INFLUENCE OF SILICON ON PLANT UPTAKE OF HEAVY METALS AND METALLOID FROM SOIL

Abstract

The second-most common element in the crust of the earth is silicon, performs a variety of beneficial roles in soils and plants. It helps to reduce a variety of biotic (diseases and pest insects) and abiotic pressures (salt, drought and heavy metals).Si influences the heavy metal and metalloid uptake by plants through different mechanisms including (1) Si bioavailability in soil is influenced by biological factors, (2) by altering the soil's properties, (3) heavy metal co-precipitation, (4) heavy metals being changed into less solubility forms, (5) root architecture modification, (6) controlling antioxidant enzymes, (7) gene expression that controls how well heavy metals are absorbed by and transported to plants is regulated both up and down. In this chapter it is discussed about the various mechanisms involved in heavy metal and metalloid uptake by Silicon. The application of industrial by products (fly ash, steel slag etc.) decreased the conversion of soluble metals into insoluble metal silicates, phosphates, and hydroxides reduces the intake of heavy metals. Si application can reduce heavy metal bioavailability in soil. Silicon nanoparticles along with Pb-resistant microbes significantly reduced the Pb concentration in plants. Si application changes mineral composition of Fe plaque in rice root which decreases both shoot As and grain As. A significant decrease in Cd and Pb toxicity of wheat along with increased grain yield can be possible by the application of organic and inorganic silicon fertilisers. By preventing the production of low affinity cation transporter, silicon nanoparticles can decrease the uptake of Cd into rice grains and phloem (OsLCT1). Through decreased electrolytic leakage, lower levels of malondialdehyde and hydrogen peroxide, and increased antioxidant enzyme activity, si treatment reduces Cd toxicity in cotton. To assess the viability of using Si for the remediation of metal-contaminated soils, extensive field tests are needed.

Keywords: Silicon, heavy metals, metalloid, toxicity, remediation

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I. INTRODUCTION

The second-most prevalent element in the crust of the earth, Silicon (Si) performs a variety of beneficial roles in soils and plants. It helps to reduce a variety of biotic (diseases and pest insects) and abiotic pressures (salt, drought and heavy metals) (Ma *et al.*, 2021). Amorphous elemental silicon was first isolated by Jöns Jacob Berzelius (1824), element name derived from Latin silex or silicis ("flint" or "hard stone"), includes to group 14 [IVa], havingan atomic weight of 28.086, an atomic mass of 14, a specific gravity of 2.24, a density of 2.33gcm-3, and an oxidation state of (-4), (+2), +4. Metals with relatively high densities, atomic weights, or atomic numbers are typically referred to as heavy metals. Mercury (Hg), cadmium (Cd), chromium (Cr), thallium (Tl), and lead are some examples of heavy metals (Pb). Commonly recognised metalloids include boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb), and tellurium (Te).

II. VARIOUS SILICON FRACTIONS IN SOILS

According to Souri *et al.* (2020) the main two fractions of Si in soil are liquid and solid phase. Liquid phase includes monosilicic, polysilicic acid, orano-silicon compounds etc. Amorphous and crystalline forms include two solid phase, where quartz, feldspar, mica, kaolinite, smectite includes two crystalline form and biogenic and non- biogenic include to amorphous form (Fig: 1).

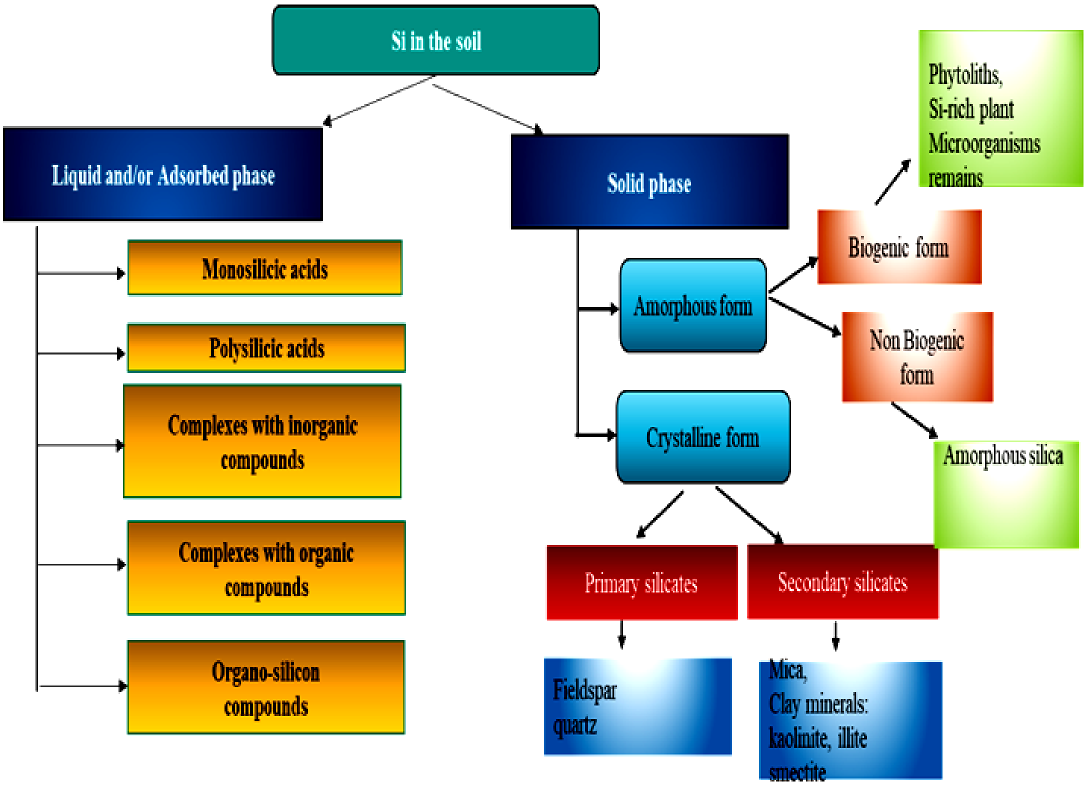


Figure 1: Different Fractions of Silicon

III. SILICA ACCUMULATOR PLANT

Meena *et al.* (2021) reported there are three categories of Si accumulator high accumulator (>1.5% Si) - rice, sugarcane, wheat etc, intermediate accumulator (1.5% − 0.5% Si) - soybean,squash, cucumber, pumpkin etc and Non accumulator (< 0.5% Si) - sunflower , tomato, grapesetc (Table:1).

