/plant)	IPC-05-62 (g/plant)	JG-14 (g/plant)	ICCV-1205 (g/plant)
0 µM	1.42 ± 0.5 (100%)	1.88 ± 0.6 (100%)	2.10 ± 0.6 (100%)	6.23 ± 0.3 (100%)	1.01 ± 0.9 (100%)	1.49 ± 0.03 (100%)	1.89 ± 0.39 (100%)
25 µM	1.75 ± .6 (120%)	2.21 ± 0.7 (117%)	1.55 ± 0.09 (73%)	2.44 ± 0.88 (39%)	.97 ± 0.01 (96%)	1.16 ± 0.24 (77%)	1.38 ± 0.01 (73%)
50 µM	1.24 ± 0.02 (87%)	2.08 ± 0.04 (110%)	1.26± 0.04 (60%)	2.42 ± 0.83 (38%)	1.18 ± 0.7 (116%)	1.38 ± 0.05 (92%)	1.84 ± 0.24 (97%)
75 µM	1.22 ± 0.06 (85%)	1.63 ± 0.7 (86%)	.16 ± 0.33 (55%)	3.19 ± 0.50 (51%)	.95 ± 0.02 (94%)	1.47± 0.11 (98%)	1.83 ± 0.17 (96%)
100 µM	1.61 ± 0.51 (113%)	1.51 ± 0.06 (80%)	1.16± 0.18 (69%)	1.98 ± 0.4 (31%)	1.06 ± 0.1 (104%)	1.44 ± 0.03 (96%)	1.95 ± 0.30 (103%)

Note : Chickpea seedling were grown hydroponically on nutrient medium supplemented with different concentration of $CdCl_2$ (0-100 µM). Ten-day-old seedling were randomly selected for the measurement of dry weight. Value are expressed as mean ±standard error (SE) of replications and percentage value are given relative to control (0 µM), which was considered as 100%. The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

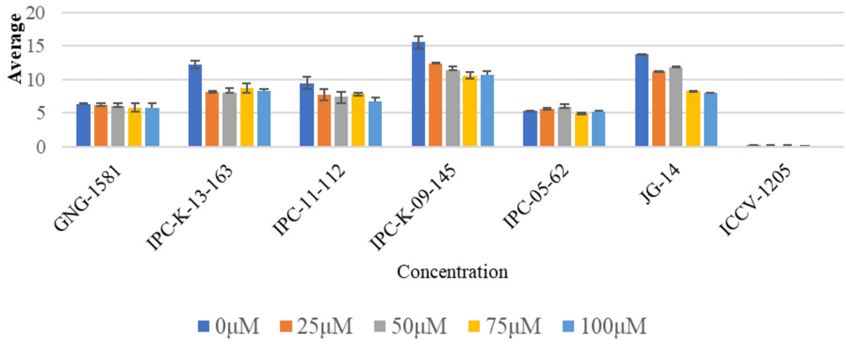

Fig. 4. The comparative study of fresh weight in chickpea cultivars (GNG-1581,IPC-K-13-163,IPC-11-112,IPC-K-09-145,IPC-05-62, JG-14, ICCV-1205) grown under various concentration of Cd (0,25, 50, 75, 100 µM. Data are presented as mean ± standard error (SE, n=3). The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA ($p<.05$).

this metabolic process, cadmium effectively restricts cell division and elongation, ultimately hindering the development of root and stem tissues (El-Okkiah *et al.* 2022, Ur-Rahman *et al.* 2021). Cadmium-induced stress suppresses the mitotic division of meristematic cells (Ullah *et al*. 2020), a metabolic disruption that directly manifests as a reduction in root diameter, length, and overall dry biomass (El-Okkiah *et al.* 2022. Shehzadi *et al.* 2025, Hu *et al.* 2025, Zhang and Dong 2025).

