Screening of Tomato Cultivars for Cadmium Tolerance Based on Growth and Biomass attributes in Pot Experiment

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Abstract: Tomatoes are an important vegetable crops and consumed all over the world as in either fresh or process food. Despite its nutritional significance, tomato production is increasingly challenged by cadmium (Cd) contamination, increasing Cd concentration in agriculture soils threaten both crop productivity and public health, posing a major risk to tomato production and consumption. Very limited research has been conducted on the effects of Cd on screened tomato cultivars at seedling stage. A controlled shade pot experiment was conducted to assess the effects of different Cd concentrations on two pre-screened two cultivars Red Pearl and Qinzu Shanghai 903. The physiological and morphological properties and seed germination of both cultivars were examined under low irrigation with 0, 10, 20, 40 and 60 (Cd) mg/kg. The results revealed that increasing Cd concentration decreased seed germination (25.52-25%), survival rate (56.52-45.83%), average shoot height (50-40%), root length (17.46-23%), stem, leaves, root and total fresh biomass decreased by (48-61%, 63-64%, 63.5-59.7 and 63.10-61.79%) and dry stem, leaves, root and total biomass decreased by (29.68-24.59%, 30.70-25%, 28.51-25% and 29.66-23.89%) respectively in both tomato cultivars. Among Cd treatments, 10 mg/kg Cd caused the least reduction in germination, growth, and biomass compared to higher Cd levels, although all Cd treatments were significantly lower than the control. However, Red Pearl exhibited greater tolerance than Qinzu Shanghai 903 by maintaining better growth and biomass under Cd stress. Overall, both tomato cultivars exhibited significant reductions in morphological traits with increasing Cd concentrations. These findings suggest that Red Pearl is a promising Cd-tolerant

cultivar with potential for cultivation in Cd contaminated soils and as valuable genetic material for breeding programs aimed at improving Cd tolerance.

Keywords: *Cadmium concentrations, Morphological properties, Survival Rate, Seed germination, Tomato.*

1. Introduction

Among the major environmental pollutants, cadmium (Cd) is a non-essential and one of the most phytotoxic (Rahoui *et al.*, 2008) heavy metal that adversely affects plant growth, development, and productivity (Dong *et al.*, 2005). It is highly mobile in the soil-plant system and can impair several processes, resulting in poor growth and low economic yield of plants (Rahoui *et al.*, 2008). It is also easily taken up by plants and then enters the food chain (Dong *et al.*, 2005). Along with other heavy metals such as Chromium (Cr), Arsenic (As), Nickel (Ni), Mercury (Hg), and Lead (Pb), Cd is considered dangerous poisons due to its high mobility (Afzal *et al.*, 2019; Palansooriya *et al.*, 2020; Tian *et al.,*2011).

Cd with a character of white-silver metal and high-water solubility, toxic even at low concentrations (El Rasafi *et al.*, 2021). Scientist have observed that Cd toxicity disturbs the vital morphological and physiological processes, such as photosynthesis, seed germination, restrict root growth and impair root penetration into the soil (Wang *et al.*, 2015; Hussain *et al.*, 2012; Rizwan *et al.*, 2017). Several studies have shown that this metal can inhibit seed germination, reduce plant height, inhibit root growth, and reduce the number of leaves per plant, leading to plant death (Bae *et al.*, 2016; Mani *et al.*, 2012; Soudek *et al.*, 2014). Cadmium can cause physiological disorders in plants, particularly those caused by increased oxidative stress (excessive production of reactive oxygen species [ROS]) (Moradi *et al.*, 2019). Plants can easily take Cd and resulting several health issues form human, and peoples suffers from renal tubular disease if they consume rice with relatively high Cd content (Dong *et al.*, 2005; Tuna *et al., 2026*). Therefore, it is assumed that the Cd accumulation in soil transfer of toxic heavy metals into food chain considered as a major concern for the humans (Grant *et al.*, 1998).

Cd toxicity and stress have been observed in many others crops species, including wheat (*Triticum aestivum* L.) (Ozyigit et al., 2021), rice (Oryza sativa L.), Oat (Avena sativa L.), mustard (Brassica Juncea L.) and leafy vegetables such as spinach (Spinacia Oleracea L.) and coriander (Coriandrum sativum L.) (Latif *et al.*, 2020). Among all these crops Tomato is an important vegetable crops and disposed to Cd-induced toxicity (Khan *et al.*, 2019). Different studies showed that the Cd stress exposed root browning, increased root diameter, dry biomass and reduced plant root length (He *et al.*, 2017). In addition, the existence of extreme amount of Cd in soil cause many toxic symptoms in plants, which are stunted growth, chlorosis, necrosis, reduction of growth (Weigel and Jäger, 1980; Dong *et al.*, 2005). Cd exposure reduces photosynthetic efficiency and causes severe biochemical changes at different stages of plant growth (Latif *et al.*, 2020; Tian *et al.,* 2016). Collectively, these findings highlight the need for identifying Cd-tolerant cultivars and development appropriate management strategies to mitigate the adverse impacts of Cd contamination on agricultural production system.

Tomato (Solanum lycopersicum L.) considered as an important vegetable in the world (Khan *et al.*, 2015; Sootahar *et al.*, 2024), it is also rich in vitamins, antioxidants and essential nutrient, including iron, potassium and lycopene as well as numerous bioactive compounds and antioxidants that play a vital role in human health and disease prevention (Wang *et al.*, 2015) (Vélez-Terreros *et al.*, 2021). Due to the diverse range of its utility in raw, cooked, and processed food, the global demand for tomato has increased tremendously in recent years(Chaudhary *et al.*, 2019). Due to its excellent nutritional value, tomatoes are considered a unique vegetable crop and are widely grown in many parts of the world, with China (59.4 t hac^{-1}), United States (96.8 t hac^{-1}) and South Africa (75.5 t hac^{-1}) being the main producing countries (Sootahar *et al.*, 2024; Qusay Abdulhamza Muttaleb *et al.*, 2023).