Table 1: Silica Accumulator Plant

High accumulator (>1.5% Si)	Intermediate accumulator (1.5%−0.5% Si)	Non accumulator (< 0.5% Si)
Rice	Soybean	Sunflower
Wheat	Pumpkins	Tomato
Lentils	Rose	Snapdragon
Spinach	Squash	Gerbera
Ferns	Chrysanthemums	Petunia
Conifers	Zinnia	Pansy

IV. BENEFITS OF SI

Si is not believed to be required for the formation and growth of plants, but mounting research suggests that this metalloid has advantages for plants, particularly under stressful situations. Si does, in fact, reduce the harmful consequences of abiotic stimuli, such as salt stress, drought, and heavy metals (Gaur *et al*., 2020) (Fig : 2).

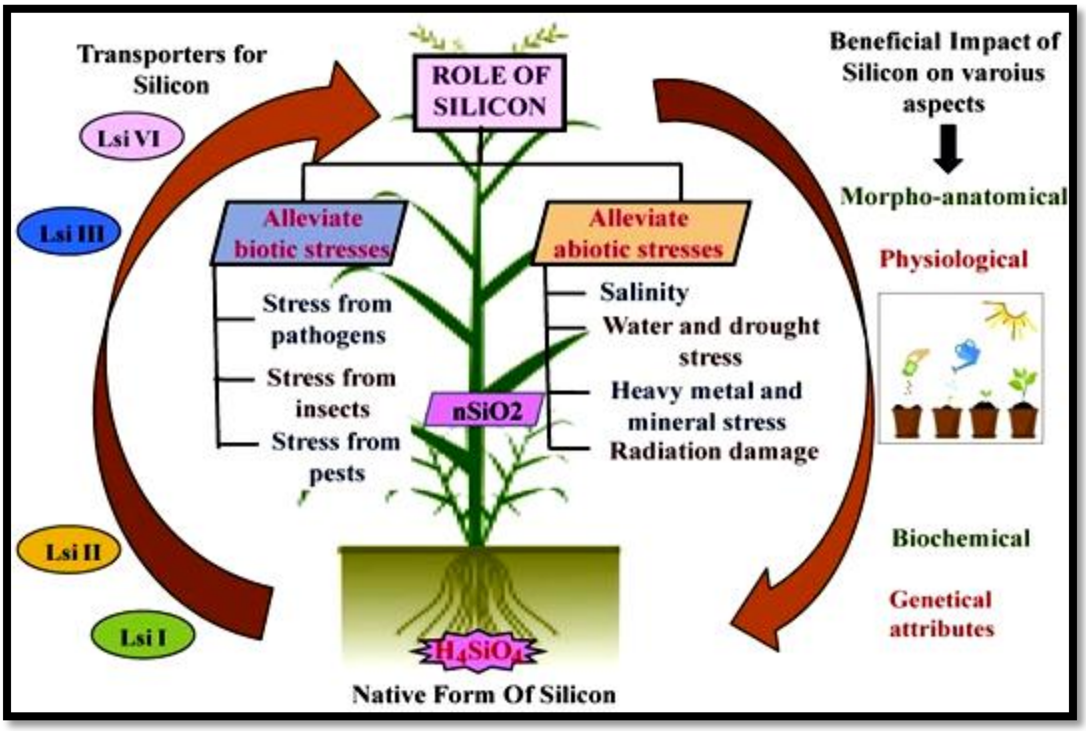
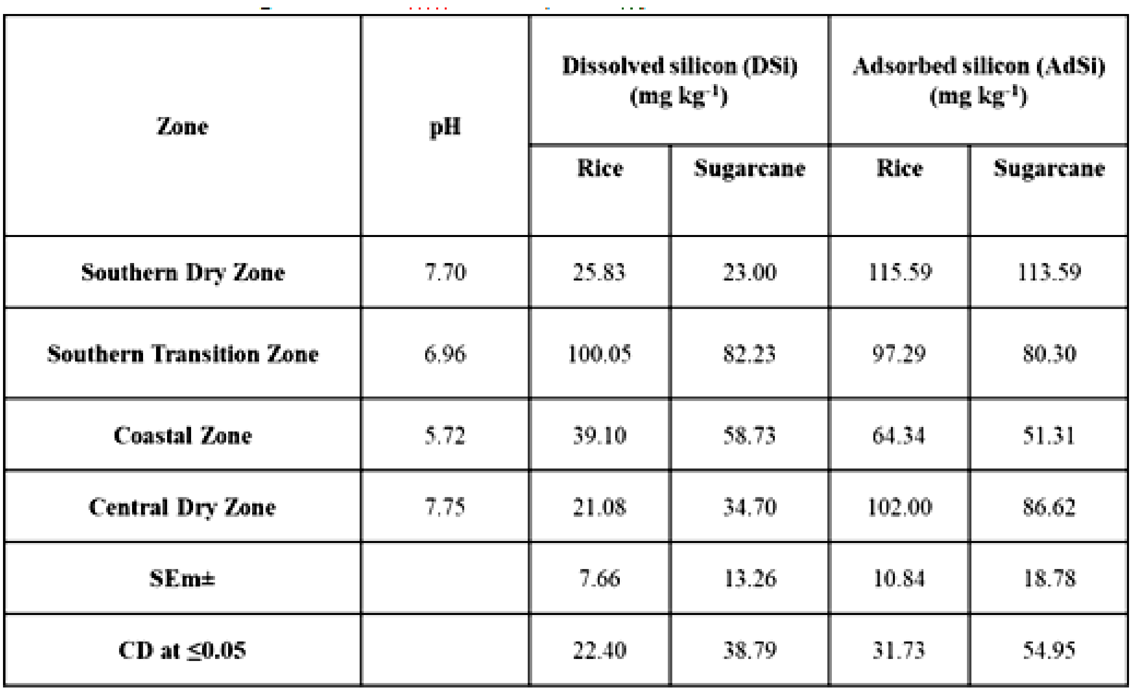


Figure 2: Benefits of Si for Plants

V. PLANT AVAILABLE SILICON (PAS)

Si is commonly found in soil in a variety of forms, particularly quartz, silicates, biogenic SiO_2(found in things like diatoms and phytoliths), and silica gel. The soil contains amorphous, active, and water soluble forms of silicon that are all extractable. Plants can readily access thewater soluble forms of silicon while the remainder of the silicon must first be transformed to a water soluble form under favourable conditions before being used by plants. (Ma *et al*., 2006).The four primary agro-climatic zones of Karnataka are the southern dry zone (SDZ), southerntransition zone (STZ), coastal zone (CZ), and central dry zone that Majumder et al. (2021) outlined the soils' plant-accessible silicon (PAS) content's vertical distribution (CDZ). No matter the crop, STZ and CZ have higher DSi contents than 40 mg kg, while SDZ and CDZ have lower DSi contents (between 20 and 40 mg kg^{-1}). The SDZ and CZ samples had the lowest levels of DSi and AdSi, respectively. The average AdSi content was 2.4 and 4 times higher than DSi in the CDZ and SDZ soil profiles of rice, respectively. In sugarcane soil profiles, CDZ and SDZ, respectively, had AdSi contents that were 2.6 and 4 times greater thanDSi levels (Table:2).



