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Effect of cadmium on the physicochemical characteristics and bioactive c~~C~~ompounds of tomato (*Lycopersicon esculentum* Mill.)

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ABSTRACT:

The tomato (*Lycopersicon esculentum* ~~Mill.~~), a member of the Solanaceae family, is a widely cultivated vegetable known for its nutritional and therapeutic properties. Heavy metal (HM) contamination of soil has become a significant problem for the modern world as a result of the quick modernization and development of agricultural sectors as well as the growth of chemical industries. Low concentrations of heavy metals (HMs), which are high-density transition metals, can be hazardous. The purpose of this study was to explore the effects of **cadmium** (Cd) on some physicochemical characteristics and bioactive compounds of *Lycopersicon esculentum* ~~Mill. (Var. Pusa Ruby)~~. ~~Control plants were maintained separately~~ *L. esculentum* plants were grown in pots containing 3 kg of ~~air dried~~air-dried sandy loam soil and treated with different concentrations of cadmium at doses 25, 50, 75 and 100mg/kg. It was observed that there was a progressive increase in the total soluble solids (TSS) and Titrable acidity (TA), while the fruit pH decreased significantly on treatment with higher doses of Cd. Tomato plants showed declines in germination percentage, survival percentage, plant height, root length, average number of ~~fruit~~fruits, and fruit weight, all to ~~varying degrees~~varying degrees. By contrast, the ascorbic acid content, total phenols, flavonoids, total reducing sugars had rising effects under the influence of Cd toxicity. The lycopene content presented no standard response, decreasing and even increasing according to Cd concentrations.

Keywords: *Lycopersicon esculentum* Mill, cadmium, total soluble solids, lycopene, flavonoids.

1. INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is one of the most widely grown vegetables worldwide **(Shah *et al*., 2021),** with a present production of 186.8 million tons of fruits per year from a total farmed area of 5.1 million hectares **(FAOSTAT, 2020).** Tomatoes are annual herbaceous plants that belong to the Solanaceae Family **(Makhadmeh *et al.*, 2022)**. The tomato was first cultivated in the Andean region of South America, and it has since spread all over the world. Because of their special flavor, high nutritional value, and use in tomato paste, tomato juice, and other products, grown tomatoes have substantial economic worth. The highest amounts of yield in tons per ha in 2020 were reached in the USA (110.72), Morocco (94.64), Turkey (72.60), Brazil (72.24), Italy (62.63), and China (58.36) **(Nasreen et al. 2019)**. Tomatoes are a fantastic source of macronutrient composition and bioactive compounds. They are high in protein, fat, glucose, fructose, dietary fiber, vitamins, minerals, glutathione (GSH), carotenoids, and polyphenolic compounds, among other nutrients. In addition to supplying the body with nutrients, tomatoes also aid in a number of physiological processes, such as preventing obesity, treating constipation, lowering blood pressure, and lowering hyperlipidemia **(Yang *et al*., 2023)**.

Cadmium is a superlatively poisonous element that can easily penetrate the soil and is highly enriched in the crop, as cadmium in the soil is easily absorbed by the well-developed root system of tomatoes and accumulated cadmium contamination transfers to fruit. It is necessary to know the quality of tomatoes grown on lightly to moderately cadmium-contaminated soils to observe the possible effects of cadmium on the quality of tomatoes. Combined with the related studies on PSC (pollution-safe cultivar) strategy **(Yu et al., 2006; Zhu et al., 2006).** Cadmium contamination not only damages the structural diversity of soil microbial communities **(Deng et al., 2015)**, but it can also be harmful to soil quality **(Zhu et al. 2022)**, and adversely affect crop biomass and yield **(Yilmaz and Temizgül 2014)**. Soil microbial community composition can reflect soil fertility and soil quality, and when the bacterial community composition diversity increases, the overall soil conditions will improve **(Wu et al. 2020)**. Long-term Cd exposure, on the other hand, tends to reduce crop yield by reducing the weight and number of fruits, which is typically accompanied by a decrease in the number of flowers and fruit setting rate **(Hédiji *et al.*, 2010, 2015; Hussain *et al.*, 2017).** Furthermore, Cd accumulation in fruits causes stem-end yellowing in tomatoes **(Kumar *et al*., 2015),** resulting in aesthetic damage that may lower the commercial value of the crop.

Heavy metal (HM) contamination of soil has become a significant problem for the modern world as a result of the quick modernization and development of agricultural sectors as well as the growth of chemical industries **(Muhammad *et al*., 2023)**. Low concentrations of heavy metals (HMs), which are high-density transition metals, can be hazardous **(Thakare *et al.*, 2021).** Moreover, HMs retards plant growth by impeding a number of processes like photosynthesis, respiration, glucose metabolism, and water interactions **(Hossain and Bakhsh 2020)**. The aim of this study was to evaluate the effect of cadmium on physicochemical and bioactive parameters of *Lycopersicon esculentum* Mill. (Var. Pusa Ruby).

~~2.~~

~~3.~~2. MATERIAL AND METHODS

Experimental Site and Design:

The seeds of tomato (var. Pusa Ruby) were obtained from the Indian Institute of Vegetable Research, Varanasi (IIVR). Seeds with uniform size, color and weight were chosen for the experimental purpose. The soil used in the experiment was red soil 40%+sandy loam 60% in nature and the pH of the soils was 7.2. It contains major nutrients of 118 kg available N, 88 kg P and 106 kg k/ha and micronutrients of 21.89 mg available Cu, 219.11 mg Fe, 168 mg Mn, and 28.13 mg Zn/kg, cadmium was not available in this experimental soil. The cadmium chloride ($CdCl_2$ ½ H_2O) was used as a cadmium source.
The pot culture experiments were conducted in the green house of the Department of Botany, Glocal University, Uttar Pradesh. Tomato plants were grown in pots containing untreated soil (Control) and soil mixed with various levels of cadmium (viz., 25, 50, 75 and 100 mg/kg). The inner surfaces of pots were lined with a polythene sheet. Each pot contained 3 kg of air-dried soil. Six seeds were sown in each pot. All pots were watered to field capacity daily. Plants were thinned to a maximum of three per pot, after a week of germination. Each treatment including the control was replicated three times. Three plants from each replicate of the pot wereanalyzed for the various physicochemical and bioactive parameters.

Physical parameters

Percent Germination:

The number of seeds that germinated in each day (24 hours) was recorded. To calculate the percentage of germination, we used the formula:

Percent germination= number of seeds germinated/total number of seeds taken×100

Plant height: The height of the plant was measured using the tape rule and stated in centimeters. It was calculated from the plant’s base above ground to the last enlarged leaf at the growing tip.

Number of fruits/plantfruits: Each plant's total quantity of fruits was counted and recorded.

Fruit weight: An analytical balance with 0.0001 g precision was used to determine the fruit weight (PR-series, Ohaus, NJ, US).

