Foliar Application of Silicon-based Nanoparticles Improve the Adaptability of Maize (Zea mays L.) in Cadmium Contaminated Soils

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Abstract

Heavy metals (HMs) are a serious threat all over the world and show a different impact on plants and human life by contaminating the plant. Among all HMs cadmium (Cd) is one of the serious metals that are absorbed by the roots of the plant and are transported from root to leaves and fruit. Cd stunted plant growth causes the death of plants, causes, and disturbance in photosynthetic machinery and nutrient homeostasis process. Based on a serious problem a controlled experiment was conducted in the Department of Botany, University of Central Punjab, Bahawalpur Campus, Bahawalpur, Pakistan on "inducing cadmium stress tolerance in maize by exogenous application of silicon nanoparticles" in an experiment with a completely randomized design (CRD) with the factorial arrangement was used with five different treatments of silicon nanoparticles Si NPs (T_o = control group, T_1 = Si NPs @ 100 ppm, T_2 = Si NPs @ 200 ppm, T_3 = Si NPs @ 300 ppm and T_4 = Si NPs @ 400 ppm) and three cadmium treatment (C_o= control, C_1 = Cd @ 15ppm and T_2 = Cd @ 30 ppm(on a maize hybrid ('SF-9515' F_1 Single cross maize hybrid) and each replicated thrice. Results of the controlled experiment indicated that the Cd at 30 ppm affects the maize plants and reduced the morphological attributes such as shoot length (39.35 cm), shoot fresh weight (9.52 g) and shoot dry weight (3.20 g), leaf pigments such as chlorophyll *a* (0.55 mg/g FW), chlorophyll *b* (0.27 mg/g FW), total contents (0.84 mg/g FW) and carotenoids contents (0.19 µg/g FW), biochemicals traits such as TSP (4.85 mg/g FW), TP (252.94 nmol/g FW), TSAA (18.92 µmol g^{-1} FW), TSS (0.85 mg/g FW) and antioxidant activities such as POD (99.39 min^{-1} g^{-1} FW), CAT (81.58 min^{-1} g^{-1} FW), APX (2.04 min^{-1} g^{-1} FW), and SOD (172.79 min^{-1} g^{-1} FW) but root length (87.63 cm) and root fresh weight (16.43 g) and root dry weight (6.14 g) of maize and Cd concentration in the root (2.52 µg/g^{-1}) and shoot (0.48 µg/g^{-1}) were increased through the application of Cd. The silicon nanoparticles (Si-NPs) treatment significantly increased all measured attributes of maize. There is highest value was noted of all the parameters such as chlorophyll a (0.91 mg/g FW), chlorophyll b (0.57 mg/g FW), total chlorophyll contents (1.48 mg/g FW), total carotenoids contents (0.40 µg/g FW), TSP (6.12 mg/g FW), TP (384.56 nmol/g FW), TSAA (24.64 µmol g^{-1} FW), TSS (1.87 mg/g FW), POD (166.10 min^{-1} g^{-1} FW), CAT (149.54 min^{-1} g^{-1} FW), APX (3.49 min^{-1} g^{-1} FW), and SOD (225.57 min^{-1} g^{-1} FW) in which the treatment T_4 were silicon nanoparticles added at the rate of 400 ppm compared to the control group

1. Introduction

Maize (*Zea mays)* belongs to the angiosperm family Poaceae (Gramineae). Maize is one of the three domesticated food in the world (Yang et al. 2015; Ahmad et al. 2021). Maize is a highly cultivated crop and the most used staple food in the world. Maize is consumed by the world population of almost 10.98 billion bushels per year. Maize is the third most important cereal according to the deity intake by the peoples of the world. In cereals crops according to the yield maize has the highest yield in the world (Ahmad et al. 2021). The demand for maize increased day by day by increasing the Human population (Qiao et al. 2022). Maize is produced about 1.05 million thousand tonnes/annual over the entire world (Ahmad et al. 2021).

The HMs pollution due to the worldwide continuous development of industrialization and urbanization is one of the most topical issues threatening the ecosystem and human health. The coastal soil is easily polluted by heavy HMs through direct emission, surface runoff, atmospheric deposition, etc. (Yan et al. 2022). HMs are dangerous metals for human and plants. HMs accumulated in the body of the organism directly and indirectly at low concentrations and cause different physiological diseases including Brain disorders, cancer and genetic toxicity (Xu et al. 2022). Cd is a harmful heavy metal. The plant growth is affected by the accumulation of Cd. The Cd decreases the biomass of plant this cause a lower rate of photosynthesis because due to Cd the decreases in photosynthetic pigments and inhabits the formation of pigments. The photosynthetic efficiency is reduced. Cd causes an imbalance in nutrient uptake this cause oxidative damage. The accumulation of oxygen increased and enhanced the peroxidation in Cd stress. The plant promotes the formation of antioxidants, osmolytes, chelating agents and non-enzymatic antioxidants to reduce the Cd concentration. Cd causes a bad impact on humans in the food chain this causes chronic poisoning in the human body (Zhao et al. 2021).

Silicon (Si) is an abundant element on the earth planet. Earth crust contains more than 25% Si. That is beneficial to the plant's diversity on the earth and the physiological role of Si is to regulate the biotic and abiotic stress in the plants that have made huge interest among researchers around the world (Rehman et al. 2020). Si is available in the form of mono-silicic acid. The Si shows a beneficial impact on a plant's growth and development directly and indirectly. It increases the tolerance in the plants to reduce the effect of Cd, iron, aluminum, chromium, zinc, and manganese. These are toxic HMs. The different strategies in which the application of Si affects the resistance of metal in plant species are present. By the experiment, the result showed the Si supply decreased the uptake of manganese (Tripathi et al. 2017). The NPs also showed a role in defeating infections, nutrients decrease and damage, recovering the crop yield to harvest, helping the germination of seed, initiate the photosynthesis in plants (Khan et al. 2017). The Si NPs provide the best solution to protect the soil against HMs. The Si NPs protect the water, by increasing the worldwide diet quality and production of crops (Iavicoli et al. 2017). The Si deposit within cell layers of cell wall and lignified the cell wall. This stabilized the structure of proteins by reducing electrolytic leakage. The Si ions improve the antioxidant system during salinity stress. The Si is a deposit in the roots by absorption and translocation process. These reduce the apoplastic flow of water and food and create the sites for binding of metals and decrease the absorption of sodium chloride by roots and shoots. The Si NPs also decrease ROS accumulation (Moradi et al. 2022). Cd is a toxic metal. Plants absorbed Cd directly by the roots and are transported from roots to leaves and fruit. Cd stunted plant growth causes the death of plants, disturbance in photosynthetic machinery and nutrient homeostasis process. Cd reduced morphology, leaf pigments, biochemicals and antioxidants in plants cause disturbance and decrease the yield of plants. A high concentration of Cd causes a reduction in the growth rate Cd was able to influence the cell diameter, cell elongation rate, and thickness of the meristem (Rehman et al. 2015). A study was conducted to evaluate the impact of Cd on maize plant growth and its physiology and also check the role of Nano silicon particles on the growth and physiology of maize plants and improving antioxidant activity and enhancing the Cd stress tolerance in maize under Nano silicon particles application.

2. Materials And Methods

2.1 Experiment site and Location of Experiment

A present pot experiment was performed to induce Cd stress tolerance in maize by exogenous application of Si NPs through alteration it's physiological and antioxidant activities in the Department of Botany, University of Central Punjab, Bahawalpur Campus, Punjab Group of Colleges Bahawalpur, Pakistan.

2.2 Experiment Design and layout

CRD with the factorial arrangement and three replication was used for this research experiment.