Zone	pH	Dissolved silicon (DSi) (mg kg^{-1})		Adsorbed silicon (AdSi) (mg kg^{-1})	
		Rice	Sugarcane	Rice	Sugarcane
Southern Dry Zone	7.70	25.83	23.00	115.59	113.59
Southern Transition Zone	6.96	100.05	82.23	97.29	80.30
Coastal Zone	5.72	39.10	58.73	64.34	51.31
Central Dry Zone	7.75	21.08	34.70	102.00	86.62
SEm±		7.66	13.26	10.84	18.78
CD at ≤0.05		22.40	38.79	31.73	54.95

Table 2: Relationship between Rice and Sugarcane Soil Characteristics and Silicon Accessibleto Plants in Four Different Agro-Climatic Zones of Karnataka (PAS)

Diatomite grades (diatomite-1, diatomite-2, diatomite-3, diatomite-4, and diatomite-5) and amounts (0, 250, 500, 750, 1000, and 1500 kg ha-1) have been studied to see how they affect silicon availability in acidic and alkaline soils under field capacity. Anitha *et al.* (2015) conducted a pot experiment. In both soil types, diatomite-3 and diatomite-4 applied at 750 kg ha^{-1} each together with RDF resulted in considerably higher straw and grain yields, silicon content, and rice uptake. Higher straw silicon concentration was discovered in alkaline soil ascompared to other grades of diatomite when diatomite-4 @ 1000 kg ha^{-1} + RDF was applied. This may be due to higher dissolution of Si at high pH levels as well as the mechanism of silicic acid deposit in the plant parts and dissemination in the shoots. Diatomite-4 @ 750 kg ha^{-1} + RDF treatment in acidic soil resulted in greater straw Si% content (5.9%) compared to other grade of diatomite. (Fig : 3)

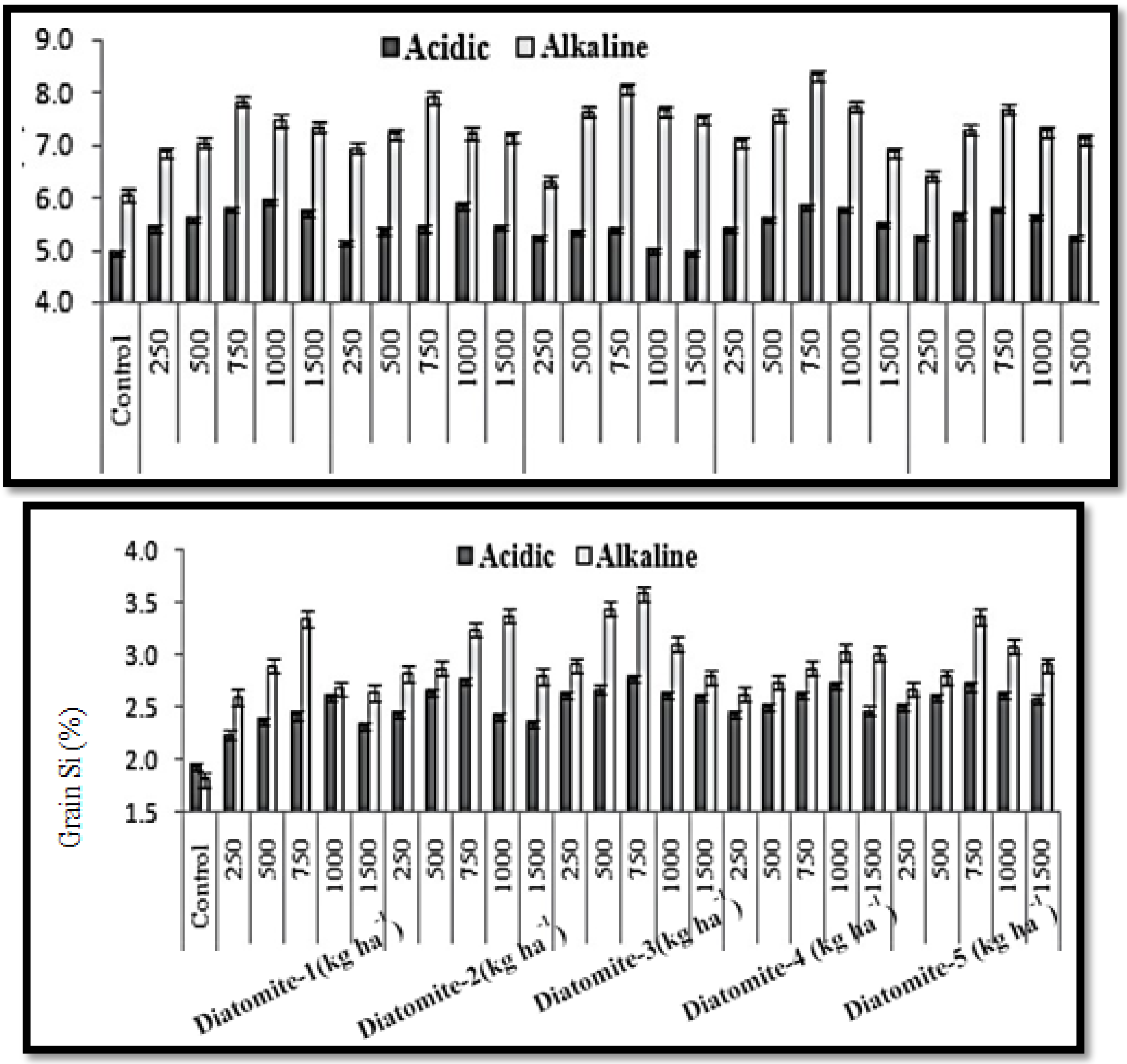


Figure 3: Evaluation of Different Grades of Diatomite on Paddy Straw and Grain Si (%) Plant inAcidic and Alkaline Soils at Harvest

As a result, diatomite can be used as a source of silicon due to the increased breakdown of themineral and release of silicon in both soils. According to Khan *et al.* (2021) reported Plants have detoxifying systems based on silicon including (1) the antioxidant defence system is activated, decreasing oxidative damage, (2) Removal of heavy metals and metalloid from the cells, (3) Relocation of heavy metals and metalloid at subcellular level (4) Improvement in photosynthetic system (5) Repair of injured cell membranes (6) Regulation of phytochelatins.

Si influences the heavy metal and metalloid uptake by plants through different mechanisms including (1) Si bioavailability in soil is influenced by biological factors, (2) by altering the soil's properties, (3) heavy metal co-precipitation, (4) heavy metals being changed into less solubility forms, (5) root architecture modification, (6) controlling antioxidant enzymes, (7) up and down-regulation of gene expression responsible for heavy metals uptake and transportationto plants (Khan *et al*., 2021).