Root length: Root length was measured using a cm scale.

Chemical parameters

The following traits were analyzed in tomato fruits:

PH: The pH was measured with a pH 700 Digital meter. PH buffers of 4.0, 7.0, and 10.2 were used to normalize the pH meter **(Kathiravan *et al*., 2014).**

Titratable acidity (TA): By titrating a sample of composted, homogenized powder with 0.01 N NaOH and phenolphthalein indicator (reported as % citric acid), the titrable acidity (TA) of the sample was ascertained.

Total Reducing Sugars: Miller's approach **(Miller, 1959)** was used to compute reducing sugars. Then, in 80 percent pure alcohol, 0.1 g of oven dried sample was homogenized. 3 mL DNSA was added to 3 mL of the aforesaid homogenate. DNSA was freshly produced by combining 200 mg of phenol crystals, 50 mg of Na2SO3, and 100 mL of 1% NaOH in a 100 mL flask at 4°C. After that, 1 mL of 40 percent KNaC4H4O6•4H2O was added. After that, it was cooled to 25°C, and the optical density was measured at 510 nm.

Total soluble solids (TSS): A refractometer was used to measure the TSS of tomatoes in triplicates (ATAGO-RX-7000). To measure the readings directly, a few drops of tomato juice were poured on the prism of the refractometer, and the mean values with standard deviation were expressed in terms of °Brix. **(Ranjitha *et al*., 2019)**

Total Chlorophyll and Carotenoid Content: Arnon's approach **(Arnon 1949)** and Maclachlan and Zalik's method were used to determine total chlorophyll and total carotenoid content **(Maclachlan and Zalik 1963).** Using 80 percent acetone, 1g of plant sample was macerated in an autoclaved and cooled motor and pestle. This was then transferred to a centrifuge tube and spun for 20–25 minutes at 12, 000 rpm at 4°C. Total chlorophyll absorbance was measured at 645 nm and 663 nm for total chlorophyll, while total carotenoids absorbance was measured at 480 nm and 510 nm for total carotenoids, respectively.

Bioactive parameters

Lycopene content: The low volume hexane extraction method was used to determine the lycopene concentration **(Davis *et al*., 2003; Fish *et al*., 2002).** In a vial, tomato puree (0.6 g) was combined with 5 mL acetone containing 0.05 percent butylated hydroxyl-toluene, 5 mL of 95 percent ethanol, and 10 mL of hexane and extracted for 15 minutes at 180 rpm on a shaker. After that, three mL of the mixture were added to deionized water and agitated for five minutes. The vial was set aside for 5 minutes. The absorbance of the supernatant was measured using a hexane blank at 503 nm. The lycopene content was calculated using the extract's absorbance at 503 nm.

Vitamin C content: The titration method was used to determine the vitamin C level **(Lam *et al*., 2004)**. Tomato puree (10 g) was filtered through a filter paper after being filled to a volume of 100 mL with a 5 percent HCl solution. The filtrate (10 mL) was titrated with the 0.001 N KIO3/KI solutions until a blue-black tint developed after five drops of the 1 percent starch solution were added. The sample extract was replaced with a 1 percent HCl solution as a control. The volume of 0.001 N KIO3/KI solution used for titration of the extract and the control were used to calculate the vitamin C concentration.

Total phenolic content: The total phenolic content was determined with certain modifications using the Folin–Ciocalteu reagent **(Teixeira et al., 2013).** Tomato puree (5 g) was diluted in 95 percent ethanol to a volume of 50 mL and extracted for 60 minutes. After that, the mixture was centrifuged for 10 minutes at 7000 g. The supernatant (0.2 mL) was treated with one milliliter of 10% Folin–Ciocalteu reagent, which was left for 5 minutes before being replaced with 1.2 milliliters of a 5% Na2CO3 solution**.** The absorbance was measured at 750 nm after 2 hours. Based on the Gallic acid concentration taken from the standard curve, the total phenolic content was estimated as Gallic acid equivalent (GAE).

Total flavonoids: 250 µL of methanolic extract were combined with 1.25 mL of distilled water and 75 µL of a 5% NaNO2 solution. 150 µL of a 10% AlCl3•H2O solution was added after 5 minutes and filtered for 6 minutes. The A510 was calculated after adding 500 µL of 1 M NaOH and 275 µL of distilled H2O to the mixture. The standard was quercetin (QU), and the results were given as mg of quercetin equivalents 100 g-1 FW **(Jia *et al*., 1999).**

Proline Content: Bates *et al* techniques ~~was~~were used to determine proline levels **(Bates *et al*., 1973)**. The first step was to macerate 0.5 g of plant material in 10 mL of 3 percent Sulphosalicylic acid. After that, it was centrifuged at 13,000 rpm for 15–20 minutes at 4°C. 2.0 mL of this extract was combined with 2 mL of ninhydrin reagent and 2 mL of glacial acetic acid. To stop the reaction, the reaction mixture was boiled at 100°C and then moved to ice. After that, 4 mL of toluene was added to the reaction mixture and agitated for 40–50 seconds. The red toluene layer was carefully removed, and an optical density of 520 nm was recorded. L-proline was used to create a standard curve.

Statistical analysis: The significant differences between the samples during the investigation were determined using a probability level of significance (p 0.05), and a simple t test with two samples assuming unequal variance was done using Microsoft Excel 2016. For the triplicate values, the findings of the experimental data are expressed in terms of the mean standard deviation.

~~4.~~3.RESULTS & DISCUSSION:

Effect of Cadmium (Cd) on germination rate:

The germination rate in the control samples was 96%. With increasing concentration, the percentage of germination decreased gradually. In 25, 50, 75, and 100 mg/kg treated samples, it was 93, 87, 78, and 67 percent, respectively. When compared to controls, the germination of the cadmium-treated sample was delayed. The percentage of seedlings that survived in the control samples was 91%. In all of the Cd-treated samples, the percentage of seedlings that survived declined steadily **(Table-1)**. It was 88% in 25 mg/kg, 83, 74, and 62 % in 50, 75, and 100 mg/kg treated samples, respectively. (**Fattahi *et al*., 2019**) found that increased Cd concentrations leads to increase in germination time and a decrease in germination percentage. The decrease in growth caused by cadmium stress could be due to tighter connections between pectin molecules in the cell wall, which is linked to a reduction in intercellular space. Injection of lignin into the cell wall under cadmium stress, on the other hand, causes the wall to harden and shrink **(Pál *et al*., 2006).** This stress also increases the generation of reactive oxygen species (ROS), which causes damage to the cell membrane and macromolecules **(Gonçalves *et al*., 2009),** as well as alterations in photosynthesis and dietary element absorption **(Pál *et al*., 2006).** This discovery is consistent with **Peters *et al.* (2000)** findings, which said that the first symptom of heavy metal toxicity is reduced plant development, which leads to poorer yields.