2.3 Experimental detail

The study was performed by using the different treatments of Si NPs concentration such as control, 100ppm, 200ppm, 300ppm and 400ppm and Cd concentration such as control, 15ppm, 30ppm applied on maize hybrid (SF-9515 F1 Single cross hybrid.

One latest hybrid (SF-9515 F1 Single cross) of maize was selected and purchased from Seyfert Seed Company Hasilpur, District Bahawalnagar, Province Punjab (Private limited). The sand was collected and washed to free from nutrients and dry under shade conditions. The measured amount of sand by digital weight balance was added into each pot at the rate of 2 kg. Pot height is 18 cm and pot width are 20 cm. After filing the pots 5seed was sowed in each pot. The seed of maize was sown and watering the pot after the calculation of the field capacity of sand. The field capacity was measured and calculated by using the procedure and formula of (Ahmad et al. 2021). During the sowing of maize plants, the recommended dose NPK at 120, 60, 40 kg/ha was incorporated in the sand at the time of pre-sowing irrigation, with a full dose of PK and half dose of N, while the remaining dose of N was applied during the different split periods of maize. After the completion of seed germination, the thinning of plants from each pot was done and maintain three plants per pot. Three treatments of Cd at the rate of 15 ppm, 30 ppm induced stress including one control treatment was applied with water in the sand after the completion of seed germination. Five foliar silicon-nanoparticles treatments at the rate of 100ppm, 200ppm, 300ppm and 400ppm including one control treatment were applied in three splits with one-week intervals 2nd, 3^{rd,} and 4th week after germination of seed. The maize plant will be grown up to 40 days (8th leaf stage) and the following traits were recorded by using standard procedure.

2.4 Morphological traits

Two maize plant was removed from the sand of each pot and washed properly. The plant shoot and root are cut off with the help of a blade at the portion of the stem where the base is present and measure the length of the shoot and root in centimetres with the ruler and noted its average values. The plants were blotted with soft paper to remove the moisture present on the surface plants and weight by the digital weight balance immediately because the plants have a high composition of water in their body parts waiting may lead to some drying. Dry the plants in the oven overnight at low heat temperature (100°F). Plants put in the bag and placed in a cool environment will keep moisture out. When the plant cools the

weight of the plant was recorded by using a digital measuring scale. Plants are not placed in a moisture environment because plant tissues will uptake moisture from the environment. Milligram digital scale was used because the plant weight after dehydration is decreased.

2.5 Leaf pigments determination

Removed the leaves from plants and added 0.5g of leaf into pestle mortar with 80% Acetone for making a paste of leaves. Then added the paste of leaves into the cube of the spectrophotometer and then put it into the spectrophotometer for calculated the absorption of the given supernatant at 663, 652, 642 nm. The chlorophyll content was estimated as per the following equations:

2.5.1 Measurement of the chlorophyll

Measurement of the chlorophyll *a* (Eq. 1)

Chl *a* = [12.7 (OD 663) -2.69 (OD 645)] x V/1000 x W….. (Eq. 1)

Measurement of the chlorophyll *b* (Eq. 2)

Chl *b* = [22.9 (OD 645) -4.68 (OD 663)] x V/1000 x W….. (Eq. 2)

Total Chlorophyll content was measured by the following equation (Eq. 3).

Total Chl = [20.2 (OD 645) + 8.02 (OD 663)] x V/100 x W….. (Eq. 3)

2.5.2 Total Carotenoids contents

Carotenoids ($g.mL^{-1}$) = A^{car}/E_{mx}^{100}…… (Eq. 4)

In this equation, the vindicated that the volume of a sample of the plant was extracted and W indicate the weight of the plants.

Total carotenoid concentration is calculated by the following formula (Eq. 4).

Acar = (OD480) + 0.114 (OD663)-0.638 (OD645); E_{max}^{100} cm = 2500….. (Eq. 5)

2.6 Biochemical attributes

2.6.1 Total soluble Protein (TSP)

Total proteins in the form of soluble in plants were analyzed in the laboratory by using the process of the (Assay 1951).

2.6.2 Process of Extraction:

From the plant, the Fresh leaves were cut at the rate of 0.6 g then chopped and added to 10 mL of phosphate buffer. The buffer pH is 7.0 and was ground. After adding the buffer, the sample material was

placed into the centrifugation machine at 5000 x g for 6 minutes. For protein determination used some supernatant. From each treatment extract of the leaf was full in a holed test tube. Firstly, add phosphate buffer to this buffer (pH 7.0) and take the solution and added into a test tube. The test tube was allowed to stand for 15 minutes at the normal temperature. After the rest of 15 minutes, the folin phenol reagent was added at the rate of 0.5 mL and retained on starrier then sting for 30 minutes at normal room temperature. Then for the analysis result, the sample was placed into the spectrophotometer and read the density at 620 nm.

2.6.3 Total Proline (TP)

The environmental stress increases the proline accumulation that occurs in higher plants with a high accumulation rate. The molecule of proline shows an important role in plants. In the laboratory, the proline was determined by the method of (BATES et al. 1973). In the first stem cut the fresh leaves 0.5 g from the plant and then add the 10 ml of sulfosalicylic acid to dissolve and ground. Before the test, the sample was filtered with the filter paper name Whatman number 2 filter paper and added sample into the test tube, and deed 2 ml of ninhydrin solution. By dissolving the 1.2 ninhydrin molecules in 30 ml glacial acetic acid and taking the 20 ml of 6 M orthophosphoric acid than by method the acid ninhydrin was formed. After this added the 2 ml of glacial acetic acid to a test tube and kept the rest under the temperature of 100 centigrade for 1 hr. The reaction mixture was extracted after the rest period reaction of terminating the ice bath. Then extracted the 10 ml of the mixture. After this, the sample was placed in the steamer and for 1–2 minutes the steam was passed. Then noted the value by the spectrophotometer. Noted the absorption of the proline and calculated the proline by the slandered curve.

2.6.4 Total soluble Amino Acid (TSAA)

The quantity of amino acid was determined by the method of (Hamilton. 1965). Cut the fresh leaves (0.5 g) from the plant. The plants with phosphate buffer (0.2 M) were chopped and extracted having pH 7.0. In the new test tube of 25, then 1 mL of extract was added. Then added 1 mL of pyridine with the percentage of 10% and 1 mL of ninhydrin solution in each test tube with the percentage of 2%. The ninhydrin was dissolved in a distilled water test tube at the rate of 2 g then the ninhydrin solution was peppered. The sample in the test tube was heated in a boiling water bath for 30 min. the 50 ml of distilled water of Volume of each test tube was gored. Then the density of colours is noted by the spectrophotometer at 570 nm and formed a slandered curve.

2.6.5 Amino acid estimation formula

$$\mathrm{TotalsolubleAminoAcid} = \frac{\mathrm{GraphreadinofsamplexVolumeofsamplexDilutionfactor}}{\mathrm{Weightoffreshtissuesx1000}}$$

2.7 Total Soluble Sugar (TSS)

For the extraction of soluble sugar the method of (Yemm and Willis 1954). The plant dried with the help of an electric oven and then crushed into small pieces like a fine powder and the sample sieve with the 1

mm sieve of micromill. The material was taken and added into the test tube with the 80% of ethanol solution the weight of the sample used is 0.1 g. Then placed into the incubator for 6 hrs at 60°C temperature. Then extract the total soluble sugar. Then 25 ml plant extract was taken in a test tube and added 6 ml of enthroning reagent then heated and boiled for 10 min then cooled at low temperature. After ice cooling for 10 min, the sample was transferred into the incubator for 20 min at room temperature. The sample was placed into the spectrophotometer and read at a density of 625 nm. Calculated the value of sugar by Hitachi LaChrom Elite.