1. **Impacts of silicon-rich amendments on metalloid and heavy metalaccumulation: Effects of silicon-rich amendments on rice's toxicity to heavy metals (*Oryza sativa* L.)** In the treatments of Fly ash (FA20) and Steel slag (SS3), the concentrations of cadmium, zinc, copper, and lead (Pb) calculated using the DGT technique (the DGT pools) all dramatically dropped (Table:3), and the reduction was at least 84%. Fly ash, steel slag, and other industrial byproducts reduced heavy metal absorption by converting soluble metals to insoluble metal silicates, phosphates, and hydroxides (Gu *et al*., 2011)

Table 3: Effects of silicon-rich amendments on rice's toxicity to heavy metals (Oryza sativa L.)

Treatments	**Cd (μg kg^{-1})**	**Zn (mg kg^{-1}soil)**	**Cu (mg kg^{-1}soil)**	**Pb (mg kg^{-1}soil)**	**pH**
Control	7.3 ± 0.30a	6.7 ± 0.73a	6.3 ± 0.79a	57 ± 7.8a	3.9–4.0d
Fly ash -1 (20 g kg)	1.7 ± 0.18b	0.56 ± 0.07c	1.0 ± 0.07b	4.1 ± 0.50c	5.0–5.2c
Fly ash -1 (40 g kg)	0.06 ± 0.01c	0.01 ± 0.01c	0.76 ± 0.08b	0.30 ± 0.04c	6.3–6.5a
Steel slag -1 (3 g kg)	2.1 ± 0.30b	1.4 ± 0.32b	1.3 ± 0.19b	9.8 ± 2.5b	4.9–5.1c
Steel slag -1 (6 g kg)	0.10 ± 0.17c	0.11 ± 0.07c	0.72 ± 0.06b	0.53 ± 0.15c	6.0–6.2b

Hamsa *et al.* (2018) assess the impact of several Si sources, such as rice hull biochar, diatomaceous earth, and calcium silicate at various quantities, minimising the absorption of heavy metals by spinach. In RDF + Diatomaceous earth @ 500 kg Si ha-1, the uptake of Cr inspinach shoot and root is 10.10 m kg^{-1} and 1.12 mg kg^{-1}, respectively, which is significantly less. Due to its increased solubility and the availability of other nutrients, diatomaceous earth application was observed to be more effective than other treatments in lowering the Cr concentration in spinach shoots (Table:4). Effect of various silicon sources on spinach's absorption of chromium

Table 4: Chromium Uptake by Spinach and the Impact of Various Silicon Sources

Treatments	**-1 Cr content (mg kg)after harvest**	
	Shoot	**Root**
Control	16.20 ±0.81 a	2.45 ±0.034 a
-1 Rice hull biochar @ 200 kg Si ha	15.40 ±0.74 ab	2.22 ±0.031 c
-1 Rice hull biochar @ 500 kg Si ha	10.70± 0.54 fg	1.95 ± 0.027 ef
-1 Diatomaceous earth @ 200 kg Si ha	11.20 ±0.56 def	1.88 ±0.026 g
-1 Diatomaceous earth @ 500 kg Si ha	**10.10 ±0.50 g**	**1.12 ±0.030 h**
-1Calcium silicate @ 200 kg Si ha	11.80 ±0.59 cde	1.83 ±0.026 g
-1 Calcium silicate @ 500 kg Si ha	10.30 ±0.52 fg	1.98 ±0.028 e

(n =3) ±SD. $p < 0.05$

Coriander's response to the combination usage of silicon nanoparticles (Si-NPs) and lead (Pb) resistant microorganisms (*Coriandrum sativum* L.) under Pb stress: The combination use of silicon nanoparticles (Si-NPs) and lead (Pb) resistant microorganisms was assessed by Fatemi *et al*. (2020) under Pb stress. It has been proposed that Si-NPs and Pb- resistant microorganisms would be employed to increase plant growth, photosynthesis, and antioxidant capacity, hence reducing Pb stress in coriander. The plants with the treatment of 500 mg/kg Pb had the highest concentration of shoots and roots, whereas the plants treated with the control treatment had the lowest concentration of Pb. Comparing the identical Pb treatments with and without the application of silicon, Pb levels in the roots and shoots decreased by 2% and 22%, respectively (Fig : 4). T1: Command, T2: 500 mg/kg of lead T3: S-6 + Pb-500 Inoculation, T4: S-19 + Pb-50 Inoculation T5: Foliar Si-NPs 1.5 mM application Si-NPs + S6 + Pb in T6, and T7: Si-NPs + S19 + Pb

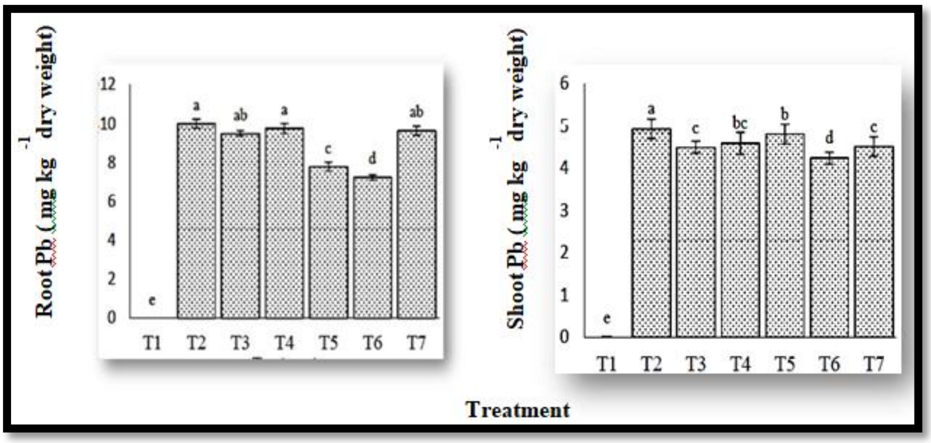
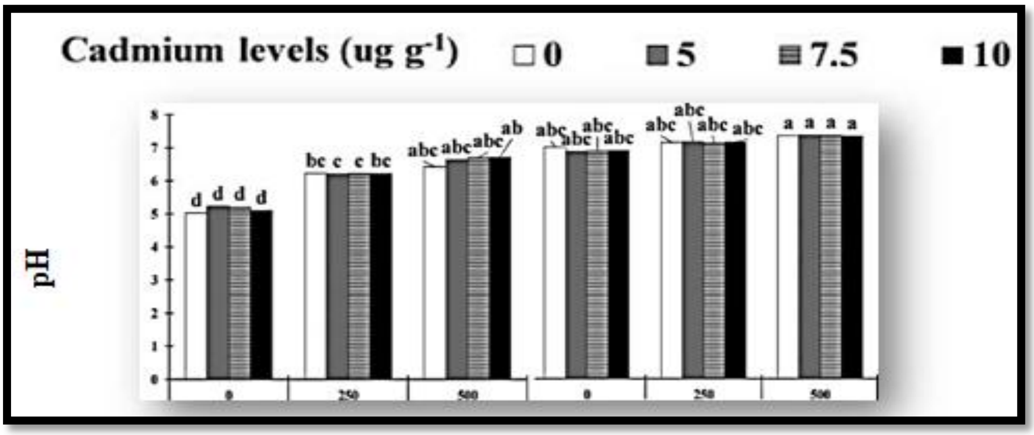