Despite its nutritional significance, tomato production has been challenged by different factors around the globe such as soil salinization, water shortage, abiotic stress and heavy metal contamination, Cr (Malhi *et al.*, 2026), Salinity (Sootahar *et al.*, 2025) and particularly Cd (Adil *et al.*, 2020) which adversely enter human food chain. Egan et al. (2007) showed that around 80% Cd exposure creates from adaptation of vegetables and cereals. In recent decades, the continuous rise in environmental Cd contamination has emerged as a major challenge for sustainable vegetable production. Although vegetables are indispensable for human nutrition and food security, increasing Cd levels in agricultural soils threaten both crop productivity and public health. Consequently, understanding the response of tomato cultivars to Cd toxicity has become essential for developing effective mitigation strategies and ensuring safe food production. Therefore, the present study was conducted to evaluate the effects of Cd toxicity on two tomato cultivars and to identify Cd-tolerant genotypes with superior growth performance.

2. Materials and Methods

2.1. Plant Material

There were fourteen Cherry tomatoes (Solanum lycopersicum L.) cultivars were collected from Longmen Town, Fucheng District, Mianyang City, Sichuan Province, China. Fourteen cherry tomato (Solanum lycopersicum L.) cultivars were collected from Longmen Town, Fucheng District, Mianyang City, Sichuan Province, China. After collection, the seeds were cleaned, packed in airtight polyethylene bags, and stored under ambient laboratory conditions until the commencement of the experiments. Prior to the pot experiment, all fourteen cultivars were subjected to a preliminary in vitro cadmium (Cd) tolerance screening to identify genotypes differing in their response to Cd stress. The screening was conducted following the aseptic seed culture protocol described by (Sootahar *et al.*, 2024). Briefly, surface-sterilized seeds of each cultivar were cultured on growth medium supplemented with cadmium under controlled environmental conditions. Each treatment was replicated, and the experiment was arranged in a completely randomized design to minimize experimental bias. Cadmium tolerance was evaluated by comparing seedling performance under Cd stress using multiple morphological indicators, including germination percentage, shoot length, root length, seedling fresh biomass, seedling dry biomass, and seedling vigor index. These parameters are widely recognized as reliable indicators of early-stage heavy metal tolerance because Cd toxicity primarily inhibits seed germination, root elongation, and seedling establishment. The relative performance of each cultivar under Cd stress was compared with its respective control to determine its tolerance level. Based on the collective performance across all measured parameters, the cultivars were ranked according to their overall Cd tolerance. Cultivars exhibiting the highest germination, minimal reduction in root and shoot growth, greater biomass accumulation, and superior seedling vigor under Cd stress were considered Cd tolerant. Among the fourteen cultivars evaluated, **Red Pearl and Qinzu Shanghai 903,** consistently exhibited the greatest tolerance to Cd stress and were therefore selected for the subsequent greenhouse pot experiment

2.2.Experimental Design

A pot experiment was conducted during the Rabi season of 2025 in a light-controlled greenhouse under ambient environmental conditions, with mean day and night temperatures of 24°C and 15°C, respectively, and relative humidity ranging from 40% to 85%. The experiment was arranged in a complete randomized design (CRD), the seeds of both tomato cultivars were sown in tray by splitting into five groups. Each group consists of 5 replications. Approximately, 30 seeds were sown per replicate to ensure sufficient germination and to obtain an adequate number of healthy, uniform seedlings for transplantation, cadmium (Cd) stress may reduce seed germination and early seedling survival.

Prior to sowing, seeds were surface-sterilized using 0.1% mercuric chloride $HgCl_2$ solution for 10 mints, then repeatedly washed with distilled water to remove any residual sterilant and prevent microbial contamination. Seeds were germinated under controlled conditions, and uniform seedlings were selected for transplantation. Twenty-five plastic pots with 20 cm upper diameter and 15 cm height) were filled with 3 Kg air-dried soil. Cadmium was applied as $CdCl_2$ at concentrations of 0, 10, 20, 40, and 60 mg Cd kg^{-1} soil by thoroughly incorporating the appropriate amount into the soil before transplanting to ensure uniform Cd distribution. A uniform fifteen-day old seedlings were transplanted into pots, maintaining five seedlings per port. The Cd treatments were applied at the time of sowing followed by 250 ml of Canal water was applied uniformly in all treatments for the identical irrigation and to minimize the experimental variation throughout the experiment.

2.3. Growth Parameters and Morphological Observation

After the harvesting the three where five plants from each replication were randomly selected for morphological and biomass assessments. Seedling survival percentage was calculated based on the number of surviving plants relative to total transplanted seedling. Shoot height and root length were measured sung a standard graduated scale, leaf area was determined using the grid-counting method and expressed as cm^2 plant^{-1}, while the number of leaves per plant was recorded manually. Fresh biomass of leaves and shoots was measured immediately after harvest using a digital analytical balance. For dry biomass determination, plant tissue (leaves, shoots, and roots) were oven-dried at 65 °C until constant weight and subsequently weighted an electronic balance. All biomass data were expressed on a per-plant basis for statistical analysis.