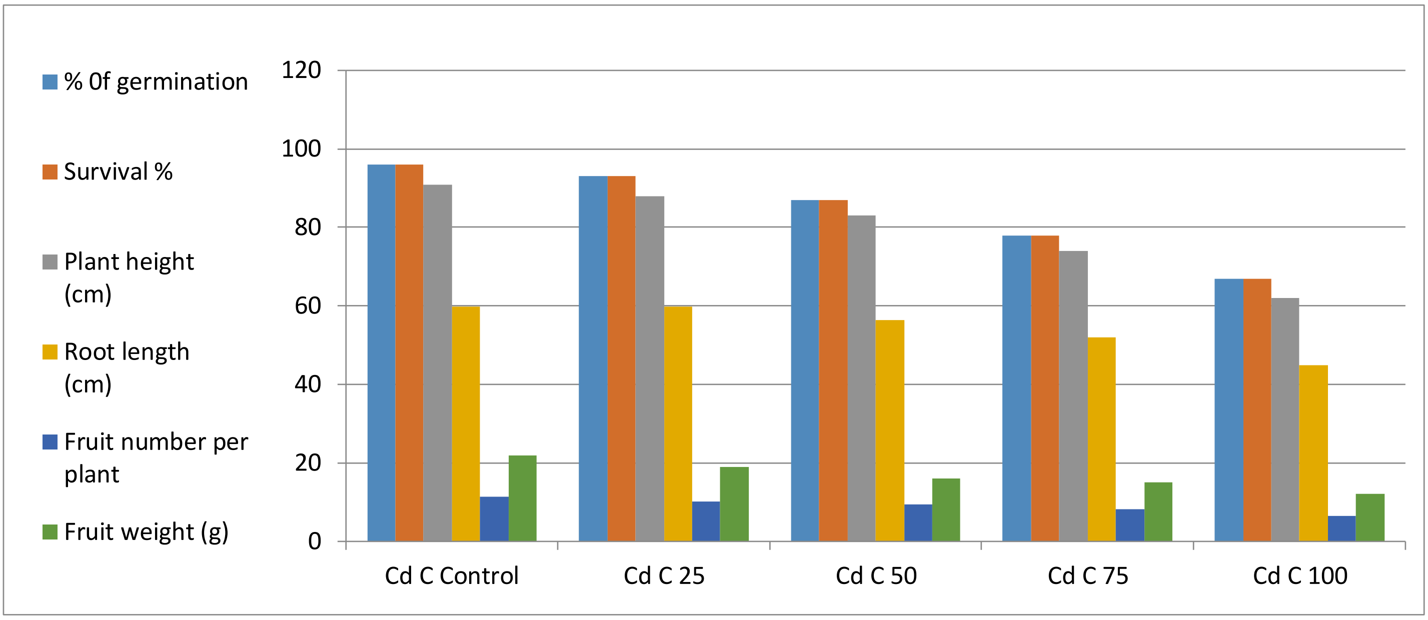
Effect of cadmium on physical parameters:

Plant height above ground level was measured in the field during flowering and fruiting. The average plant height in the control samples was 59.9 cm. In the cadmium 25 µM treated sample, there was no difference in plant height **(Table 1)**. The average height of the plant in 50, 75, and 100 mg/kg treated samples was 56.5, 52.1, and 44.8, respectively. In Cd 50 mg/kg treated soil, plants with increased branching and early ripening were observed. The average root length in the control samples was 11.3 cm. As the concentration of Cd was increased, the root length of all Cd treated samples decreased **(Table-1)**. A root system with an extended root system and a greater number of lateral roots was seen in control samples. A considerable reduction in fruit number and weight was reported in the current investigation **(Table1)**. The results are in line with the findings of **Shekar *et al*., (2011),** which found a decrease in tomato flower and fruit number as well as mean fruit weight in response to elevated Cd levels in the soil. Furthermore, Cd toxicity reduced LA in tomato plants **(Djebali *al*., 2005, 2010; Hayat *et al*., 2012),** which was attributed to a reduction in leaf growth as a result of smaller cell sizes and intercellular gaps **(Djebali *et al*., 2005).** Plants subjected to the highest Cd level (50 mm Cd) showed indications of leaf chlorosis, particularly on older leaves, as described in previous research on tomatoes in response to Cd stress **(Hasan *et al*., 2011; Lopez ~~Millan~~ *et al*., 2009).** The poisoning symptoms on older leaves are explained by the high mobile nature of Cd in plants **(Gallego *et al*., 2012).**

The number of fruits generated in the control group was 22. In Cd 25 mg/kg, a total of 19 fruits were developed. In Cd 25, 75, and 100 mg/kg treated samples, the number of fruits was 16, 15, and 12, respectively **(Table-1)**. Fruit development was earlier in the control samples than in the metal-treated ones. Fruits ripened early in 25 mg/kg treated samples, which was surprising. The average fruit weight in control samples was 58.29 g. Fruit weight declined with increasing concentration in all Cd treatments **(Table-1).** In addition to foliage chlorosis, stem-end-fruit yellowing was seen in this study, which is a common problem in fruit. Despite the fact that abiotic pressures reduced vegetable crop output, some qualitative parameters were reported to improve **(Rouphael *et al*., 2010, 2012).** In fact, in the presence of Cd in the nutrient solution, fruit quality indicators such as DM, TSS, TA, and firmness increased; this was owing to reduced water accumulation in the fruits, resulting in a higher concentration of various fruit solids (e.g., sugars and acids), as described under saline stress **(Flores *et al*.,2010).**

Effect of Cadmium (Cd) on plant height, root length, fruit number and fruit weight of *Lycopersicon esculentum*:

The interaction of heavy metal Cd in tomato plants (var. Pusa Ruby) has been introduced. In general, heavy metal Cd amendment reduces germination, survival rate, plant height, root length, average number of fruit, and fruit weight to variable degrees. The percentage of seeds that germinated reduced dramatically as the number of Cd levels increased **(Figure 1).** Cadmium exposure had a negative effect on tomato plant development indices in this study. A decrease in the seed germination percentage with increasing the concentration has been observed in all cadmium-treated samples. (**Munzurolu *et al*., 2008)** show that the inhibition of germination is related to the accumulation of abscisic acid in seeds. (**Kranner and Colville 2011)** claim that Cd hinders water uptake, inhibits seed germination and prolongs their dormancy at room temperature. As Cd concentrations in the growth medium grew, the features of seed germination (germination percentage (GP), germination rate (GR), and germination index (GI) decreased, which might be attributed to the presence of hazardous Cd in the germination medium. The generation of energy is necessary for seed germination, and its obstruction affects the synthesis of proteins, RNA, and DNA because energy is involved in these processes.