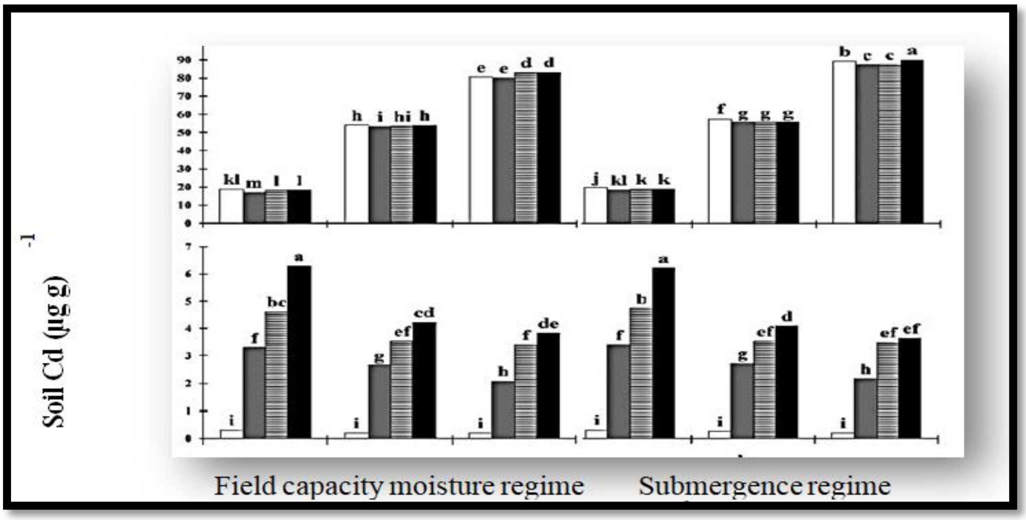
Figure 4: Coriander's response to the combination usage of silicon nanoparticles(Si-NPs) and lead (Pb) resistant microorganisms (*Coriandrum sativum* L.) under Pb stress

2. **By altering the soil's properties:** To investigate the effects of silicon on rice soil availability and cadmium uptake cultivated in a soil that has been kept under two different moisture regimes, Babu *et al*. (2017) carried out a greenhouse experiment (field capacity or submergence). Due to lowering circumstances in the soil and the addition of Si as

wollastonite, soil pH rose after keeping submergence and reachedto pH 6.5 to 7.1 during harvesting. Contrary to changes in soil pH, the amount of Cd^{2+} that wasreadily available in the soil changed. In soils that were kept in a waterlogged condition, it waslower (Fig : 5).



Field capacity moisture regime level (Kg ha_1 Submergence regime)



Silicon level (kg ha)$^{-1}$ $p<0.05$ by Tukey – Kramer post – hoc test.

Figure 5: Effect of soil pH and soil-cadmium availability and absorption in rice on siliconamendment

Effect of silica fertilisation and a nano-MnO_2 amendment on the composition of the bacterial community in paddy soils with elevated arsenic levels: According to Shao *et al*. (2015), Chloroflexi, Proteobacteria and Acidobacteria were the threephyla that predominated in all of the paddy soil samples used in this investigation. Reduced relative Chloroflexi abundance were accompanied by increases in the relative ratio of Acidobacteria and the addition of nano-MnO2. According to earlier research, low soil pH was advantageous to Acidobacteria and substantially regulated the amount of Acidobacteria present. Arsenite methylation, volatilization, arsenite reduction, and efflux are just a few of thedifferent ways that cyanobacteria, including Microcystis, Nostoc, and Synechocystis, detoxify arsenic. Under silica fertilisation or amendment with nano-

MnO_2, the amount of bioavailable arsenic reduced (Fig: 6). If silica fertilisation or nano-MnO_2 amendment reduce arsenic biotoxicity (Table : 5), cyanobacteria may compete less fiercely, resulting in a reduction in the relative abundance of this microorganism in the environment.

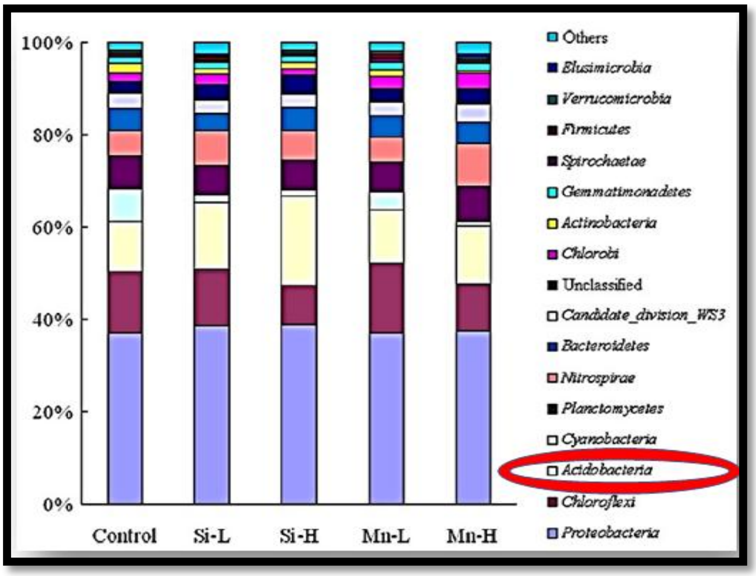


Figure 6: Effect of silica fertilisation and a nano-MnO_2 amendment on the composition of thebacterial community in paddy soils with elevated arsenic levels

Table 5: Effect of a nano-MnO2 Amendment and Silica Fertilisation on the Bacterial Diversityin Arsenic-Contaminated Paddy Soil

Treatment	Bioavailable As -1 (mg kg)	pH
Control	a 0.95±0.14	a 7.35±0.05
Si-L	b 0.66±0.05	ab 7.25±0.07
Si-H	bc 0.55±0.13	b 7.26±0.01
Mn-L	bc 0.55±0.01	ab 7.33±0.04
Mn-H	c 0.36±0.02	b 7.25±0.01

Means ± SD ($p<0.05$)

3. Heavy metal co-precipitation

Comparison of organic and inorganic silicon fertilisers' effects on wheat's (*Triticum aestivum* L.) Cd/Pb accumulation: Through a soil pot experiment, the effects of three silicon fertilizers—two organic (OrgSiFA and OrgSiFB) and one inorganic (InOrgSiF)—on wheat heavy metal uptake and biochemical parameters in a soil with concurrent Cd and Pb contamination were evaluated and contrasted. By increasing Si uptake in roots and shoots using OrgSiFA, OrgSiFB, and In OrgSiF, the Cd and Pb accumulation in wheat shoots, bran, and flour was reduced. In particular, the amount ofCd and Pb in the flour was reduced by 17%, 10%, and 31%, and by 74%, 53%, and 48%, respectively (Huang *et al*., 2019) (Table:6).