2.4. Statistical analysis

The Cd concentration effect on two tomato cultivars, and their interaction were evaluated using two-way analysis of variance on SPSS data analysis software 24.0. Mean comparison among treatment combination were performed using LSD test at $P < 0.05$ whenever significant main or interaction effects were detected. Prior to statistical analysis, the data were examined form normality and homogeneity of variance to ensure that the assumption of ANOVA were satisfied. Differences were considered statistically significant at $P < 0.05$.

3. Results

3.1. Effect of Cd on Seed germination of screened tomatoes

The average seed germination of Red Pearl cherry tomato and Qinzu Shanghai 903 was significantly decreased under various concentrations of Cd exposure. However, increasing Cd concentration in the soil induced a significant decline ($p<0.05$) in seed germination of two tomato cultivars and the deleterious effect of Cd became more severe with increasing Cd level. The maximum seed germination numbers were recorded under control for Red Pearl and Qinzu Shanghai 903 with 17.80 and 17.60 respectively and the minimum seed germination numbers was noted under 60 mg/kg Cd exposure for Red Pearl (4.60) and Qinzu Shanghai 903 (4.40) (**Figure 1**).

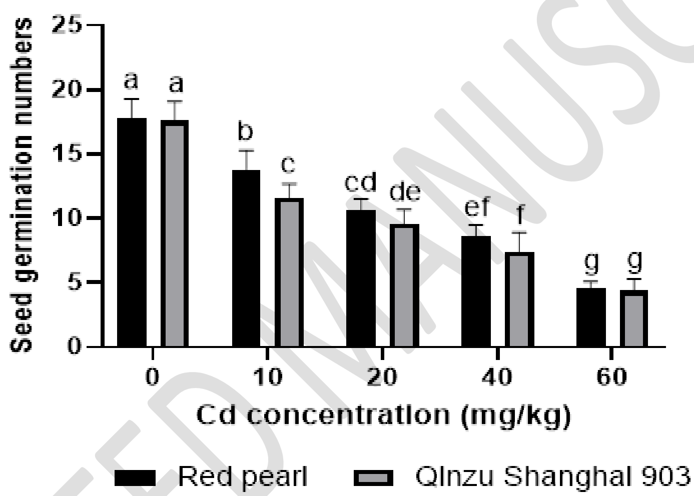

Figure 1. Effect of Cd treatment on seed germination of two tomato cultivars. The value is the number of germinated seeds from 30 sown seeds. Different alphabets among the mean values denotes significant difference at 0.05 probability level. Bar at each value represents the standard deviation of measured values (n=5).

3.2. Impact of Cd treatment on the seedlings Survival rate (SRS) of two tomato cultivars

The results regarding the SRS of two tomato cultivars are presented in the (**Figure 2**). The data showed that there was a non-significant difference observed on 10 and 20 mg/kg of both tomato cultivars comparing with the other treatments. However, increasing Cd concentration in the soil induced a significant decline ($p<0.05$) in SRS of two tomato cultivars. The maximum SRS was recorded under control for Red Pearl with 92.0% and Qinzu Shanghai 903 with 96.0% while the minimum SRS was noted under 60 mg/kg Cd exposure for Red Pearl with 52.0% and Qinzu Shanghai 903 with 44.0%. At the control and the same Cd concentration treatment, Red Pearl and Qinzu Shanghai 903 showed approximate SRS without significant difference (**Figure 2**).

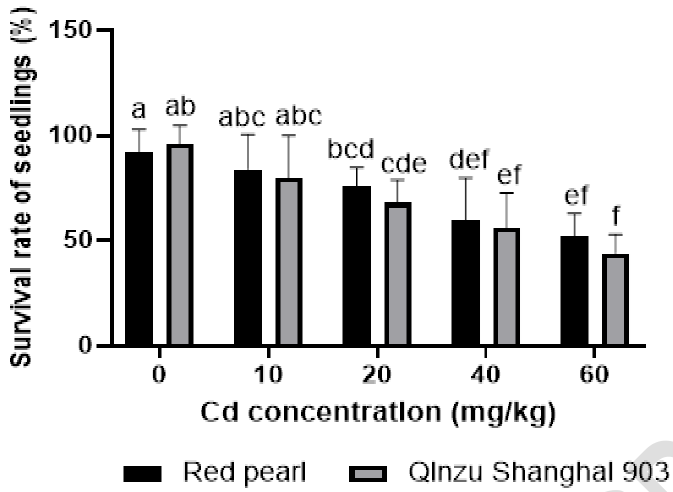

Figure 2. Effect of Cd treatment on seedling survival rate of tomato. Different alphabets among the mean values denotes significant difference at 0.05 probability level. Bar at each value represents the standard deviation of measured values (n=5).

3.3. Cd treatment effect on the Average shoot height of two tomato cultivars

Shoot height of both tomatoes decreased very obviously at four Cd concentrations when compared to the control and all the differences were significant at $p<0.05$ level. Among the four Cd concentrations, increasing Cd concentration led the decreasing shoot height significantly. However, Cd treatment at four concentrations showed stronger inhibitory effect on Qinzu Shanghai 903 than on Red Pearl. Similarly, the maximum shoot height was recorded under control for Red Pearl with 16.72 cm and Qinzu Shanghai 903 with 15.13 cm while the minimum shoot height was noted under 60 mg/kg Cd exposure for Red Pearl and Qinzu Shanghai 903 with 8.37 cm and 5.96 cm respectively (**Figure 3**).