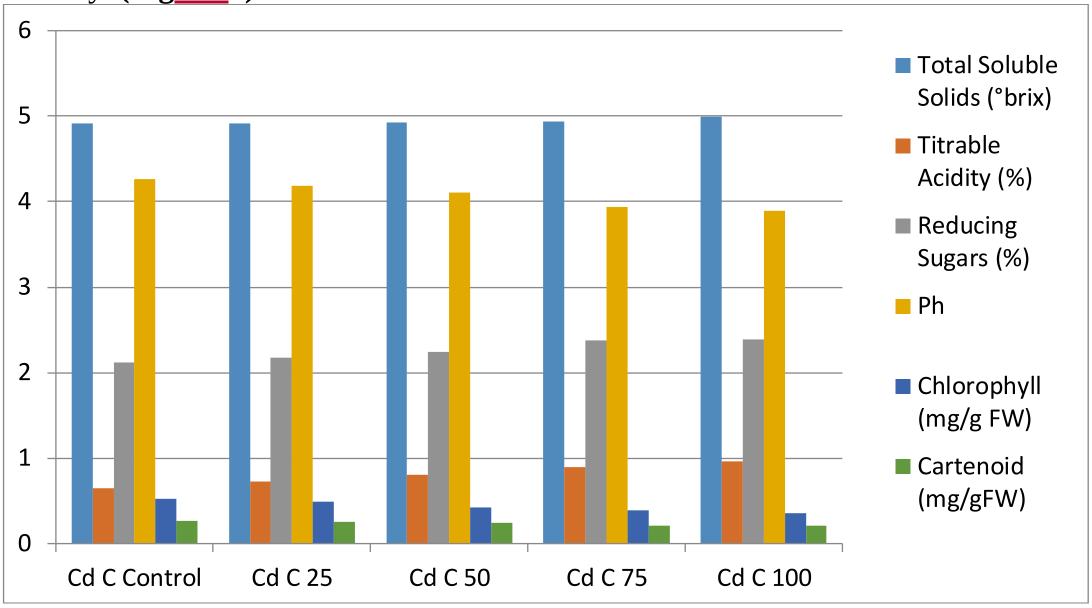
(Figure 1) Impact of varying Cd levels on germination, plant height, root length, fruit number and fruit weight of *Lycopersicon esculentum* Mill (Pusa Ruby)

Table1: Physical parameters of *Lycopersicon esculentum* Mill (Pusa Ruby)

cadmium concentration (mg/kg)	% 0f germination	Survival %	Plant height (cm)	Root length (cm)	Fruit Number (per plant)	Fruit weight (g)
Control	96	91	59.9	11.3	22	58.29
25	93	88	59.9	10.1	19	54.12
50	87	83	56.5	9.4	16	48.32
75	78	74	52.1	8.1	15	43.74
100	67	62	44.8	6.4	12	41.10

Effect of Cd levels on total soluble solids, Titrable acidity, reducing sugars, chlorophyll~~chlorophyl~~ and carotenoid:

The quantity of chlorophyll and carotene in control samples was 0.52 and 0.27 respectively. In a concentration-dependent way, the amount of chlorophyll and carotenoid content reduced dramatically. **(Figure 2)**



(Figure 2) Impact of varying Cd levels on total soluble solids, Titrable acidity, reducing sugars, ~~chlorophyll~~chlorophyll and carotenoid of *Lycopersicon esculentum* Mill (Pusa Ruby)

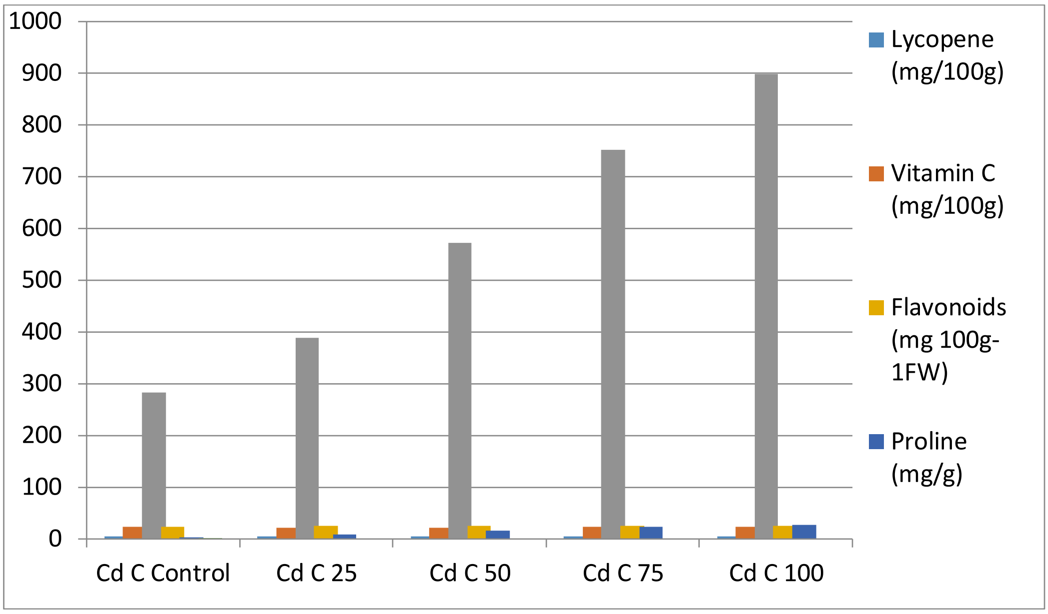
Effect of Cadmium (Cd) on chemical parameters:

Fruit PH fell at all Cd levels (25, 50, 75, and 100 mg/kg), but in a comparable way **(Table-2)**. At only 50 mg/kg, TSS content (°brix) increased, whereas Titrable acidity increased in a similar way **(Table-2).** Although the production of chlorophyll content and photosynthetic traits in leaves is lowered under diverse environmental conditions, overall chlorophyll levels in plants are nevertheless important stress indicators **(Abu-Shahba *et al.*, 2022)**. Chlorophyll content and photosynthetic properties in tomato leaves were severely reduced by Cd and Ni stress. Reduced production of these photosynthetic pigments revealed oxidative stress in leaves under Cd and Ni poisoning **(Abu-Shahba *et al.*, 2022; Nasibi *et al.*, 2013)**. Tomato leaves with higher Cd and Ni concentrations may have experienced more oxidative stress, which led to a decline in chlorophyll exposed to HM **(Badawy *et al.*, 2022)**. *Urginea maritima*, a rare species subjected to heavy metals (Cd, Pb, Al, and Cr), showed a drop in total chlorophyll and carotenoid content, affecting the entire photosynthetic process (**Houri *et al.*, 2019)**. Cucumber plants were shown to have decreased levels of photosynthetic pigments, particularly chlorophyll a, when exposed to Cd **(Dresler *et al.*, 2019).** It was also discovered that when *Petunia hybrid* AL. and *Nicotiana alata* L. were grown under different metal stressed conditions such as Cd, Cr, Ni, Cu, and Pb, total chlorophyll, chlorophyll a and b, and total carotenoids were depleted, which was attributed to the increased accumulation of heavy metals in different plant parts **(Khan *et al.*, 2019).** However, carotenoids' primary function is to protect plant cells by acting as an antioxidant molecule that prevents oxidative damage caused by effective ROS scavenging **(You and Chan 2015)**. In *Xanthium strumarium*, several heavy metals such as Pb, Ni, Cd, and Zn caused a decrease in photosynthetic pigments such as total chlorophyll concentration **(Khalid *et al.*, 2019)**. The degradation of enzymes involved in pigment synthesis, which eventually leads to its reduction, is directly connected to the depletion of plant pigments due to Cd toxicity in the current study.