Table 6 : Wheat (*Triticum aestivum* L.) Cd/Pb Accumulation and the Effectiveness of Organic and Inorganic Silicon Fertilisers

	Cd concentration				**Pb concentration**				**Si concentration**		
	Root	Shoot	Bran	Flour	Root	Shoot	Bran	Flour	Root	Shoot	Grain
	1	1	1	1	1	1	1	1	1	1	1
Control with common fertilizer	1.07	1.44	2.22	1.46	1.06	1.67	3.72	3.84	0.57	0.84	0.90
Org Si FA	1.05	1.24	1	1.22	1.51	1.21	2.11	1	1	0.97	0.81
Org Si FB	1	1.34	1.79	1.31	1	1.30	1.50	1.82	0.90	1	0.42
Sodium silicate with common fertilizer	1.05	1	1.38	1	1.06	1	1	2.02	0.87	0.92	1

Results of standardised data on the Cd and Pb contents of wheat root, shoot, bran, and flour, as well as the Si content of wheat root, shoot, and grain

Exogenous Si's effects on rice (*Oryza sativa* L.) Cd toxicity and translocation: In a experiment with rice (*Oryza sativa* L.), Zhang *et al*. (2008) showed that the addition of Compared to the zero-Si treatment, Si increased shoot and root biomass by 125–171% and 100–106%, respectively(Fig : 7). In comparison to the treatment without silicon supply, siliconsupply reduced the Cd concentrations in the shoot by 30–50% and the Cd distribution ratio by 25.3–46% (Table : 7).

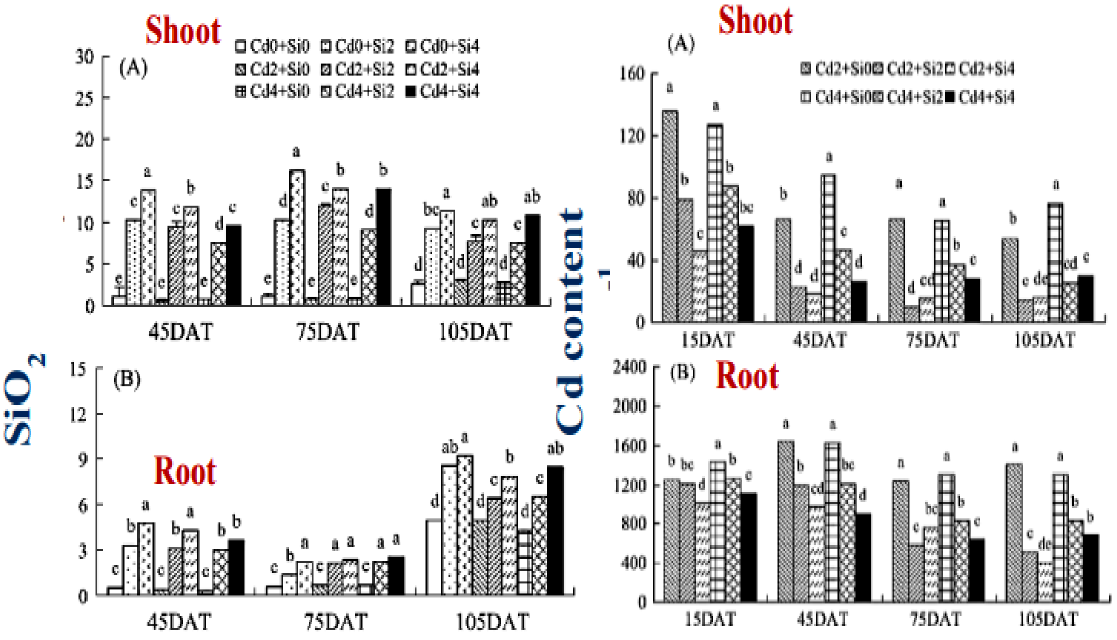


Figure 7: Effects of exogenous Si on Cd translocation and toxicity in rice (Oryza sativa L)

Table 7: Impact of Si on the distribution of Cd in rice shoots (*Oryza sativa* L.)

Cd concentration ($\times 10^{-6}$ mol L^{-1})	**SiO_2 Concentration ($\times 10^{-3}$ mol L^{-1})**	**Days after Cd treatment**			
		15	45	75	105
		Cd distribution in shoots (% of total Cd in plant)			
2	0	^{a} 30.0	^{b} 11.7	^{a} 12.5	^{ab} 9.9
	2	^{b} 23.1	^{c} 6.62	^{b} 5.65	^{ab} 8.7
	4	^{c} 16.2	^{c} 6.08	^{b} 4.57	^{b} 7.4
4	0	^{b} 24.2	^{a} 17.3	^{a} 11.6	^{a} 12.5
	2	^{bc} 21.9	^{b} 11.5	^{a} 11.0	^{ab} 10.4
	4	^{bc} 18.5	^{bc} 8.1	^{a} 10.5	^{ab} 10.0

Effect of Si on composition in the Fe minerals of Fe plaque and shoot As in rice: Amaral *et al*. (2017) evaluate Si's effects on the mineral makeup of root Fe plaques and howthey affect rice's uptake of As. Si content is essential for managing the concentration of shoot As. Rice shoot As accumulation and inorganic rain As content are both affected by increasing solution Si and ferrihydrite concentration, higher Si's ability to precipitate and encrust As containing ferrihydrite, and lower ferrihdrite. As a result, As becomes less mobile as Si precipitates, resulting in plaques of As carrying ferrihydrite (Fig : 8).