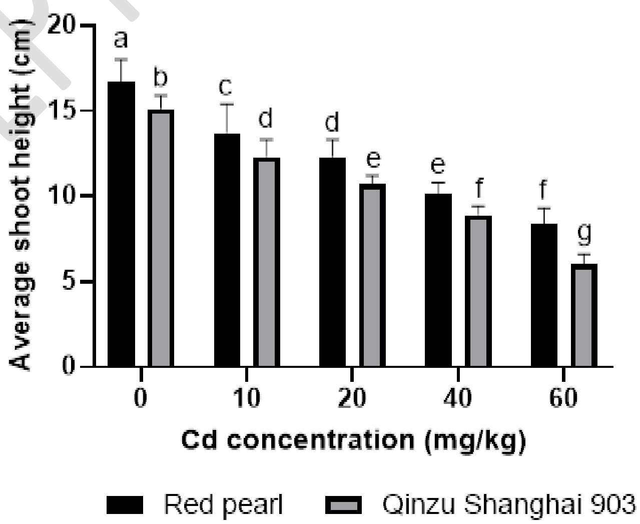

Figure 3. Effect of Cd treatment on shoot height of two tomato cultivars. Different alphabets

among the mean values denotes significant difference at 0.05 probability level. Bar at each value represents the standard deviation of measured values (n=5).

3.4.Average root length

The average root length of both tomato cultivars was reported in (**Figure 4**). The root length of Qinzu Shanghai 903 was decreased as the Cd concentration increased. In comparison of the control, the growth of root in Red Pearl was inhibited significantly only at high Cd concentrations (20, 40 and 60 mg/kg) but without significant difference at 10 mg/kg Cd treatment. This concentration dependent effect was also found in Qinzu Shanghai 903. In two tested tomatoes Red Pearl and Qinzu Shanghai 903, even if at 60 mg/kg of Cd treatment, the root length only decreased 17.46% and 22.94% compared to the control respectively (**Figure 4**).

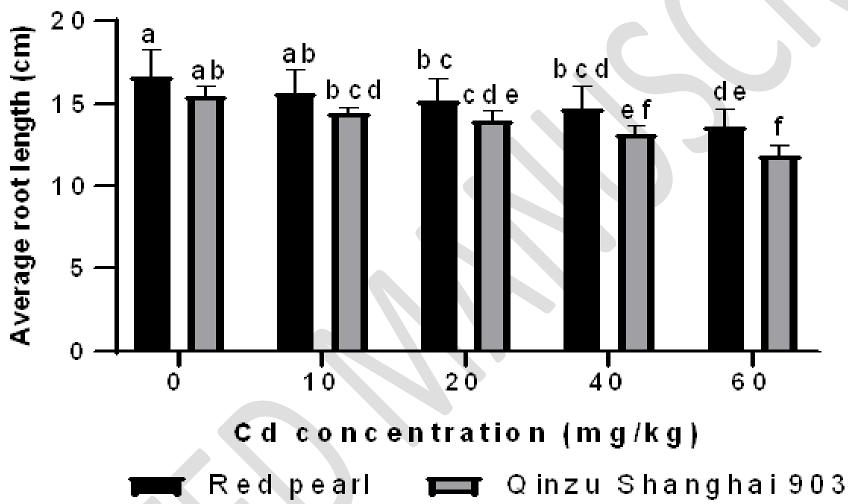

Figure 4. Effect of Cd treatment on root length of two tomato cultivars. Different alphabets among the mean values denotes significant difference at 0.05 probability level. Bar at each value represents the standard deviation of measured values (n=5).

3.5. Effect of Cd treatment on Average leaf numbers of tomatoes

The effect of Cd concentration on average leaf numbers of both tomato cultivars was observed in (**Figure 5**). The results revealed that the average leaf numbers of both Red Pearl and Qinzu Shanghai 903 decreased leaf numbers significantly along with increasing Cd concentration (20, 40 and 60 mg/kg). However, non-significant difference was observed between Red Pearl and Qinzu Shanghai 903 at control and 10 mg/kg Cd treatment. Comparing with control the average leaf numbers of single plant of Red Pearl and Qinzu Shanghai 903 significantly decreased 35.58% and 34.7% at 60 mg/kg Cd treatment respectively (**Figure 5**).

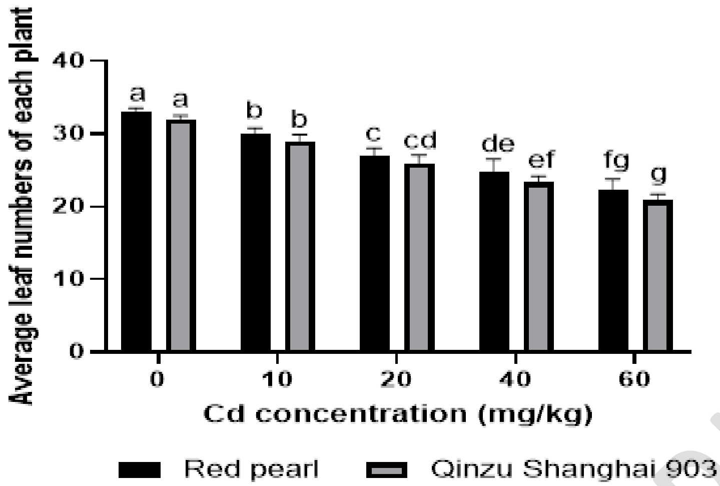

Figure 5. Effect of Cd treatment on leaf numbers per plant of two tomato cultivars. Different alphabets among the mean values denotes significant difference at 0.05 probability level. Bar at each value represents the standard deviation of measured values (n=5).

3.6. Impact of Cd on Average leaf area of tomatoes

The Cd exposure on average leaf area of both cultivars recorded in (**Figure 6**). The data showed that the similar decreasing trend of leaf area was observed when Cd concentration increased from 0 to 60 mg/kg. Comparison with control, the average leaf area of Red Pearl decreased significantly and the differences among four treatments were significant at $p<0.05$ level. Maximum leaf area of Red Pearl and Qinzu Shanghai 903 was recorded at the control with 14.9 cm2 and with 15.8 cm2 while the minimum leaf area was noted under 60 mg/kg Cd exposure for Red Pearl and Qinzu Shanghai 903 with 8.2 cm2 and 6.9 cm2 respectively (**Figure 6**).