Cadmium concentration (mg/kg)	Total soluble solids (°brix)	Titrable Acidity (%)	Reducing sugars (%)	PH	Chlorophyll (mg/g FW)	carotenoid (mg/gFW)
Control	4.92	0.65	2.12	4.26	0.52	0.27
25	4.92	0.73	2.17	4.18	0.49	0.26
50	4.93	0.81	2.24	4.11	0.42	0.24
75	4.94	0.89	2.38	3.94	0.39	0.21
100	4.99	0.96	2.39	3.89	0.36	0.21

Table 2: Chemical parameters of *Lycopersicon esculentum* Mill (Pusa Ruby)

Cadmium concentrations showed a growing influence on ascorbic acid levels; however, the effects were only significant at low Cd doses (25 and 50 mg/kg). In comparison to the control, the levels of total phenols and flavonoids were up-regulated in L. esculentum plants under the influence of Cd toxicity. **(Figure 3 ~~3~~).** The levels of phenolic substances such as total phenols and flavonoids were observed to be up-regulated in plants growing in Cd-saturated soils in the current study. Phenolics, as a secondary metabolite, are prevalent in plants and serve as pigments, signalling molecules, and antioxidants in order to protect them from stress **(Santos-Sanchez *et al.*, 2019)**. It has been claimed that phenolic compounds, such as flavonoids, operate as a potent protective agent against transition metals that form hydroxyl ions via Fenton's reaction, such as Fe, Zn, Cu, Cd, and Ni **(Williams *et al.*, 2004)**. According to a study published in Al-stressed *Zea mays*, root exudates included higher quantities of phenolic compounds such as catechin and quercetin **(Michalak 2006)**. Furthermore, when red cabbage seedlings were subjected to Cu toxicity, they accumulated more phenolic compounds, which were attributable to increased PAL activity **(Posmyk *et al.*, 2009).** Our findings support **(Chen *et al.*, 2019)** findings in *Kandelia obovata* under Cd and Zn toxicity, in which they found a greater accumulation of total phenols in plant tissues under metal-stressed circumstances. Phenols act as chelators and participate in plant defense mechanisms in response to environmental stresses, which is why their levels were elevated during metal toxicity **(Chen *et al.*, 2019)**. Furthermore, plants develop larger amounts of Phenolics to effectively scavenge metal ions or reactive oxygen species (ROS), indicating that they are the best detoxifying agents **(Manquian-Cerda *et al.*, 2016).** Similarly, when *Digitalis lanata* was treated with Cu, the production of flavonoids increased **(Bota and Deliu 2011).** The modification of anthocyanin synthesis was also observed in Ni-stressed L. sativa plants **(Hawrylak *et al.*, 2007)**.



(Figure 33) Impact of varying Cd levels on lycopene, vitamin c, flavonoids, and proline of *Lycopersicon esculentum* Mill (Pusa Ruby).

Effect of Cadmium (Cd) on bioactive parameters:

Cd concentrations had no effect on color characteristics or lycopene concentrations in the fruit mesocarp. In comparison to the control group, Cd poisoning resulted in greater levels of total reducing sugars. **(Table-3).** The results showed that the minimum proline level was in control (2.224), but that as the cadmium concentration increased (25, 50, 75, 100 mg/kg), the proline content increased significantly. **(Table-3)** The current study looked at how Cd treatment affected the amounts of different secondary metabolites, including reducing sugars and proline, in plants. Increased amounts of proline have been observed in tomato and pea plants subjected to Cd toxicity, which is similar to our findings **(Ahmad *et al.*, 2018; Jan *et al.*, 2018).** Proline plays a key role in determining a plant's ability to withstand environmental stress. By reducing ROS levels, stabilizing enzymes that are affected by stress, and buffering cellular redox, it aids plants in avoiding environmental stress **(Sofy *et al.*, 2021).** Proline and other osmolytes are said to protect the body by balancing water and nutrients, stabilizing membrane structures, and scavenging reactive oxygen species (ROS) **(Ahmad *et al.*, 2018; Jan *et al.*,2018; Hasanuzzaman *et al.*, 2019)** . Many additional physiological activities, including osmotic balance, leaf expansion, photosynthesis, and many other biochemical events, rely on osmoprotectantsosmoprotectants **(Nahar *et al.*, 2016). (Shen *et al.*, 2019)** found that seedlings of *K. obovata* treated with Zn, Pb, and Cu accumulated more soluble sugars and had a higher proline content. According to their findings, increased levels of these osmolytes are likely related to their ability to act as scavenging agents during metal toxicity, balancing oxidative stress and lipid peroxidation in plant cells **(Shen *et al.*, 2019).** Furthermore, under the influence of certain heavy metals such as Ni, Cd, Cu, and Pb, the free proline concentration as well as soluble sugars were increased in *Capsicum annuum* L **(Desoky *et al.*, 2019)**. Proline is involved in the detoxification of metal ions and reactive oxygen species (ROS) via chelation, as well as the quenching of singlet oxygen species **(Howladar 2014).** Sugars like carbohydrates, trehalose, and reducing sugars regulate osmotic homeostasis through regulating gene expression of enzymes engaged in various metabolic processes, defensive actions, energy flow, leaf water potential, and a variety of other storage functions **(Herbers and SonnewaldSonnewald 1998; Babaeian *et al.*, 2011).** Proline buildup in plant tissues is most likely caused by changes in the activity of enzymes involved in proline biosynthesis. Sugars such as carbohydrates and reducing sugars were also found to accumulate in metal-stressed *O. sativa*, most likely due to a disruption in the sugar transport route through xylem, which elevated their levels at specific places **(Verma and Dubey 2001)**.

Cadmium concentration 0 (mg/kg)	Lycopene (mg/100g)	vitamin c (mg/100g)	Flavonoids (mg 100g-1 FW)	Phenolic content (mgGAE/100g))	Proline (mg/g)
Control	4.88	22.71	283	24.12	2.224
25	4.89	21.99	389	24.64	9.127
50	4.87	22.42	573	24.98	16.636
75	4.87	22.91	752	25.18	22.734
100	4.91	23.67	899	25.29	26.894

Table 3: Bioactive parameters of *Lycopersicon esculentum* Mill (Pusa Ruby).