2.8 Antioxidant activities

2.8.1 Peroxidase dismutase (POD)

The activity of Peroxide dismutase was analyzed by the method of Chance and Maehly, in which the method measured the peroxidation of hydrogen peroxide. The peroxidase dismutase was measured by using an organic compound named guaiacol. Guaiacol is an electron donor (Chance and Maehly 1955).

2.8.2 Catalase (CAT)

Chance and Maehly (1955) method was used to determine the catalase. Catalase was measured by measuring the alteration rate of the water molecule and hydrogen peroxide from the oxygen molecule. The 3 ml solution sample solution comprised a phosphate buffer at the rate of 50 mm. Their pH is neutral (7.0) not acidic and does not have basic properties with 5.9 mM H_2O_2 and an enzyme extract at the rate of 0.1 mL. The result was noted by the spectrophotometer by a decline in absorption at 240 mm. These are the consumption of H_2O_2 after every minute.

2.8.3 Ascorbate peroxidase (APX)

To analyse the APX a method of monitoring the reduction in absorbance of ascorbic acid. The absorbance was noted at 290 nm. The mixture of the sample containing 50 mM phosphate buffer with 7.6 pHs. In 1 ml reaction and 0,1 mN of Na EDTA, 0.25 mM of ascorbic acid, 12 mM H_2SO_4. This description method was determined by the scientist (Cakmak et al. 1994).

2.8.4 Superoxide dismutase (SOD)

The superoxide dismutase was measured from the plant according to the Zhang method. Firstly took the plants and ground them with N_2 solution. If the plant is ground (convert into small pieces) then uniform by the phosphate buffer at the pH of 7.6. Then noted the result.

2.9 Cadmium in leaf and root

Cut the fresh leaves from three replication of plants. Two to three leaves were selected from every replication. Then put all the leaves into the polythene bag along with the name tag of treatment and replication. The leaves were brought to a laboratory for analysis.

Firstly, took the plant leaves and placed them in the air for the air-dry process then placed them into the electric oven at a constant time and temperature of 65° C. When the sample is fully dried then crush with pestle mortar to convert into powder shaped then stored in a zipper bag for further analysis.

Apply the digestion process proposed by the U.S. salinity lab staff, 1954. Leaves sample digested by the di-acid in ration 1: 2. Took a conical flask and added sample (Roots and leaves) at the rate of 0.5 g. Added HNO_3 sample into a given conical flask where the sample was added and then kept overnight. On the next day, the conical flask was placed on the hot plate at the temperature of 150° C. Keep heating until showed a yellow colour. When the sample turns yellow then added 2 ml of $HClO_4$ and the sample is cool at room temperature. After cooling at room temperature heated the sample until colourless. The colourless is the endpoint. After the digestion, the volume of the sample was made in a 25 mL flask and filtered with Whatman filter paper. The filtered sample was stored in a clean and air tide bottle then apply AAS analysis was to detect metal.

2.8 Statistical analysis

The collected data from the different plant's parameters after the analysis were analyzed statistically using the method of Fisher’s Analysis of Variance technique and the least significant difference (LSD) test was applied to compare the treatments’ means (Steel and Blaszczynski 1998).

3. Results

3.1 Morphological parameters

Recorded data showed that Cd stress and different treatments of Si NPs as well as the interaction between Cd and treatments significantly affected the growth attributes such as shoot, root and their fresh as well as dry weight of maize (Table 1).

Table 1
Mean squares from Analysis of variance (ANOVA) for Morphological, Leaf pigments, Biochemical, Antioxidant and Cd concentration in leaf and root-related parameters

Traits	SOV	T	cd	T x cd	Error
	DF	**4**	**2**	**8**	**30**
Morphological	SL	1151.37***	88.85***	12.6***	0.57
	SFW	87.46***	4.86***	0.09 ns	0.57
	SDW	14.25***	0.69***	0.0047 ns	0.14
	RL	2489.38***	144.61***	5.85***	0.64
	RFW	195.05***	12.98***	0.37 ns	0.59
	RDW	19.29***	1.84***	0.31***	0.00
Leaf Pigments	Chl a	0.48***	0.03***	0.00168**	0.00063
	Chl b	0.314***	0.024***	0.00073**	0.00063
	TChl	1.56***	0.1***	0.003**	0.002
	TCar	0.16***	0.01***	0.00013 ns	0.00043
Bio-Chemical Tests	TSP	4.38***	2.55***	0.01***	0.00063
	TP	75112.7***	4283.2***	107.2***	0.3
	TSAA	99.8***	17.6***	0.81***	0.08
	TSS	1.22***	3.68***	0.00058*	0.00063
Antioxidant	POD	18883.9***	1429.4***	1.9***	0.3
	CAT	20464.7***	1240.2***	42.3***	0.3
	APX	9.25***	0.76***	0.01***	0.00063
	SOD	13393.3***	968.7***	19.3***	0.3
Cd Analysis	Cdl	0.86***	0.04***	0.00092 ns	0.00043

*** = $P \leq 0.001$, ** = $P \leq 0.01$, * = $P \leq 0.05$, ns = Non-Significant

Note: SOV; Source of variance, **DF**; Degree of freedom, **T**; Treatment, **Cd**; Cadmium, **SL**; Shoot length (cm), **SFW**; Shoot fresh weight (g), **SDW**; Shoot dry weight (g), **RL**; Root length (cm), **RFW**; Root fresh weight (g), **RDW**; Root dry weight (g), **Chl a**; Chlorophyll a (mg/g FW), **Chl b**; Chlorophyll b (mg/g FW), **TChl**; Total Chlorophyll (mg/g FW), **TCar**; Total Carotenoids (µg/g FW), **TSP**; Total soluble protein (mg/g FW), **TP**; Total proline (nmol/g FW), **TASS**; Total soluble amino acid (µmol g^{-1} FW), **TSS**; Total soluble sugar (mg/g FW), **POD**; Peroxidase dismutase (min^{-1} g^{-1} FW), **CAT**; Catalase (min^{-1} g^{-1} FW), **APX**; Ascorbate peroxidase (min^{-1} g^{-1} FW), **SOD**; Superoxide dismutase (min^{-1} g^{-1} FW), **Cdl**; Cadmium in leaf (µg/g^{-1}), **Cdr**; Cadmium in root (µg/g^{-1}).

	Cdr	1.05***	0.05***	0.00037*	0.00043
*** = P ≤ 0.001, ** = P ≤ 0.01, * = P ≤ 0.05, ns = Non-Significant					
Note: SOV; Source of variance, **DF**; Degree of freedom, **T**; Treatment, **Cd**; Cadmium, **SL**; Shoot length (cm), **SFW**; Shoot fresh weight (g), **SDW**; Shoot dry weight (g), **RL**; Root length (cm), **RFW**; Root fresh weight (g), **RDW**; Root dry weight (g), **Chl a**; Chlorophyll a (mg/g FW), **Chl b**; Chlorophyll b (mg/g FW), **TChl**; Total Chlorophyll (mg/g FW), **TCar**; Total Carotenoids (µg/g FW), **TSP**; Total soluble protein (mg/g FW), **TP**; Total proline (nmol/g FW), **TASS**; Total soluble amino acid (µmol g^{-1} FW), **TSS**; Total soluble sugar (mg/g FW), **POD**; Peroxidase dismutase (min^{-1} g^{-1} FW), **CAT**; Catalase (min^{-1} g^{-1} FW), **APX**; Ascorbate peroxidase (min^{-1} g^{-1} FW), **SOD**; Superoxide dismutase (min^{-1} g^{-1} FW), **Cdl**; Cadmium in leaf (µg/g^{-1}), **Cdr**; Cadmium in root (µg/g^{-1}).					