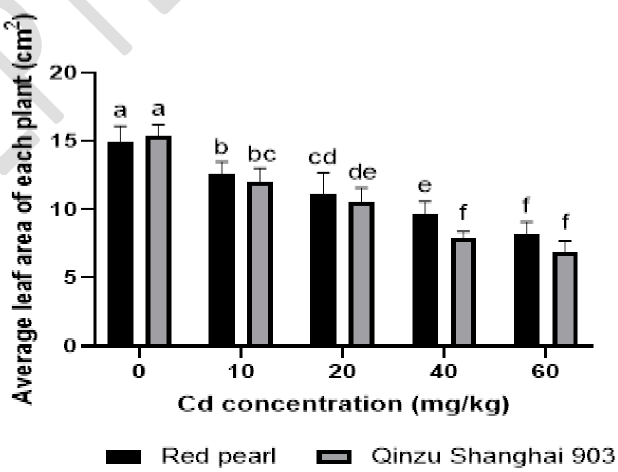

Figure 6. Effect of Cd treatment on leaf area of two tomato cultivars. Different alphabets among the mean values denotes significant difference at 0.05 probability level. Bar at each value represents the standard deviation of measured values (n=5).

3.7. Effect of Cd treatment on Fresh weight of Stem, Root, leaves and total weight of single plant

The effect of Cd treatment on fresh weight (FW) of stem, leaves, root and whole plant presented in (**Figure 7)**. The FW of stem in Red Pearl and Qinzu Shanghai 903 reduced significantly at high Cd concentration (20, 40 and 60 mg/kg), the non-significant difference was observed in Red Pearl and Qinzu Shanghai 903 at control, 10 and 60 mg/kg Cd treatment. Comparing with control the FW of stem in Red Pearl and Qinzu Shanghai 903 significantly decreased 36.92% and 38.49% at 60 mg/kg Cd treatment respectively (**Figure 7 A)**. The results of (**Figure 7B)** showed that the FW of leaves of single plant in both tomatoes decreased very obviously at four Cd concentrations and all the differences were significant at $p<0.05$ level. Among the four Cd concentrations, increasing Cd concentration led the decreasing FW of leaves significantly. Similarly, the FW of root decreased significantly when Cd concentration increases. The minimum FW of root was 10.1 and 8.9 g was observed at 60 mg/kg treatment (**Figure 7C)**. Whereas the total FW of Red Pearl subdued significantly only at high (20, 40 and 60 mg/kg) Cd treatments as compare with control, there was non-significant difference were detected at control in both tomatoes (**Figure 7D)**.