5.

6.4. CONCLUSION

In conclusion, the global safety risk posed by cadmium has escalated to exceedingly dangerous and concerning levels, particularly in light of technological advancements. Plants are primary producers, and high concentrations of Cd in them impede their growth and photosynthetic activity, lowering agricultural output. Furthermore, through its effects on enzymes and early development stages, Cd appears to have a significant negative impact on germination. These effects include primary carbon metabolism, oxidative stress response mechanisms, and the formation of chlorosis particlarly in the youngest leaves, as well as a decrease in growth and yield. On the other hand, bioremediation techniques used to decontaminate Cd, comprehension of Cd accumulator plant mechanisms, and the selection of resistant species may provide environmentally and financially feasible options for remediating Cd-contaminated soil.

Tables and Figures:

7.5. LITERATURE CITED

1. Abu-Shahba, M.S.; Mansour, M.M.; Mohamed, H.I.; Sofy, M.R. (2022) Effect of biosorptive removal of cadmium ions from hydroponic solution containing indigenous garlic peel and mercerized garlic peel on lettuce productivity. Sci. Horti. 293, 110727.
2. Ahmad, P., Ahanger, M.A., Alyemeni, M.N., Wijaya, L. and Alam, P. (2018) exogenous application of nitric oxide modulates osmolyte metabolism, antioxidants, and enzymes of ascorbate-glutathione cycle and promotes growth under cadmium stress in tomato. Protoplasma. 255: 79–93.
3. Arnon, D.I. (1949) Copper enzymes in isolated chloroplasts, polyphenoxidase in Beta vulgaris. Plant Physiol. 24: 1–15.
4. Babaeian, M., Tavassoli, A., Ghanbari, A., Esmaeilian, Y. and Fahimifard, M. (2011) Effects of foliar micronutrient application on osmotic adjustments, grain yield and yield Components in sunflower (Alstar cultivar) under water stress at three stages. Afr. J. Agric. Res. 6: 1204–1208.
5. Badawy, I.H.; Hmed, A.A.; Sofy, M.R.; Al-Mokadem, A.Z. (2022) Alleviation of Cadmium and Nickel Toxicity and Phyto-Stimulation of Tomato Plant L. by Endophytic Micrococcus luteus and Enterobacter cloacae. Plants. 11, 2018.

6. Bates, L.S., Waldren, R.P. and Teare, I.D. (1973) Rapid determination of free proline for water-stress studies. Plant Soil 39: 205–207.
7. Bota, C. and Deliu, C. (2011) the effect of copper sulphate on the production of flavonoids in Digitalis lanata cell cultures. Farmacia 59: 113–118.
8. Chen, S., Wang, Q., Lu, H., Li, J., Yang, D., Liu, J. and Yan, C. (2019) Phenolic metabolism and related heavy metal tolerance mechanism in Kandelia Obovataunder Cd and Zn stress. Ecotoxicol. Environ. Saf. 169: 134–143.
9. Davis, A.R., Fish, W.W. and Perkins-Veazie, P. (2003) A Rapid Spectro photometric Method for Analyzing Lycopene Content in Tomato and Tomato Products. Postharvest Biol. Tec. 28: 425–430.
10. Deng, L.; Zeng, G.; Fan, C.; Lu, L.; Chen, X.; Chen, M.; Wu, H.; He, X.; He, Y. (2015) Response of rhizosphere microbial community structure and diversity to heavy metal co-pollution in arable soil. Appl. Microbiol. Biotechnol. 99, 8259–8269.
11. Desoky, E.-S.M., Elrys, A.S. and Rady, M.M. (2019) Integrative moringa and licorice extracts application improves Capsicum annuum fruit yield and declines its contaminant contents on a heavy metals-contaminated saline soil. Ecotoxicol. Environ. Saf. 169: 50–60.
12. Djebali, W., Hediji, H., Abbes, Z., Barhoumi, Z., Yaakoubi, H., Zoghlami, L.B. and Chaïbi, W. (2010). Aspects on growth and anatomy of internodes and leaves of cadmium-treated *Solanum lycopersicum* L. plants. J.Biol . . . Thessalonica 13:75–84.
13. Djebali, W., Zarrouk, M., Brouquisse, R., ElKahoui, S., Limam, F., Ghorbel, M.H and Chaïbi, W (2005) Ultrastructure and lipid alterations induced by cadmium in tomato (Lycopersicon esculentum) chloroplast membranes. Plant Biol. 7:258–368.
14. Dresler, S., Hawrylak-Nowak, B., Kovácˇik, J., Pochwatka, M., Hanaka, A., Strzemski, M., Sowa, I. and Wójciak-Kosior, M. (2019) Allantoin attenuates cadmium-induced toxicity in cucumber plants. Ecotoxicol. Environ. Saf. 170: 120–126.
15. FAOSTAT. Crops and Livestock Products in 2020. Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 20 September 2022).
16. Fattahi, B., Arzani, K., Souri, M. K., Barzegar, M. (2019) Effects of cadmium and lead on seed germination, morphological traits, and essential oil composition of sweet basil (*Ocimum basilicum* L.). – Industrial Crops & Products. 138: 111584.
17. Fish, W.W., Perkins- Veazie, P. and Collins, J.K. (2002) A Quantitative Assay for Lycopene That Utilizes Reduced Volumes of Organic Solvents. J. Food Compost. Anal. 2 15: 309–317.
18. Flores, F.B., Sanchez-Bel, P., Estan, M.T., Martinez-Rodriguez, M.M., Moyano, E., Morales, B., Campos, J.F., Garcia-Abellan, J.O., Egea, M.I., Fernandez-Garcia, N., Romojaro, F. and Bolar M.C (2010).The effectiveness of grafting to improve tomato fruit quality. Sci. Hort. 125: 211–217
19. Gallego, S.M., Pena, L.B., Barcia, R.A., Azpilicueta, C.E. Iannone, M.F., Rosales, E.P., Zawoznik, M.S., Groppa, M.D. and Benavides, M.P. (2012) Unravelling cadmium toxicity and tolerance in plants: Insight into regulatory mechanisms. Environ. Expt. Bot. 83:33–46.0
20. Gonçalves, GF., Antes, FG., Maldaner, J., Pereira, LB., Tabaldi ,LA., Rauber, R., Rossato, LV., Bisognin, DA., Dressler, VL., Flores, EMDM. And Nicoloso, FT. (2009) Cadmium and mineral nutrient accumulation in potato plantlets grown under cadmium stress in two different experimental culture conditions. Plant Physiol Biochem. 47:814–821.
21. Hasan, S.A., Hayat, SH. and Ahmad, A. (2011). Brassino steroids protect photosynthetic machinery against the cadmium induced oxidative stress in two tomato cultivars. Chemosphere. 84:1446–1451.