Different levels of cd stress significantly affect the shoot-root length and the fresh and dry weight of maize. The maximum shoot length (56.60 cm) and their fresh weight (14.34 g) and dry weight (5.15 g) were recorded where Cd was not applied such as control treatment while the lowest shoot length (39.35 cm) and their fresh (9.52 g), as well as the dry weight (3.22 g), was noted in treatments where Cd was applied at the rate of 30 ppm. While the root length (87.63 cm) their fresh (16.58g), as well as his dry weight (6.14g), were noted more in pots where cd was applied at the rate of 30 ppm. The highest shoot length (50.91 cm) and their fresh weight (12.72g) and dry weight (4.50g) were recorded in the treatments where foliar Si NPs were applied at the rate of 400 ppm while the lowest shoot length (43.08 cm) and their fresh (10.91g), as well as dry weight (3.78g), was noted in the treatment where no foliar Si NPs was applied and highest root length (79.91 cm) and their fresh weight (14.38g) and dry weight (5.55g) was recorded in the treatments where foliar Si NPs were applied at the rate of 400 ppm while the lowest shoot length (69.41 cm) and their fresh (11.36g), as well as dry weight (4.35g), was noted in the treatment where no foliar Si NPs was applied such as control treatment (Fig. 1).

3.2 Leaf pigments

Recorded data showed that Cd stress and different treatments of foliar Si NPs as well as the interaction between Cd and treatments significantly affected the leaf pigments attributes such as chlorophyll a, chlorophyll b, total chlorophyll as well as carotenoids pigments leaf of maize (Table 1). Different levels of cd stress significantly affect the chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoid content in the leaf of maize. The maximum chlorophyll *a* (0.64 mg/g FW), chlorophyll *b* (0.35 mg/g FW), total chlorophyll (1.0027 mg/g FW) and carotenoids (0.24 µg/g FW) were recorded where Cd was not applied such as control treatment while the lowest chlorophyll *a* (0.55 mg/g FW), chlorophyll *b* (0.27 mg/g FW), total chlorophyll (0.84 mg/g FW) and carotenoids (0.19 µg/g FW) was noted in treatments where Cd was applied at the rate of 30 ppm. The highest chlorophyll a (0.91 mg/g FW), chlorophyll b (0.57 mg/g FW), and their total chlorophyll content (1.49 mg/g FW), as well as carotenoids contents (0.40 µg/g FW), was recorded in the treatments where foliar Si NPs particles were applied at the rate of 400 ppm while the lowest chlorophyll *a* (0.34 mg/g FW), chlorophyll *b* (0.12 mg/g FW), and total chlorophyll (0.46 mg/g FW), as well as carotenoids content (0.46 µg/g FW), was noted in the treatment where no Si NPs was applied such as control treatment(Fig. 2).

3.3 Biochemical attributes

Recorded data showed that Cd stress and different treatments of Si NPs as well as the interaction between Cd and treatments significantly affected the biochemical attributes such as total soluble proteins, total proline and total soluble amino acid as well as total soluble sugar in maize (Table 1). Different levels of cd stress significantly affect the soluble proteins, proline and soluble amino acid as well as soluble sugar in maize. The maximum soluble proteins (5.65 mg/g FW), proline (282.60 mmol/g FW) and soluble amino acid (21.07 µmol g-1 FW), as well as soluble sugar (1.76 mg/g FW), were recorded where Cd was not applied such as control treatment while the lowest soluble proteins (4.85 mg/g FW), proline (252.94 mmol/g FW) and soluble amino acid (18.92 µmol g-1 FW), as well as soluble sugar (0.85 mg/g FW), was noted in treatments where Cd was applied at the rate of 30 ppm.

Highest soluble proteins (6.12 mg/g FW), proline (384.56 mmol/g FW) and soluble amino acid (24.64 µmol g^{-1} FW), as well as soluble sugar (1.87 mg/g FW), were recorded in the treatments where foliar Si NPs particles were applied at the rate of 400 ppm while the lowest soluble proteins (4.40 mg/g FW), proline (152.66 mmol/g FW) and soluble amino acid (16.02 µmol g^{-1} FW), as well as soluble sugar (0.94 mg/g FW), was noted in the treatment where no Si NPs was applied (Fig. 3).

3.4 Antioxidant activities

Recorded data showed that Cd stress and different treatments of foliar Si NPs as well as the interaction between Cd and treatments significantly affected the antioxidant attributes such as peroxidase dismutase, catalase and ascorbate peroxidase as well as superoxide dismutase in maize (Table 1). Different levels of cd stress significantly affect the peroxidase dismutase, catalase and ascorbate peroxidase as well as superoxide dismutase in maize. The maximum peroxidase dismutase (116.68 min^{-1} g^{-1} FW), catalase (97.72 min^{-1} g^{-1} FW) and ascorbate peroxidase (2.47 min^{-1} g^{-1} FW), as well as superoxide dismutase (187.09 min^{-1} g^{-1} FW), was recorded where Cd was not applied such as control treatment while the lowest peroxidase dismutase (99.39 min^{-1} g^{-1} FW), catalase (81.58 min^{-1} g^{-1} FW) and ascorbate peroxidase (2.04 min^{-1} g^{-1} FW), as well as superoxide dismutase (172.79 min^{-1} g^{-1} FW), was noted in treatments where Cd was applied at the rate of 30 ppm.

The highest peroxidase dismutase (166.10 min^{-1} g^{-1} FW), catalase (149.54 min^{-1} g^{-1} FW) and ascorbate peroxidase (3.49 min^{-1} g^{-1} FW), as well as superoxide dismutase (225.57 min^{-1} g^{-1} FW), was recorded in the treatments where foliar Si NPs were applied at the rate of 400 ppm while the lowest peroxidase dismutase (45.27 min^{-1} g^{-1} FW), catalase (34.83 min^{-1} g^{-1} FW) and ascorbate peroxidase (0.97 min^{-1} g^{-1} FW), as well as superoxide dismutase (132.93 min^{-1} g^{-1} FW), was noted in the treatment where no foliar Si NPs was applied such as control treatment (Fig. 4).

3.5 Cadmium concentration in plants leaf and root

Recorded data showed that Cd stress and different treatments of foliar Si NPs as well as the interaction between Cd and treatments significantly affected the cd in maize root and leaf while under the different treatments of Si NPs. The treatment showed a good result about Cd. Their interactions displayed non-significant results noted in the plant maize (Table 1). Noted data indicate that the maximum value of cd in root content (2.52 $\mu g/g^{-1}$) and in Leaf content (0.89 $\mu g/g^{-1}$) under the stress of Cd where Cd was applied @ 30 ppm while under the condition of normal treatment. The minimum value of Cd root (2.08 $\mu g/g^{-1}$) and Cd in leaf (0.04 $\mu g/g^{-1}$) was recorded. Different levels of Si NPs that applied in the form of a foliar spray that is highly significantly affected the concentration of Cd in the root and Leaf of maize and noted that the more Cd in root content (2.94 $\mu g/g^{-1}$) and in leaf content (0.39 $\mu g/g^{-1}$) was indicated in the control group. In the control group, foliar Si NPs were not added while the lowest Cd concentration in roots (2.08 µg/g-1) in leaf (0.09 µg/g-1) was recorded where the SiNPs foliar spray on plants was applied @ 400 ppm in the stressful situations of Cd. Analysis showed that interaction between the Cd and treatment of Si NPs were detected non- Significantly. more Cd content was noted in root areas (2.94 $\mu g/g^{-1}$) and in leaf areas (0.86 $\mu g/g^{-1}$) of maize in the control treatment where no foliar SNPs application was applied under the stress of Cd and minimum concentration of Cd content in root areas (2.08 $\mu g/g^{-1}$) and leaf areas (0.09 $\mu g/g^{-1}$) was noted where Si NPs added as foliar @ 400 ppm under the stress of heavy metal Cd (Fig. 5).