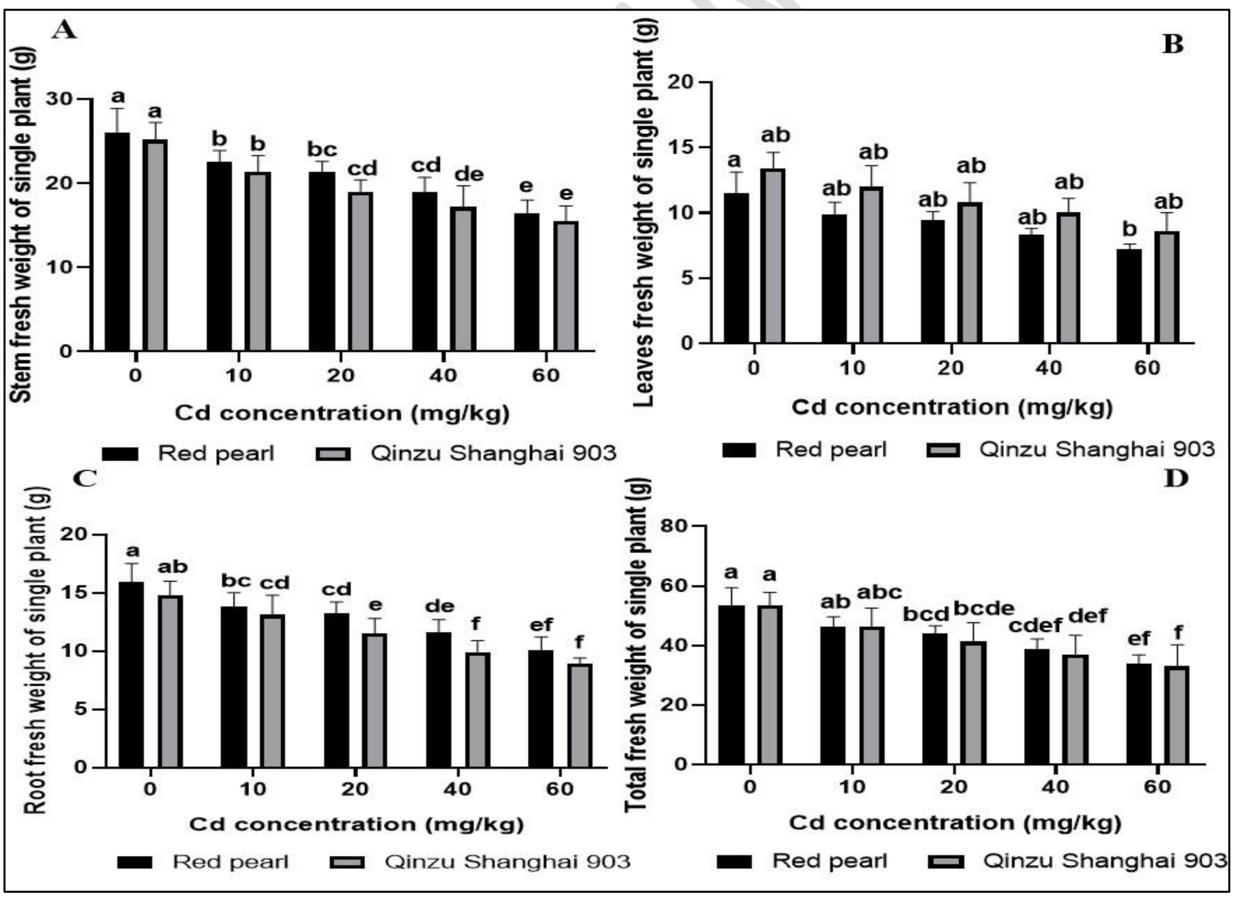

Figure 7. Effect of Cd treatment on fresh weight of two tomato cultivars. Different alphabets among the mean values denotes significant difference at 0.05 probability level. Bar at each value

represents the standard deviation of measured values (n=5).

3.8. Effect of Cd treatment on Dry weight of Stem, Root, leaves and total weight of single plant

The effect of different Cd concentration on dry weight (DW) of stem, root, leaves and whole in Red Pearl and Qinzu Shanghai 903 under pot conditions presented in (**Figure 8).** The DW of stem in Red Pearl decreased significantly at high Cd concentration and the non-significant difference were observed in Red Pearl at the control (**Figure 8A)**. The DW of stem in Red Pearl and Qinzu Shanghai 903 significantly decreased 70.31% and 75.40% at 60 mg/kg Cd treatment respectively. The leaves DW of both tomatoes decreased very obviously at four Cd concentrations when compared to the control and all the differences were significant at $p<0.05$ level (**Figure 8B)**. Similarly, the DW of root in both tomatoes decreased very obviously at four Cd concentrations and all the differences were significant at $p<0.05$ level (**Figure 8C)**. The total DW of Red Pearl significantly decreased on high Cd concentrations (20, 40 and 60 mg/kg) and the non-significant difference were detected at the control between Red Pearl and Qinzu Shanghai 903 (**Figure 8D).**

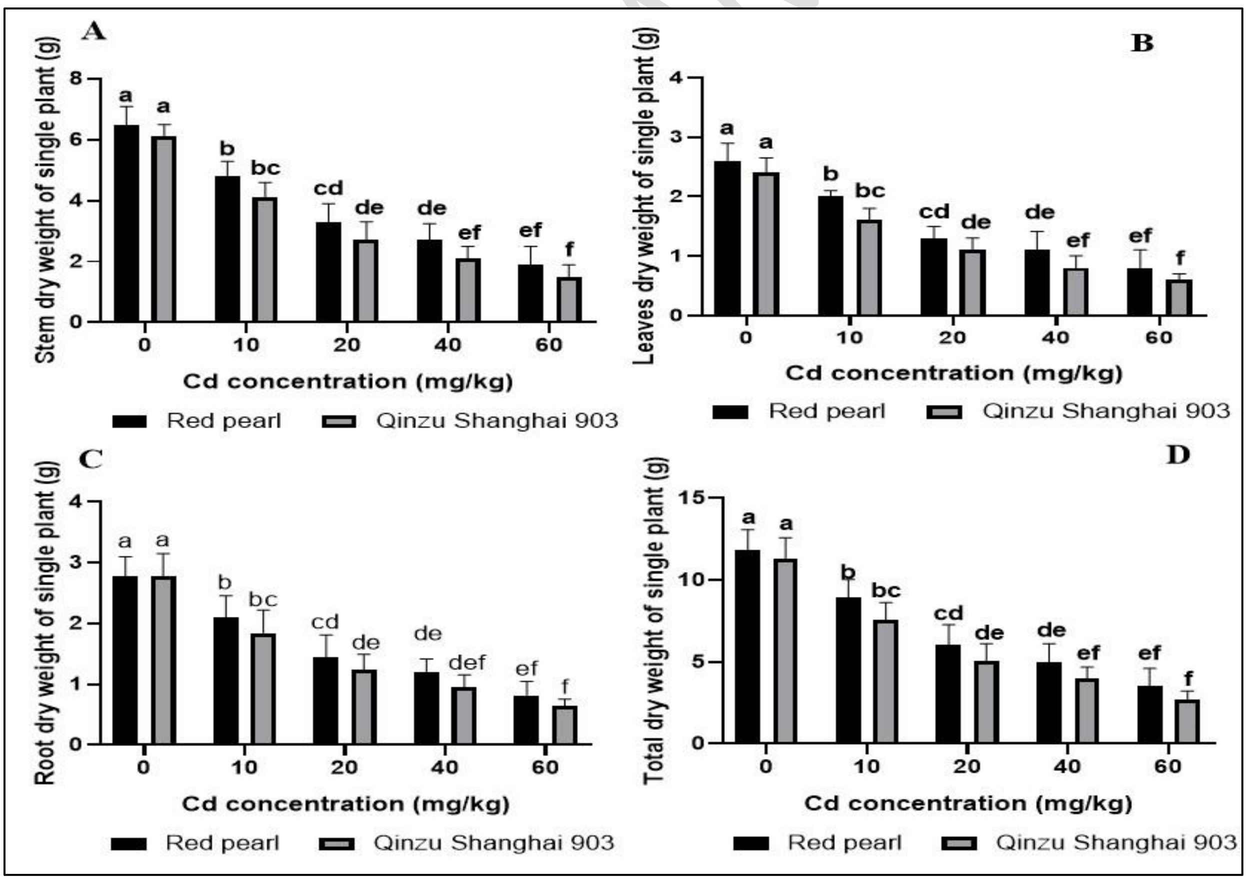

Figure 8. Effect of Cd treatment on dry weight of tomatoes. Different alphabets among the mean values denotes significant difference at 0.05 probability level. Bar at each value represents the

standard deviation of measured values (n=5).