Cadmium (Cd) toxicity poses a severe threat to legume biomass production, characterized by a substantial decline in both fresh weight (FW) and dry weight (DW) across root, leaf and shoot systems (Rehman *et al.* 2022). This reduction in biomass is primarily driven by the impairment of photosynthetic efficiency, as Cd disrupts chlorophyll biosynthesis and interferes with the acquisition of essential minerals, thereby limiting carbon assimilation (Rehman *et al.* 2022, Piršelová and Ondrušková 2021). Furthermore, the induction of oxidative stress, evidenced by reactive oxygen species (ROS) overproduction, leads to lipid peroxidation and membrane damage, which compromises cell turgor and inhibits cell division, directly contributing to the significant loss of fresh

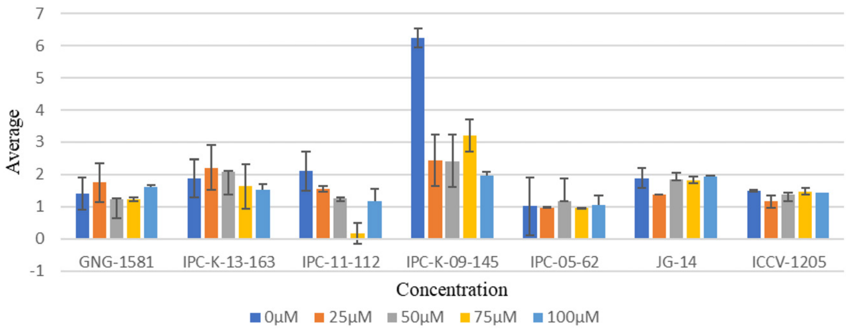

Fig. 5. The comparative study of dry weight in chickpea cultivars (GNG-1581,IPC-K-13-163,IPC-11-112,IPC-K-09-145,IPC-05-62,JG-14,ICCV-1205) grown under various concentration of Cd (0,25,50,75,100µM). Data are presented as mean ± standard error (SE, n=3). The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA ($p<.05$).

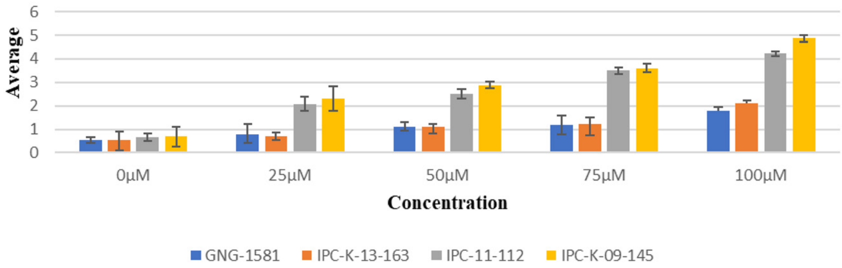

Fig. 6. The comparative study of cadmium concentration in chickpea cultivars (GNG-1581,IPC-K-13-163,IPC-11-112,IPC-K-09-145) grown under various concentration of Cd (0, 25, 50, 75,100 µM. Data are presented as mean ± standard error (SE, n=3).The effect of cadmium concentration and cultivars on shoot length were found to be statically significant as determined by one-way ANOVA (p<.05).

and dry matter (Al-Khayri *et al.* 2023). Additionally, the disruption of carbohydrate metabolism during early developmental stages further suppresses the mobilization of seed reserves, resulting in stunted growth and diminished biomass accumulation in Cd-stressed seedlings (Kaur *et al.* 2023).

In present study, exposure to elevated Cd concentration significantly altered the morphological characteristics of the tested chickpea cultivars. The decline in growth along with biomass was chiefly related with Cd absorption and its subsequent accumulation, which increased with higher Cd concentration. Further, exposure to cadmium toxicity reduced plant hight and disturbed water relations. Considerable variability in cadmium tolerance was observed among the various chickpea cultivars. Cultivars GNG-1581 and IPC-K-13-163 exhibited relatively superior growth as well as biomass performance under high Cd toxicity compared to IPC-K-09-145 and IPC-11-112.

Cadmium accumulation

Highest cadmium accumulation was recorded for cultivars IPC-K-09-145, followed by IPC-11-112, IPC-K-13-163 and GNG-1581, at 100 µM Cd concentration (Table 6, Fig. 6). Cd accumulation was recorded 339% in GNG-1581, 383% in IPC-K-13-163, in 631% in IPC-11-112 and 717% in IPC-K-09-145 at 100 µM Cd Concentration.

The accumulation of Cadmium (Cd) in chickpea (*Cicer arietinum* L.) is primarily determined by active root uptake mechanisms followed by systemic translocation to the seeds via xylem and phloem pathways (Ai *et al.* 2022). In the rhizosphere, the secretion of root exudates plays a critical role in modulating Cd bioavailability (Mei *et al.* 2022), while intracellular homeostasis is maintained through chelation

Table 6. Cadmium content in chickpea seedlings cultivated under different CD concentrations.