4. Discussion

Si NPs increase the biomass of the plant's maize and increase the growth of plants by reducing the stress of HMs (Tripathi et al. 2017). HMs present over all the world and show a different impact on human life by contaminating the process. HMs are non-degradable metals that stop the growth of plants because that is highly toxic metals. Metals have shown their impact on plants, animals, and human life (Khan et al., 2021; Zhang et al., 2014). The Si NPs are non-toxic partials that increase the silicon level in plants under heavy metal stress. Increasing the Si NPs treatment increase the growth of maize plants. The silicon increased the length of root and length of shoot under the stress of Cd. This experiment result showed an improvement in the plant's growth parameters. The Si NPs increase the quantity of silicon in the plants and increases the Si-ions concentration in the plants due to this plant growth is promoted. This finding is supported by (Hossain et al. 2021).

The experiment result showed that the length of maize shoot was decreased under Cd stress. The Cd is a heavy metal that reduces the growth of maize plants by the accumulation in the cell vacuole and stops slow the activity of the cell. The treatments of Si NPs have increased the length of the shoot. This current finding is supported by Abd El-Mageed et al., (2020), who stated that the Si NPs treatments significantly improved the length of maize roots under Cd stress conditions. Cd reduces the growth of shoot (Seregin et al. 2004). The Si NPs improved the nutrients uptake by treatment of Si NPs. Results showed that the highest shoot length was noted in the treatment where Si NPs were applied at the rate of 400 ppm while the lowest shoot length was noted in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the shoot length of maize. The maximum shoot length was recorded where Cd

was not applied such as in the control treatment while the lowest shoot length was noted in treatments where Cd was applied at the rate of 30ppm. The silicon provided the silicon to the plant to increase the growth and reduce the effect of HMs (Rastogi et al. 2019). Under the stress of Cd, the maize plant increased the length of its roots to absorb nutrients in high quantities to reduce the Cd stress. The Si NPs increased the root and shoot length. This current finding is supported by (Siddiqui et al. 2020)., who stated that the Si NPs treatments significantly enhanced the root and shoot length under Cd stress conditions.

The highest root fresh weight was noted in the T_4 treatment where Si NPs were added at the rate of 400 ppm while the lowest root fresh weight was recorded in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the root fresh weight of maize. Minimum fresh root weight was recorded where Cd was not applied such as in control treatment while the maximum root fresh weight was noted in treatments where Cd was applied at the rate of 30ppm. This current finding is supported by (Dresler et al. 2015), who stated that the Si NPs treatments significantly enhanced the root fresh weight under Cd stress conditions. The highest shoot fresh weight was noted in the T_4 treatment where Si NPs were applied at the rate of 400 ppm while the lowest shoot fresh weight was noted in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the shoot of plant fresh weight of maize. In shoot fresh, the maximum weight was recorded where Cd was not applied such as control treatment while the minimum shoot fresh weight was noted in treatments where Cd was applied @ 30ppm. This current finding is supported by (Dresler et al. 2015), who stated that the Si NPs treatments significantly enhanced the shoot fresh weight under Cd stress conditions. Recorded data showed that Cd stress and different treatments of Si NPs as well as the interaction between Cd and treatments significantly affected the shoot dry weight of maize. The highest weight of dry shoot was recorded in the treatment where Si NPs were added in the foliar form at the rate of 400 ppm while the minimum weight of dry shoot dry was noted in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the shoot dry weight of maize. The maximum shoot dry weight was recorded where Cd was not applied such as in the control treatment while the minimum shoot dry weight was noted in treatments where Cd was applied at the rate of 30ppm. The current finding is supported by (Dresler et al. 2015). Under the Cd stress, the dry leaves' weight was decreased because Cd is a toxic substance that stops the activity then highest the length noted in the Si NPs treatment at the rate of 400ppm. The result showed that under the stress the maize plant extends its roots and increased the weight of the roots. Si NPs increased the weight of roots and shoot in maize plants. Results showed the weight of the root was increased under the Si NPs treatments.

Results show that the Si NPs under Cd stress showed an impact on the leaf pigments which are chlorophyll *a, b*, total chlorophyll contents, and carotenoids. The Si NPs treatment was applied at the rate of 400ppm increased the chlorophyll contents than the control group was no Si NPs applied. The Si NPs reduced the Cd stress and increased the chlorophyll-a content in the plant. The highest value of chlorophyll-a content was recorded where cd stress was not applied such as in control treatment while the lowest value of chlorophyll-*a* content was observed in cd treatment where cd was applied at the rate

of 30 ppm. A change in the chlorophyll *b* contents was noted by the experiment. The Si NPs increased the chlorophyll *b* contents in the plants and were applied at the rate of 400ppm the control group. There is the highest concentration of chlorophyll *b* noted in the Si NPs treatment group. The Si NPs increased the photosynthetic process. Because they facilitate the uptake of essential nutrients by xylem to increase the chlorophyll b content. When the chlorophyll increased the process of photosynthetic was increased. The current finding is supported by (Khan et al. 2019). The Si NPs decreased the concentration of HMs that accumulate in the plant's body. In our result, the Si NPs treatments 400 ppm decreased the concentration of Cd and increase the chlorophyll contents (*a* and b) in maize. In maize plants, the Si NPs treatment under Cd showed the highest value of carotenoids were treatment added at the rate of 400 ppm of Si NPs. Then the lowest value was recorded where no silicon was added such as the control group. In 30 ppm Cd stress the Cd concentration decreased due to silicon treatment 400ppm then the control where no silicon was applied. The Si NPs increased the photosynthetic pigments under the stress of HMs such as Cd. The current result is supported by (Ling et al. 2017). The Si NPs showed an impact on the concentration of biochemicals such as soluble proteins, proline, soluble amino acid, and Soluble sugar. The result showed that the highest value of total soluble proteins noted was the Si NPs applied at the rate of 400 ppm then the control group. There is the lowest value of proteins noted where no silicon Si NPs applied. The proteins are the complex structure that showed an important role in the structure and function of cells. All the plant's enzymes are formed by proteins. The Cd reduced the protein concentration in the plants then reduced the growth of plants. The result showed the Si NPs increased the proteins and decreased the Cd level. The Cd decreases the synthesis of proteins and reduces the work of proteins. The NPS increased the Si concentration in the plant. Si act as a barrier responsible to repaired and decreasing the injury of the cell membrane. The results are similar to the findings of (Khan et al. 2019).

The proline showed an important role in plants. The proline protects the plant against Cd stress. When Cd stress occurs the proline act as a barrier and reduced the Cd stress to promote plant growth. There is the highest value of total proline was recorded in the treatment where Si NPs were applied at the rate of 400 ppm while the lowest value of total proline was noted in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the total proline of maize (Hayat et al. 2012). The maximum value of total proline was recorded where Cd was not applied such as in control treatment while the lowest value was noted in treatments where Cd was applied at a high rate. The maize plant showed a high level of amino acids in Si NPs treatment. The highest level of amino acid was noted where a high level of Si NPs applied then control where no treatment was applied. The Cd reduced the amino acid concentration. Reduction in the amino acid reduced the protein level. The result shows that the highest level of amino acid noted was no Cd applied than the Cd stress. The amino acid shows an important role in the structure and function of the cell.