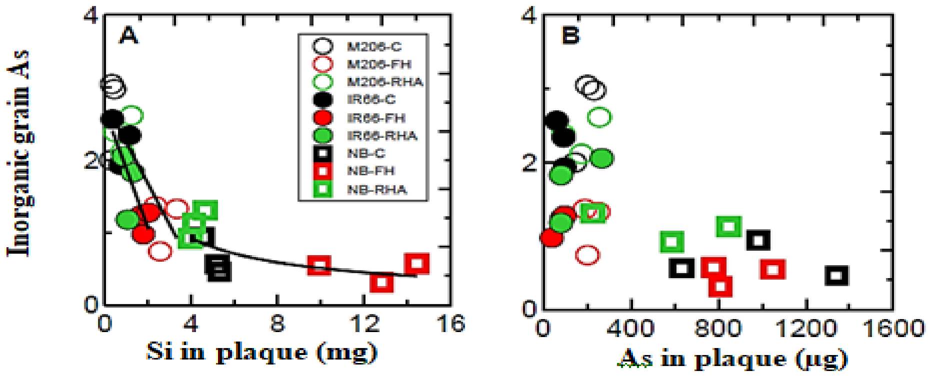


Figure 8: Impact of Si on the Modifications in the Fe Mineral Composition of Fe Plaque As in rice

4. **Heavy metals being changed into less solubility forms Effect of silicate on Cd uptake into cells of wheat by phytochelatins formation:** To investigate whether and how silicate (Si) effects cadmium (Cd) uptake at the cellular level in wheat, Greger *et al.* (2015) performed a pot experiment in wheat. Plants treated to all four treatments had their roots and shoots examined for the expression of genes related to Cd absorption, including phytochelatin (PC) content and PC gene (PCS1) expression (Fig : 9). Si promoted PC formation in the presence of Cd. Si-treated plants had higher PCS1

expression, which was much stronger in plants that had received Cd treatment. Protoplasts exposed to Cd or Cd^{2+} + Si contained PC2. Plants exposed to all treatments and controls both contained glutathione (GSH). Cell wall-bound Si hindered Cd absorption into cells, preventing Cd uptakeinto cells. Si may affect both the release of Cd from the inner side of the membrane and the binding of Cd to the membrane's uptake sites. Additionally, additional Si might bind to one Cdtransporter, preventing the transport in the event that another transport route is available. Treatments are : Control = 0 mM Si + 0 µM Cd, Si = 1 mM Si, Cd = 1 µM, Si+Cd = 1 mM Si + 1 µM Cd

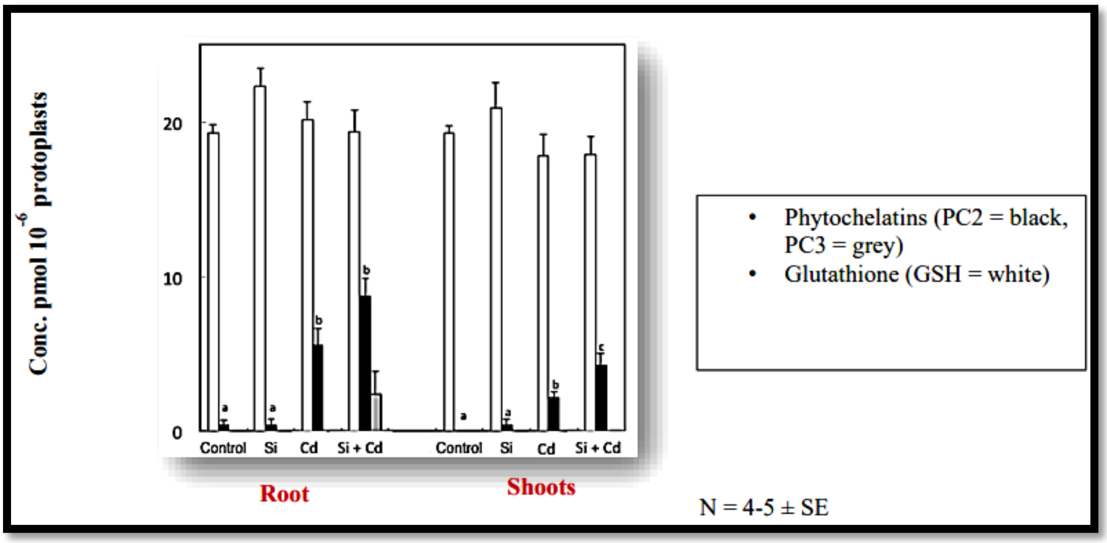


Figure 9: Effect of Silicate on Cd Uptake into Cells of Wheat by Phytochelatins Formation

Effect of silica nanoparticles in alleviating Cd toxicity in rice cells: Cui *et al*. (2017) conducted an experiment and used the CELLQuest programme to monitor the rice cells that had been treated. The threshold was established by the fluorescence emission in M2 areas, which represented the dead cells. The live cells and the dead cells, respectively, were represented by the fluorescence emission in the M1 and M2 regions. The vitality of the cells after the various treatments can be clearly seen in the data. The proportion of live cells exhibitedthe reverse tendency, and the number of dead cells was much higher in the absence of the SiNPs than it was in the presence of them (M1 area)(Fig : 10). After 48 hours of cultivation under the control circumstances, it was found that there were significantly more dead cells (65.5%) than live cells (34.5%). However, the percentage of viable cells was dramatically raised to 95.4%, 78.6%, and 66.2%, respectively, by the addition of 19 nm, 48 nm, and 202 nm SiNPs. Cells and protoplasts gradually increased in average Cd content with rising Cd concentrations in the medium in the absence of the SiNP treatments, and the protoplast's Cd content was only marginally lower than that of the cells. The diameter of SiNPs was favourably linked with the Cd concentrations of the cells and protoplasts. Cd^{2+} entry into cells was diminished in a size- dependent manner as a result of the large particles offering fewer Cd^{2+} binding sites than the small particles. More Cd binding sites are made available by the increased Si concentration in cell walls, which prevents Cd from entering cells (Fig : 11).

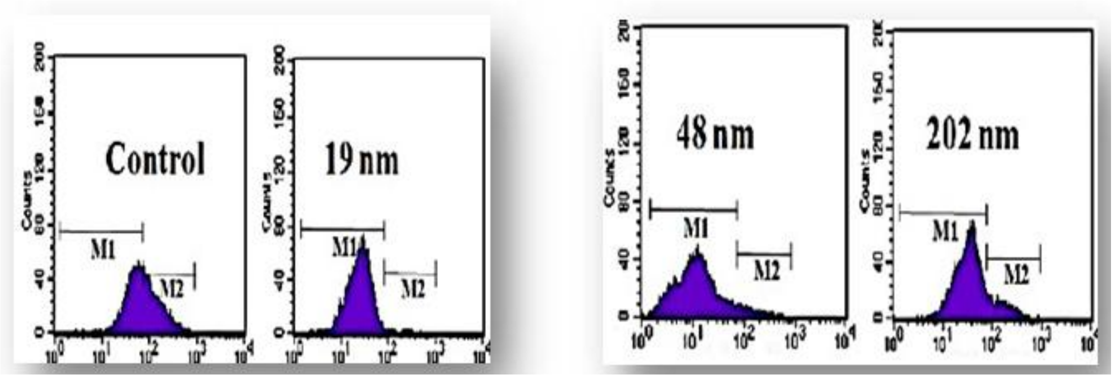
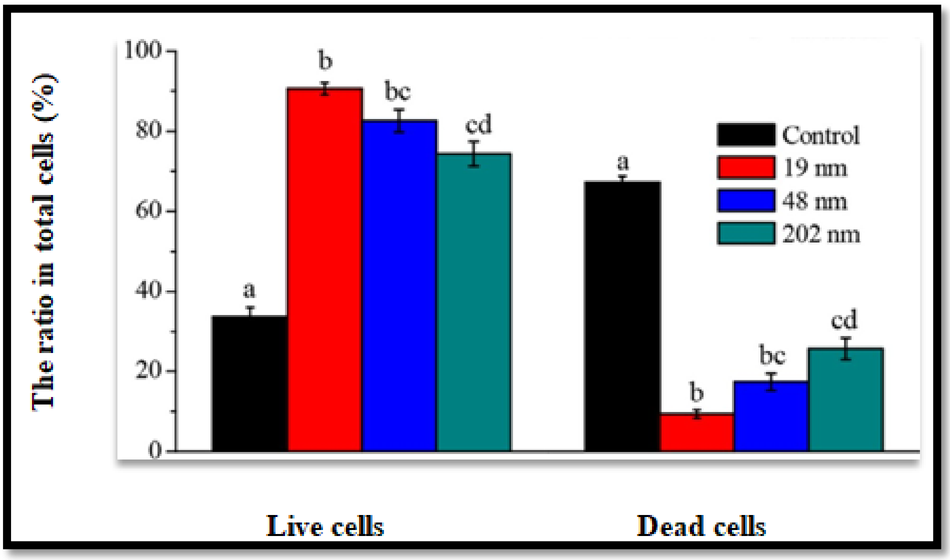