22. Hasanuzzaman, M., Alam, M.M., Nahar, K., Mohsin, S.M., Bhuyan, M.B., Parvin, K., Hawrylak-Nowak, B. and Fujita, M. (2019) Silicon-induced antioxidant defense and methyl glyoxal detoxification works coordinately in alleviating nickel toxicity in Oryza sativa L. Ecotoxicology 28: 261–276.
23. Hawrylak, B., Matraszek, R. and Szyman´ska, M. (2007) Response of Lettuce (Lactuca Sativa L.) to Selenium in Nutrient Solution Contaminated with Nickel. Veg. Crop. Res. Bull. 67: 63–70.
24. Hayat, S., Alyemenia, M.N. and Hasan, S.A. (2012) Foliar spray of Brassino steroid enhances yield and quality of Solanum lycopersicum under cadmium stress. Saudi J.Biol.Sci.19:325–335.
25. Hédiji, H., Djebali, W., Belkadhi, A., Cabasson, C., Moing, A., Rolin, D. and Chaïbi, W. (2015) Impact of long- term cadmium exposure on mineral content of Solanum lycopersicum plants: Consequences on fruit production. South African Journal of Botany, 97: 176–181.
26. Hédiji, H., Djebali, W., Cabasson, C., Maucourt, M., Baldet, P., Bertrand, A. and Gallusci, P. (2010) Effects of long- term cadmium exposure on growth and metabolomic profile of tomato plants. Ecotoxicology and Environmental Safety, 73: 1965–1974.
27. Herbers, K. and Sonnewald, U. (1998) Altered gene expression brought about by inter- and intracellularly formed hexoses and its possible implications for plant-pathogen interactions. J. Plant Res. 111: 323–328.
28. Hossain, M.J.; Bakhsh, A. (2020) Development and applications of transplastomic plants; a way towards eco-friendly agriculture. In Environment, Climate, Plant and Vegetation Growth; Springer: Berlin, Germany, pp. 285–322.
29. Houri, T., Khairallah, Y., Zahab, A.A., Osta, B., Romanos, D. and Haddad, G. (2019) Heavy Metals Accumulation Effects on The Photosynthetic Performance of Geophytes in Mediterranean Reserve. J. King Saud Univ. Sci.
30. Howladar, S. M. (2014) A novel Moringao leifera leaf extract canmiti gate the stress effects of salinity and cadmiumin bean (Phaseolus vulgaris L.) plants. Ecotoxicol. Environ. Saf. 100: 69–75.
31. Hussain, I., Ashraf, M. A., Rasheed, R., Iqbal, M., Ibrahim, M., Zahid, T. and Saeed, F. (2017). Cadmium- induced perturbations in growth, oxidative defense system, catalase gene expression and fruit quality in tomato. International Journal of Agriculture and Biology, 19: 61–68.
32. Jan, S., Alyemeni, M.N., Wijaya, L., Alam, P., Siddique, K. H. and Ahmad, P. (2018) Interactive effect of 24-epibrassinolide and silicon alleviates cadmium stress via the modulation of antioxidant defense and glyoxalase systems and macronutrient content in Pisum sativum L. seedlings. BMC Plant Biol. 18.
33. Jia, Q., Hong, MF. And Minter, DP. (1999). A novel iridoid from Picrorhiza kurroa. J Nat Prod. 62:901–903.
34. Kathiravan, T., Nadanasabapathi, S. and Kumar, R. (2014). Standardization of process condition in batch thermal pasteurization and its effect on antioxidant, pigment and microbial inactivation of ready to drink (RTD) beetroot (Beta vulgaris L.) juice. International Food Research Journal. 21(4): 1305-1312.
35. Khalid, N.; Noman, A.; Aqeel, M.; Masood, A.; Tufail, A. (2019) Phyto remediation potential of Xanthium strumarium for heavy metals contaminated soils at road sides. Int. Environ. Sci. Technol. 16, 2091–2100.
36. Khan, A.H.A., Nawaz, I., Yousaf, S., Cheema, A.S. and Iqbal, M. (2019) Soil amendments enhanced the growth of Nicotiana alata L. And Petunia hydrida L. By stabilizing heavy metals from waste water. J.Environ. Manag. 242: 46–55.

37. Kranner, I and Colville, L. (2011): Metals and seeds: biochemical and molecular implications and their significance for seed germination. – Environ. Exp. Bot. 72: 93-105
38. Kumar, P., Edelstein, M., Cardarelli, M., Ferri, E., & Colla, G. (2015). Grafting affects growth, yield, nutrient uptake, and partitioning under cadmium stress in tomato. HortScience. 50: 1654–1661
39. Lam, T.B., Nguyet, T.N.M. and Thu, D.T.N. (2004) Food Biochemistry Experiment; Ho Chi Minh City National University Publishing: Ho Chi Minh City, Vietnam, 2004.
40. Lopez-Millan, A.F., Sagardoy, R., Solanas, M A., Abad´ıa. And J. Abad´ıa. J (2009). Cadmium toxicity in tomato (Lycopersicon esculentum) plants grown in hydroponics. Environ. Expt. Bot. 65:376–385.
41. Maclachlan, S. and Zalik, S. (1963) Plastid structure, chlorophyll concentration and free amino acid composition of a chlorophyll mutant of barley. Can. J. Bot. 41: 1053–1062.
42. Makhadmeh, I.; Albalasmeh, A.A.; Ali, M.; Thabet, S.G.; Darabseh, W.A.; Jaradat, S.; Alqudah, A.M. (2022) Molecular Characterization of Tomato (Solanum lycopersicum L.) Accessions under Drought Stress. Horticulturae. 8, 600.
43. Manquián-Cerda, K., Escudey, M., Zúñiga, G., Arancibia-Miranda, N., Molina, M. and Cruces, E. (2016) Effect of cadmium on phenolic compounds, antioxidant enzyme activity and oxidative stress in blueberry (Vaccinium corymbosum L.) plantlets grown in vitro. Ecotoxicol. Environ. Saf. 133: 316–326.
44. Michalak, A. (2006) Phenolic compounds and their antioxidant activity in plants growing under heavy metal stress. Pol. J. Environ. Stud.15: 523–530.
45. Miller, G.L. (1959) Use of Di nitro salicylic Acid Reagent for Determination of Reducing Sugar. Anal. Chem. 31: 426–428.
46. Muhammad, L.; Salahuddin; Khan, A.; Zhou, Y.; He, M.; Alrefaei, A.F.; Khan, M.; Ali, S. (2023) Physiological and Ultrastructural Changes in Dendranthema morifolium Cultivars Exposed to Different Cadmium Stress Conditions. Agriculture. 13, 317.
47. Munzuroğlu, O., Zengin, F. K., Yahyagil, Z. (2008) The abscisic acid levels of wheat (*Triticuma estivum* L. Cv. Cakmak 79) seeds that were germinated under heavy metal (Hg++, Cd++, Cu++) stress. – J. Fac. Pharm. Gazi. 21: 1-7.
48. Nahar, K., Hasanuzzaman, M., Alam, M.M., Rahman, A., Suzuki, T. and Fujita, M. (2016) Polyamine and nitric oxide crosstalk: Antagonistic effects on cadmium toxicity in mung bean plants through up regulating the metal detoxification, antioxidant defense and methyl glyoxal detoxification systems. Ecotoxicol. Environ. Saf. 126, 245–255.
49. Nasibi, F.; Heidari, T.; Asrar, Z.; Mansoori, H. (2013) Effect of arginine pre-treatment on nickel accumulation and alleviation of the oxidative stress in hyoscyamus niger. J. Soil Sci. Plant Nutr. 13, 680–689.
50. Nasreen, N.; Ikramullah, K.; Bakhtiar, G.; Gohar, A.; Farooq, J.; Nawaz, J.; Muhammad, S. (2019) Response of tomato (Lycopersicon esculentum Mill.) growth to different phosphorous levels and sowing dates. Acta Ecol. Sin. 39, 30–35.
51. Pál, M., Horváth, E., Janda, T., Páldi, E. and Szalai, G. (2006) Physiological changes and defense mechanisms induced by cadmium stress in maize. J Plant Nutr Soil Sci. 169:239–246.
52. Peters, JB., Kelling, KA. And Combs, SM. (2000). Using plant analysis as a diagnostic tool. J Soil Sci. 6:1–6.
53. Posmyk, M.M., Bałabusta, M., Wieczorek, M., Sliwinska, E. and Janas, K.M. (2009) Melatonin applied to cucumber (Cucumis sativus L.) seeds improves germination during chilling stress. J. Pineal Res. 46: 214–223.
54. Ranjitha, Gracy, TK., Gupta, V. and Mahendran R. (2019) Influence of low-pressure non thermal dielectric barrier discharge plasma on chlorpyrifos reduction in tomatoes. Journal of Food Process Engineering.