Si NPs increased the level of sugar in the plant. Sugar shows an important role in the plant. Sugar has a dual role in the plant. Sugar is involved in some important metabolic processes and is also responsible for signal-regulating genes involved in the photosynthesis process and sucrose metabolism. Results showed that the Si NPs increased the level of sugar in maize plants. Cd reduced the sugar by a reduction

in uptake nutrients. The Si NPs under Cd stress increased the antioxidant concentration in the plant. The silicon produced by the Si nanoparticles increased the concentration of POD. The POD protected stress conditions. This study shows that in the Cd stress the value of POD was increased when increased the Si NPs treatment at the rate of 100 ppm to 400 ppm and decreased the concentration and uptake of Cd in stress conditions. In the result, the highest value of peroxidase dismutase was recorded in the treatment where Si NPs were applied at the rate of 400 ppm while the lowest value of peroxidase dismutase was noted in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the peroxidase dismutase of maize. The maximum value of peroxidase dismutase was recorded where Cd was not applied such as in the control treatment while the lowest value was noted in treatments where Cd was applied at the rate of 30ppm (Thind et al. 2021).

The Si NPs increased the CAT concentration. The CAT is an antioxidant enzyme. The CAT is present in all the plants. The CAT showed an important role in stress conditions when energy efficient. The CAT catalyzed the H_2O_2 molecules into O_2 and H_2O. As a result, the highest value of catalase was recorded in the treatment where Si NPs were applied at the rate of 400 ppm while the lowest value of catalase was noted in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the catalase of maize. The maximum value of catalase was recorded where Cd was not applied such as in the control treatment while the lowest value was noted in treatments where Cd was applied at the rate of 30ppm. The concentration of CAT is increased by the nanoparticle's treatment (Lukačová et al. 2013). The Si NPs treatment increased the APX (Antioxidant enzyme Ascorbate peroxidase) concentration in maize leaves under Cd stress. As a result, the highest value of ascorbate peroxidase was recorded in the treatment where Si NPs were applied at the rate of 400 ppm while the lowest value of ascorbate peroxidase was noted in treatment where no Si NPs were applied. Different levels of Cd stress significantly affect the ascorbate peroxidase of maize. The maximum value of ascorbate peroxidase was recorded where Cd was not applied such as in the control treatment while the lowest value was noted in treatments where Cd was applied at the rate of 30ppm. The APX is increased by the Si NPs under the stress of Cd (Thind et al. 2021).

The SOD is an enzyme found in all living plant cells. This is responsible for the speed of chemical reactions and speeds up the chemical reaction in the cells. The SOD breakdown the harmful molecules in the cell to prevent cell damage under stress conditions in the experiment result the highest value of superoxide dismutase was recorded in the treatment where Si NPs were applied at the rate of 400 ppm while the lowest value of superoxide dismutase was noted in treatment where no Si NPs was applied. Different levels of Cd stress significantly affect the superoxide dismutase of maize. The maximum value of superoxide dismutase was recorded where Cd was not applied such as in the control treatment while the lowest value was noted in treatments where Cd was applied at the rate of 30ppm. The concentration of SOD was increased by the Si NPs treatment under Cd stress. Results showed that the maximum Cd value present in leaves and roots under the stress of Cd where Cd was added @ 30 ppm while beneath average conditions such a control group. The minimum value of Cd in leaves and roots was recorded under the treatment of Si NPs. Different levels of Si NPs that were applied in the form of foliar spray

highly significantly exaggerated the Cd in leaf and root of maize and showed that more Cd contents in leaves and roots were noted in the controlled group in which foliar Si NPs were not applied while the lowest value of Cd content in leaves and roots was recorded where the Si NPs foliar was applied in the form of foliar at 400 ppm in the stress conditions of Cd (Shafeeq-ur-Rahman et al. 2020).

5. Conclusions

Based on the serious problem a pot was the experiment conducted on “inducing Cd stress tolerance in maize by exogenous application of Si NPs under controlled condition” in the experiment CRD Factorial design was used with five treatments of Si NPs. Three Cd treatments on a Maize Variety 1 (SF-9515 F_1 Single cross Hybrid). The result of the experiment indicated that the Cd effects on the maize plants and reduced the morphological (shoot length, shoot fresh weight and shoot dry weight), leaf pigments (Chlorophyll *a, b* and total contents and Carotenoids contents), bio-chemicals (TSP, TP, TSAA and TSS), Antioxidant (POD, CAT, APX and SOD), Cd parameters (Cd in root and Cd in the shoot) but the maize plant root length and root fresh weight and root dry weight was increased through the application of Si NPs under the stress of Cd. The Si NPs treatment significantly increased all parameters.

Abbreviations

HMs: Heavy Metals, CRD; complete randomized design, **Si**; Silicon, **Si NPs**; Silicon nanoparticles, **TSP**; Total soluble protein, **TP**; Total proline, **TSAA**; Total soluble amino acid, **TSS**; Total soluble sugar, **POD**; Peroxidase dismutase, **CAT**; Catalase, **APX**; Ascorbate peroxidase, **SOD**; Superoxide dismutase, **Cd**; Cadmium, **ROS;** Reactive oxygen species

Declarations

Author Contributions

ZA and MI planned and supervised the research, SA conducted the research work, wrote the introduction part and ZA wrote the manuscript; SA and ZA did the static analysis and graphical representation; MAI and HFA read the manuscript as proofreading and arranged it according to the journal style; AA provided reagents, assisted in the analytical work and AH & AES improved the English language quality of the manuscript.

Ethical Approval All authors approves this manuscript for submission in Environmental Science and Pollution Research

Consent to Participate All authors participate in the preparation of the manuscript.

Consent to Publish All authors consent to the manuscript publication in Environmental Science and Pollution Research.

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Competing interest All authors declare that they have no conflict of interest.

Availability of data and materials The raw data are available and will be provided on demand