Treatment	GNG 1581 (ppm)	IPC-K-13-163 (ppm)	IPC-11-112 (ppm)	IPC-K-09-145 (ppm)
0 µM	.53±.11 (100%)	.55±.37 (100%)	.67±.16 (100%)	.68±.41 (100%)
25 µM	.78 ±.46 (147%)	.70 ±.15 (127%)	2.08±. 3 (310%)	2.31±.52 (339%)
50 µM	1.10±.21 (207%)	1.11±.1 (201%)	2.49±.20 (371%)	2.89±.16 (425%)
75 µM	1.20±.39 (226%)	1.24±.28 (225%)	3.50±.15 (522%)	3.61±.19 (530%)
100 µM	1.80±.15 (339%)	2.11±.12 (383%)	4.23±.06 (631%)	4.88±.14 (717%)

Note : Chickpea seedling were grown hydroponically on nutrient medium supplemented with different concentration of $CdCl_2$ (0–100 µM). Ten-day-old seedling were randomly selected for the measurement of cadmium content. Value are expressed as mean ±standard error (SE) of replications and percentage value are given relative to control (0 µM), which was considered as 100%. The effect of cadmium concentration and cultivars on shoot length were found to be statistically significant as determined by one-way ANOVA (p<.05).

and vacuolar sequestration mediated by specialized transmembrane transporters (Huang *et al.* 2020). Significant inter-genotypic variation in seed Cd concentration suggests that genetic regulation specifically the expression of transcription factors serves as a primary determinant in limiting metal translocation to the grains (Cai *et al.* 2026). Consequently, mitigating Cd contamination in chickpeas requires an integrated approach that combines strategic agronomic management, such as soil pH optimization, with the breeding of low-accumulating cultivars to ensure both crop productivity and food safety (Mei *et al.* 2022).

Cadmium accumulation in plant tissues disrupts vital physiological as well as biochemical function by generating oxidative stress, primarily due to imbalance between the generation and detoxification of ROS (Anjum *et al.* 2010, 2012 a, b, 2013). Although Cd is not a redox-active element, its toxicity is mainly related with its capacity to induce oxidative stress, which has been widely documented (Gill *et al.* 2010, Cuypers *et al.* 2010, Anjum *et al.* 2012 a, b, 2013, 2014).

CONCLUSION

The influence of certain heavy metals or trace elements can induce toxicity in plants, adversely affecting various growth parameters like plant height, root, shoot and leaf length, fresh weight (FW), and dry weight (DW). However, the extent of these detrimental effects differs on the basis of plant species and genotype involved. These growth attributes serve as highly sensitive indicators for assessing the physiological response of plants to metal-induced toxicity. In this study, substantial differences were observed in length of root, shoot and leaf with fresh and dry weight among seven chickpea (*Cicer arietinum* L.) cultivars GNG-1581, IPC-K-13-163, IPC-11-112, IPC-K-09-145, IPC-05-62, JG-14, and ICCV-1205, when subjected to cadmium (Cd) stress. It was observed in this study that increased cd concentrations resulted in pronounced toxicity, leading to a significant decline in leaf, root and shoot development as well as in fresh and dry weight (DW) across the evaluated chickpea cultivars. Among these, GNG-1581 and IPC-K-13-163 exhibited comparatively higher growth performance and biomass accumulation, suggesting greater tolerance to Cd stress. Based on the initial screening of seven chickpea varieties, four cultivars GNG-1581, IPC-K-13-163, IPC-11-112, and IPC-K-09-145 were selected for further investigation of Cd tolerance in relation to growth and biomass attributes. Overall, the results demonstrate that GNG-1581 and IPC-K-13-163 are relatively Cd-tolerant cultivars, whereas IPC-11-112 and IPC-K-09-145 are more sensitive to Cd exposure. It is widely recognized that plants have the ability to accumulate trace metals (TMs) which varies considerably among species and cultivars, and is influenced by soil properties, metal bioavailability, and plant genetic makeup. In the present investigation, the cultivars IPC-K-09-145 and IPC-11-112 accumulated higher concentrations of cadmium (Cd) compared to IPC-K-13-163 and GNG-1581.

To further elucidate the underlying tolerance mechanisms, future research under Cd-contaminated field conditions should focus on metabolomic and proteomic profiling of these cultivars. Plants possess variety of inherent biochemical as well as physiological methods that empower them to withstand and alleviate the detrimental consequence of metal and metalloid stress, which makes them right candidates for remediation of polluted environment.

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