55. Rouphael, Y., D. Schwarz, A., Krumbein. And G. Colla. (2010) Impact of grafting on product quality of fruit vegetables. Sci. Hort. 127:172–179.
56. Rouphael, Y., M. Cardarelli., E. Rea. And G. Colla. (2012) Improving melon and cucumber photosynthetic activity, mineral composition, and growth performance under salinity stress by grafting onto Cucurbita hybrid rootstocks. Photosynthetica 50:180–188.
57. Santos-Sánchez, N.F., Salas-Coronado, R., Hernández-Carlos, B. and Villanueva-Cañongo, C. (2019) Shikimic Acid Pathway in Biosynthesis of Phenolic Compounds. In Plant Physiological Aspects of Phenolic Compounds; Intech Open: London, UK.
58. Shah, K.K., Modi, B., Lamsal, B., Shrestha, J., & Aryal, S. P. (2021). Bioactive compounds in tomato and their roles in disease prevention. Fundamental and Applied Agriculture, 6(2), 210–224.
59. Shekar, C.C., Sammaiah, D., Rambabuand, M. and K.J. Reddy. (2011) Effect of cadmium on tomato growth and yield attributes. J. Microbiol. Biotech. Res. 1:109–112.
60. Shen, X., Li, R., Chai, M., Cheng, S., Niu, Z. and Qiu, G.Y. (2019) Interactive effects of single, binary and trinary trace metals (lead, zinc and copper)on the physiological responses of Kandelia obovata seedlings. Environ. Geochem. Health 41, 135–148.
61. Sofy, A.R.; Sofy, M.R.; Hmed, A.A.; Dawoud, R.A.; Alnaggar, A.E.-A.M.; Soliman, A.M.; El-Dougdoug, N.K. (2021) Ameliorating the adverse effects of tomato mosaic tobamovirus infecting tomato plants in Egypt by boosting immunity in tomato plants using zinc oxide nanoparticles. Molecules. 26, 1337.
62. Teixeira, B., Marques, A., Ramos, C., Serrano, C., Matos, O., Neng, N.R., Nogueira, J.M.F., Saraiva, J.A. and Nunes, M.L. (2013) Chemical Composition and Bioactivity of Different Oregano (*Origanum Vulgare*) Extracts and Essential Oil: Composition and Bioactivity of Oregano Products. J. Sci. Food Agric. 93: 2707–2714.
63. Thakare, M.; Sarma, H.; Datar, S.; Roy, A.; Pawar, P.; Gupta, K.; Pandit, S.; Prasad, R. (2021) Understanding the holistic approach to plant-microbe remediation technologies for removing heavy metals and radionuclides from soil. Curr. Res. Biotechnol. 3, 84–98.
64. Verma, S. and Dubey, R. (2001) Effect of cadmium on soluble sugars and enzymes of their metabolism in rice. Biol. Plant. 44: 117–123.
65. Williams, R.J. and Spencer, J.P.E. (2004) Rice-Evans, C. Flavonoids: Antioxidants or signalling molecules? Free Radic. Biol. Med. 36: 838–849.
66. Wu, X.; He, Y.; Huang, Z.; Zhang, D.; Zheng, H.; Ding, J. (2020) Effects of different treatment levels of sewage on bacterial community structure and enzyme activity. J. Agro-Environ. Sci. 39, 2026–2035.
67. Yang, Z.; Li, W.; Li, D.; Chan, A.S.C. (2023) Evaluation of Nutritional Compositions, Bioactive Components, and Antioxidant Activity of Three Cherry Tomato Varieties. Agronomy. 13, 637.
68. Yilmaz, D.; Temizgül, A. (2014) Determination of Heavy-Metal Concentration with Chlorophyll Contents of Wheat (*Triticum aestivum*) Exposed to Municipal Sewage Sludge Doses. Commun. Soil Sci. Plant Anal. 45, 2754–2766.
69. You, J. and Chan, Z. (2015) ROS Regulation during Abiotic Stress Responses in Crop Plants. Front. Plant Sci. 6.
70. Yu, H.; Wang, J.; Fang, W.; Yuan, J.; Yang, Z. (2006) Cadmium accumulation in different rice cultivars and screening for pollution-safe cultivars of rice. Sci. Total Environ. 370, 302–309.
71. Zhu, F.; Fang, W.; Yang, Z. (2006) Variations of Cd absorption and accumulation of 36 Lycopersicon esculentum cultivars. Acta Ecol. Sin. 26, 4071–4081.

72. Zhu, Y.; Zhong, M.; Li, W.; Qiu, Y.; Wang, H.; Lv, X.(2022) Cotton straw biochar and Bacillus compound biofertilizer decreased Cd migration in alkaline soil: Insights from relationship between soil key metabolites and key bacteria. Ecotoxicol. Env. Saf. 232, 113293.