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Figures

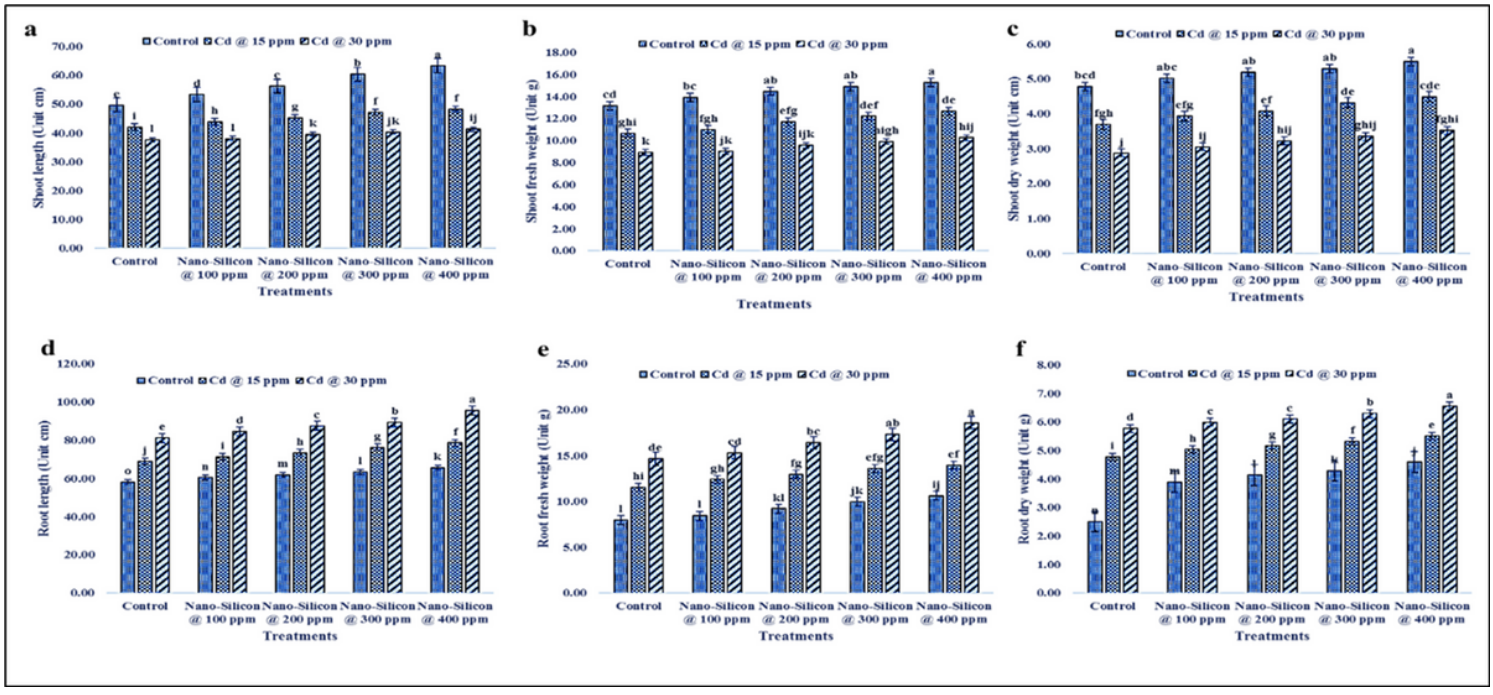

Figure 1

Effect of foliar applied Si NPs on morphological attributes of maize under Cd stress conditions. (a) Shoot length, (b) Shoot fresh weight, (c) Shoot dry weight. (d) Root length, (e) Root fresh weight (f) Root dry weight.

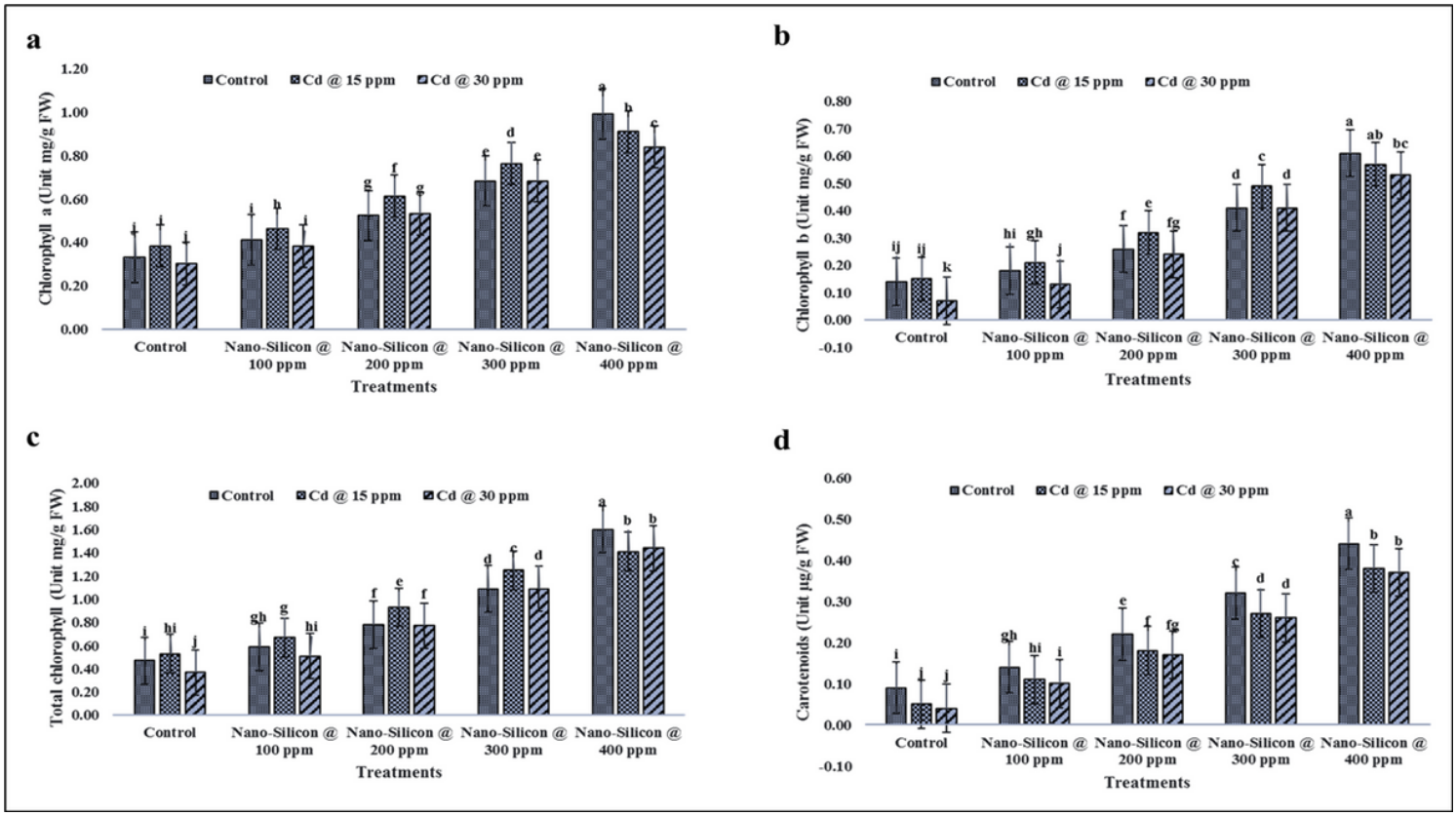

Figure 2

Effect of foliar applied Si NPs on leaf pigments of maize under Cd stress conditions. (a) Chlorophyll *a*, (b) Chlorophyll *b*, (c) Total chlorophyll contents and (d) Carotenoid contents