3.9. Pearson Correlation between the Parameters

The Pearson correlation between the parameters were observed in **(Table 1)**. The table shows that the Seed germination Numbers SGN are highly significant with all the other parameters except Rl which seems significant at the level of 0.05. Similarly, SRS is also highly significant with all the parameters except leaf fresh weight where it is significant at the level of 0.05. Plant shoot height (SH) was observed non-significant with leaf fresh weight however highly significant with all the other parameters. Moreover, root length (RL) was highly significant with SRS, SH, ALN, SFW and RFW, significant with SGN, LAP, LFW, SDW and LDW and non-significant with RDW. Similarly, LAP was showed highly significant with all other parameter, except RL. It is also observed that ALN, SFW were found highly significant with all the other parameters. However, RFW was detected highly significant with all parameters. LFW was found significant with SH, RFW, SDW, RDW and LDW. Similarly, SDW was being significant with only RL and LFW and observed highly significant with other parameters. RDW and LDW were observed significant at RL and LFW and highly significant with other parameters after the pot experiment.

	SGN	**SRS**	**SH**	**RL**	**LAP**	**ALN**	**SFW**	**RFW**	**LFW**	**SDW**	**RDW**	**LDW**
SGN	1	0.78^{**}	0.44^{**}	0.35^{*}	0.91^{**}	0.92^{**}	0.87^{**}	0.83^{**}	0.38^{**}	0.90^{**}	0.86^{**}	0.90^{**}
SRS	0.78^{**}	1	0.47^{**}	0.36^{**}	0.73^{**}	0.76^{**}	0.76^{**}	0.71^{**}	0.32^{*}	0.73^{**}	0.71^{**}	0.73^{**}
SH	0.44^{**}	0.47^{**}	1	0.45^{**}	0.49^{**}	0.53^{**}	0.48^{**}	0.49^{**}	0.32*	0.37^{**}	0.37^{**}	0.38^{**}
RL	0.35^{*}	0.36^{**}	0.45^{**}	1	0.31^{*}	0.40^{**}	0.43^{**}	0.38^{**}	0.30^{*}	0.28^{*}	0.21	0.29^{*}
LAP	0.91^{**}	0.73^{**}	0.49^{**}	0.31^{*}	1	0.91^{**}	0.87^{**}	0.89^{**}	0.31^{*}	0.87^{**}	0.85^{**}	0.88^{**}
ALN	0.92^{**}	0.76^{**}	0.53^{**}	0.40^{**}	0.91^{**}	1	0.87^{**}	0.84^{**}	0.36^{**}	0.89^{**}	0.85^{**}	0.89^{**}
SFW	0.87^{**}	0.76^{**}	0.48^{**}	0.43^{**}	0.87^{**}	0.87^{**}	1	0.91^{**}	0.49^{**}	0.83^{**}	0.79^{**}	0.83^{**}
RFW	0.83^{**}	0.71^{**}	0.49^{**}	0.38^{**}	0.89^{**}	0.84^{**}	0.91^{**}	1	0.44*	0.82^{**}	0.76^{**}	0.83^{**}
LFW	0.38^{**}	0.32^{*}	0.32*	0.30^{*}	0.31^{*}	0.36^{**}	0.49^{**}	0.44*	1	0.36*	0.39*	0.44*
SDW	0.90^{**}	0.73^{**}	0.37^{**}	0.28^{*}	0.87^{**}	0.89^{**}	0.83^{**}	0.82^{**}	0.36*	1	0.97^{**}	0.99^{**}
RDW	0.86^{**}	0.71^{**}	0.37^{**}	0.21^{*}	0.85^{**}	0.85^{**}	0.79^{**}	0.76^{**}	0.39*	0.97^{**}	1	0.96^{**}
LDW	0.90^{**}	0.73^{**}	0.38^{**}	0.29^{*}	0.88^{**}	0.89^{**}	0.83^{**}	0.83^{**}	0.44*	0.99^{**}	0.96^{**}	1

Table 1: Pearson Correlation between the parameters

Note: Seed germination number (SGN), Seed survival rate (SRS), Shoot height (SH), Root length (RL), Leaf Area/plant (LAP), Average leaf number/plant (ALN), Shoot fresh weight (SFW), Root fresh weight (RFW), Leaf fresh weight (LFW), Shoot dry weight (SDW0, Root dry weight (RDW), Leaf dry weight (LDW). ****** Correlation is significant at the 0.01 level and *****Correlation is significant at the level 0.05 (2-tailed)

4. Discussion

Cadmium (Cd) is one of the most toxic non-essential heavy metals in agricultural soils and adversely affect plant growth, development, and productivity. In the present study, increasing Cd concentrations significantly reduced seed germination, seedling survival rate, shoot growth, root development, leaf production, leaf area, and biomass accumulation in both tomato cultivars, indicating a clear dose-dependent phytotoxic effect. Similarly, inhibitory effects of Cd on germination and seedling establishment have been reported in tomato and other vegetable crops, where Cd interferes with cellular metabolism, nutrient uptake, and hormonal regulation (Huybrechts *et al.*, 2019; El Rasafi *et al.*, 2022).