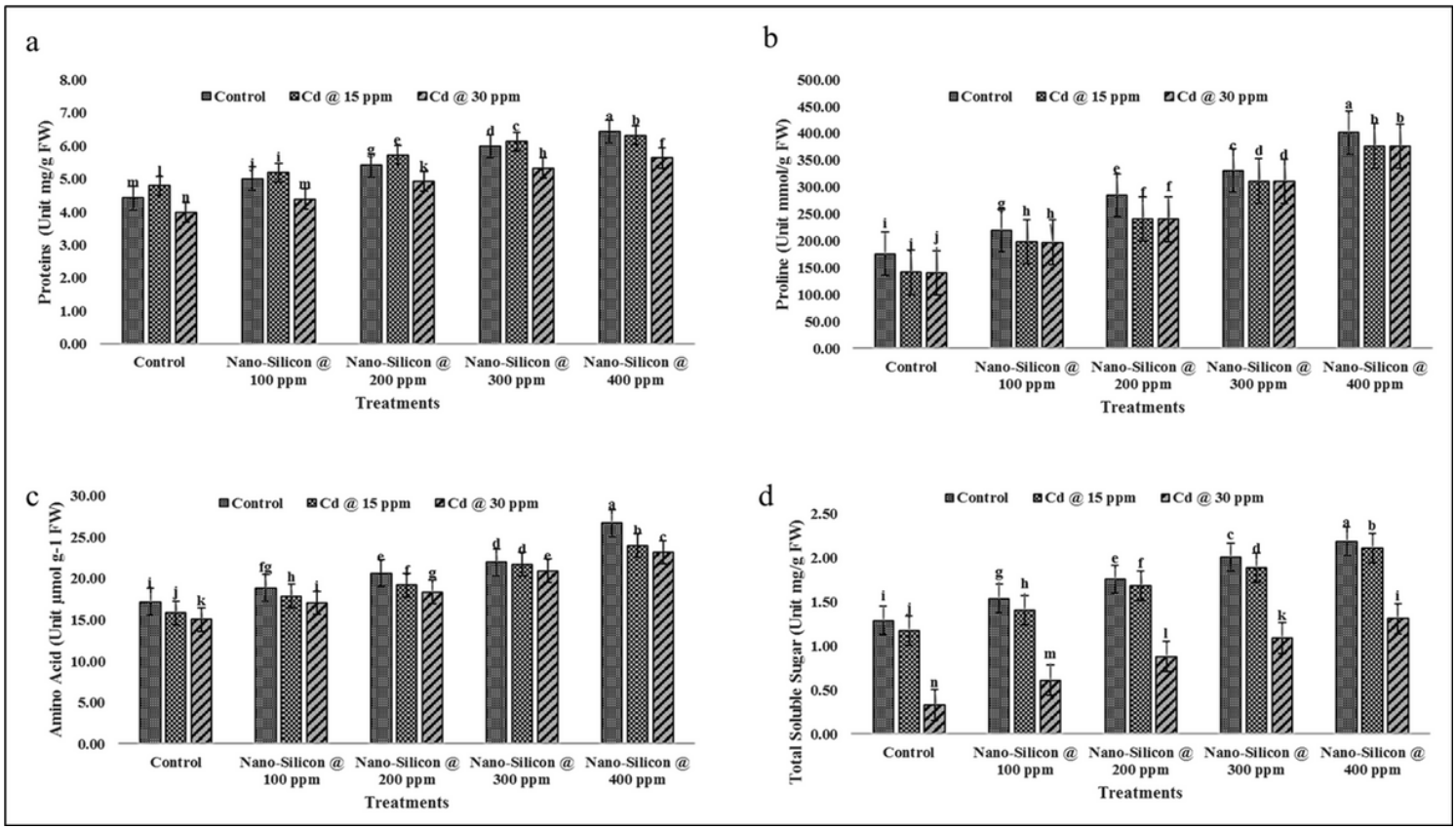

Figure 3

Effect of foliar-applied Si NPs on biochemical attributes of maize under Cd stress conditions. (a) Total soluble protein, (b) Total proline, (c) Total soluble amino acid, and (d) Total soluble sugar.

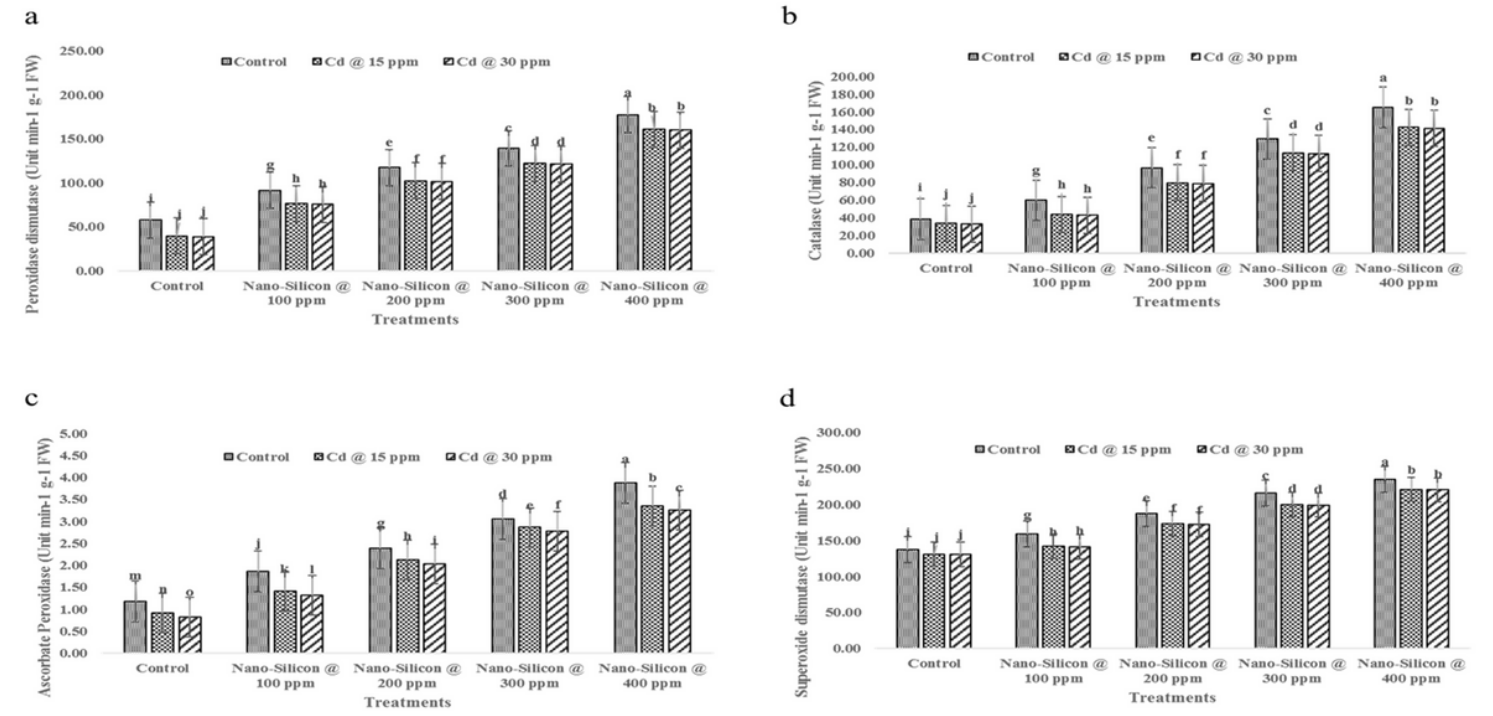

Figure 4

Effect of foliar applied foliar Si NPs on antioxidant activities of maize under Cd stress conditions. (a) Peroxidase dismutase, (b) Catalase, (c) Ascorbate peroxidase, (d) Superoxide dismutase.

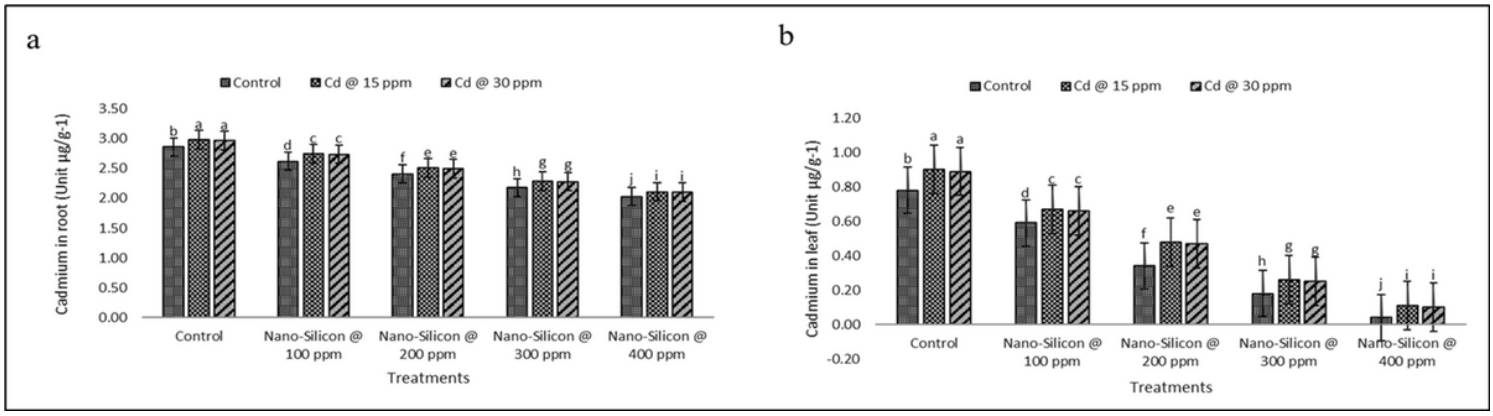

Figure 5

Effect of foliar applied foliar Si NPs on Cd concentration on leaf and root of maize under Cd stress conditions. (a) Cadmium in root, (b) cadmium in leaf.