The Cd-induced oxidative stress elevated with Cd concentration may significantly reduce the seed germination and seedling survival, and indirectly rouses the over production of reactive oxygen species (ROS), which results the DNA damage and protein degradation (Gallego *et al.*, 2012). These physiological disturbances impair cellular viability and consequently reduce germination and survival rates. Similar results were observed by Ahmed et al. (2012) they suggested that Cd significantly decreased the Seed germinations, vigour index of different crops. Our study demonstrate that the increasing Cd concentration significantly increased the shoot growth of Qinzu Shanghai 903 comparing with red pearl, which showing that the Qinzu Shanghai 903 is more susceptible to Cd toxicity. Cd stress significantly condensed shoot elongation and ascribed to decreased cell division and cell expansion, which also declined nutrient translocation (Huybrechts *et al.*, 2019). Shahid et al. (2017) suggested that Cd interrupt the chlorophyll biosynthesis, thereby restraining carbon acclimatization required for shoot development. Similar results, were observed that the Cd stress significantly reduced the shoot height of different crops, tomato, peeper and eggplant seedling (Zeeshan *et al.*, 2021). It was also reported that the composite stress of Cd and Pb exacerbated the toxic effects on tomato seedlings and survival rate, thereby stunted plant growth (Zhou *et al.*, 2024; Tian *et al.,* 2018)

Toxic Cd enters plant cells through transport system involved in micronutrient uptake. In particular Cd uptake occurs though transmembrane carters involved in the uptake of Ca, Fe, Mg, Cu and Zn (Gallego *et al.*, 2012; Clemens, 2006; Roth *et al.*, 2006). Our results indicating that there was comparatively smaller reduction in root length relative to shoot height may indicate preferential Cd retention in the root system, thereby limiting Cd translocation to the shoots, it is observed that root sequestration as a plausible. Salt et al., (1995) observed that the Cd readily enters the roots through the cortical tissue and can reach xylem via symplastic pathway, forming complexes with organic acids. Similar results were obtained by Naciri et al. (2021) Cd and K interactive effect significantly decreased the morphological characters of tomato plants such as root length and shoot height under hydroponic conditions. Lux et al. (2011) suggest that the roots are the primary carriers of Cd uptake and accumulation towards plants, its regular function to restrict Cd translocation to aerials tissues through cell walls and vacuoles. It was also observed by Vijayaragavan et al. (Vijayaragavan *et al.*, 2011) increasing Cd concentration gradually decreased the root length of Cowpea plant. Cd significantly reduced the root length of Soyabean and Garlic (Xu *et al.*, 2008; Tian *et al.,* 2012). Reduction of root length in the pot experiment might be due to reduction in cell division, and the tolerance mechanism of partially alleviated Cd toxicity in root tissue.

The average leaf area and leaf number/plants was maximized at control; they are decreasing as increasing Cd concentration on both tomato cultivars in the soil. Our results showed that the Qinzu Shanghai 903 were observed more reduction in leaf area and leaf number per plant compare with the Red Pearl cultivars. The Qinzu Shanghai 903 is more susceptible to Cd induced photosynthetic and metabolic disturbances. Decreasing leaf area per plant at high Cd concentration may be due to low enzyme activity involved in CO_2 fixation. Similar results were taken up by Zhou and Qiu, (2005) they observed that Leaf expansion and root growth were significantly inhibited at high Cd concentrations. It was also documented that Leaf area significantly decreased after the higher application of Cd in tomato, Lettuce and Spinach plants (Huybrechts *et al.*, 2019). Reduced leaf production and expansion are common response to heavy metal stress and are closely associated with weakened photosynthetic activity and cellular growth processes (Gallego *et al.*, 2012).

Fresh and dry biomass accumulation of stems, leaves, roots and whole plants decreased significantly under Cd stress, particularly at 40 and 60 mg/kg Cd treatments. Biomass reduction is considered one of the most reliable indicators of heavy metal toxicity because it reflects the cumulative effects of impaired photosynthesis, restricted nutrient uptake, oxidative stress, and metabolic dysfunction (El Rasafi *et al.*, 2022)..

The results of this study reveal that the two tomato cultivars has shown a differential response against the Cd concentrations. Increasing Cd concentration significantly reduced the seed germination, survival rate percentage, shoot height, root length and fresh and dry biomass in both Red Pearl and Qinzu Shanghai 903 cultivars compare with control. The higher performance of Red Pearl compared with Qinzu Shanghai 903 is could be due to the strong defense mechanism against Cd induced stress. Genotypic difference in Cd tolerance has previously been attributed to enhanced antioxidant enzyme activities, improved osmotic adjustment, efficient sequestration of Cd ions into vacuoles, and restricted Cd translocation from roots in shoots (Sana *et al.*, 2024). Similar, cultivars dependent variation in Cd tolerance has been reported in tomato and other horticultural crops, emphasizing the importance of genetic factors in determining plant responses to heavy metal stress (Huybrechts *et al.*, 2019).

Therefore, Red Pearl may serve as a promising genetic resource for breeding and cultivation programs in Cd contaminated agricultural soils. Further studies focusing on Cd accumulation, antioxidant defense systems, nutrient homeostasis, and molecular responses are needed to elucidate the mechanism underlying Cd tolerance in tomato cultivars.

5. Conclusion

Cadmium toxicity and stress significantly inhibited seed germination, seedling survival, growth, leaf development, and biomass accumulation in both tomato cultivars, with adverse effects becoming more pronounced at higher Cd concentrations. Red Pearl exhibited greater tolerance than Qinzu Shanghai 903 by maintaining better growth and biomass under Cd stress. These findings indicate that Red Pearl represents a potential genetic resource for future breeding studies in Cd contaminated soils.

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