Figure 10: Fluorescence Emission in the M1 and M2 Regions



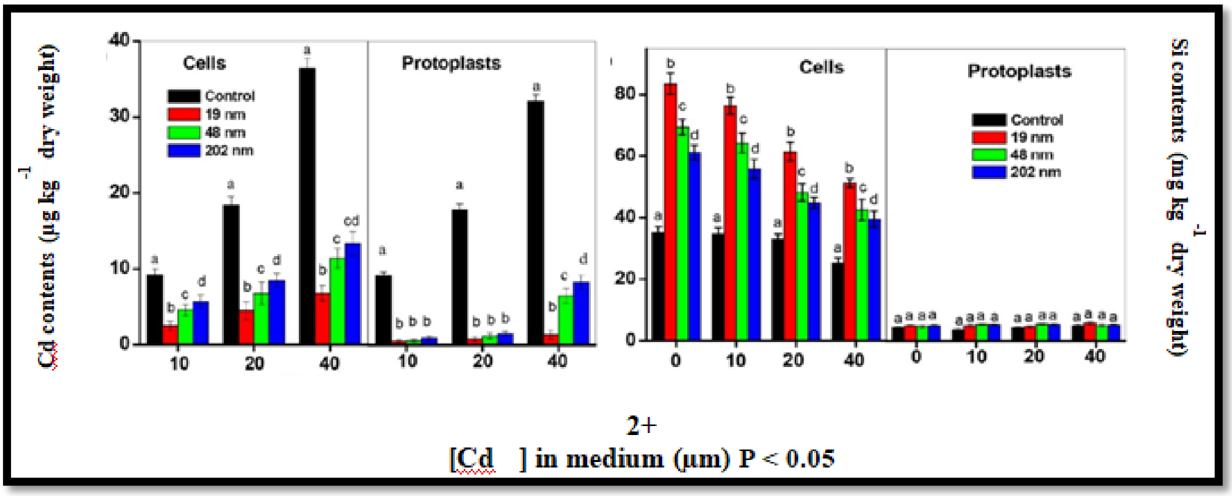
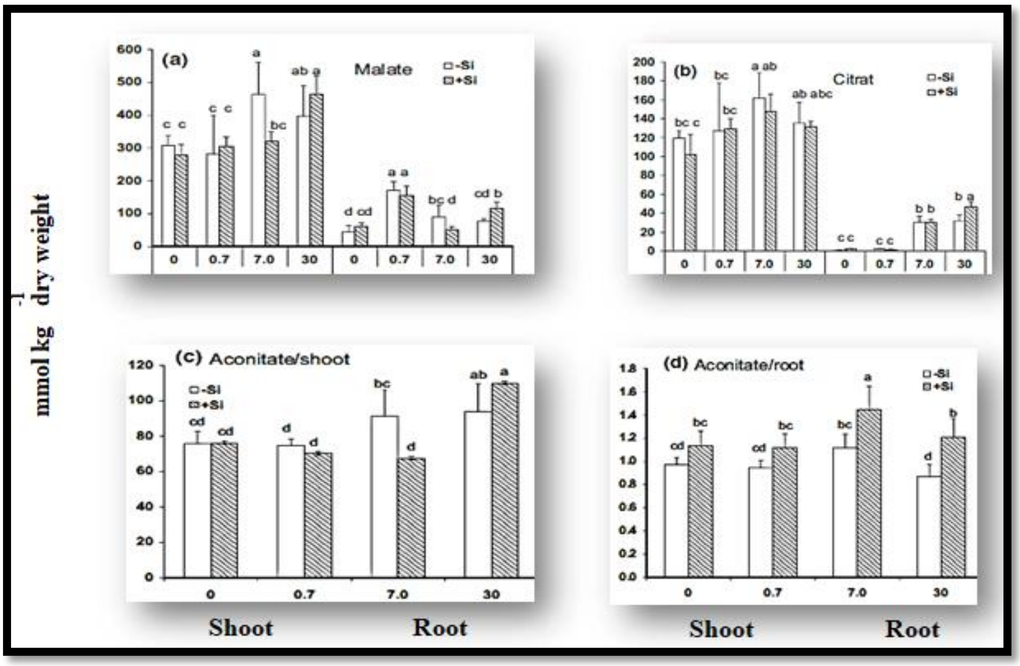


Figure 11: Effect of Silica Nanoparticles in Alleviating Toxicity of Cd in Cells (Rice)

Effect of Si on Cu uptake by wheat seedlings (*Triticum turgidum* L.) by complex formation: Durum wheat (*Triticum turgidum* L.) cultivated in 0, 0.7, 7.0, and 30 M Cu without and with1.10 mM Si is examined for its effect on Cu tolerance (Table:8) was investigated in a hydroponic study, along with the mechanisms involved in reducing Cu toxicity. Compared to the same Cutreatment without Si, Si application considerably reduced the concentration of Cu in the shootsin the Cu 30 M + Si treatment. In the Si treatment, the concentration of malate, citrate, and aconitate (Fig : 12) was higher in the shoots than the roots, which can bind the Cu and preventits concentration by complex formation (Keller *et al.*, 2014*)*.

Table 8: Effect of Si on Cu uptake by Wheat Seedlings (Triticum Turgidum L.) by Complex Formation

Treatment		Si	Cu
0 µM Cu, 0 mM Si n = 3	m	0.77	0.00
	sd	0.12	0.00
7 µM Cu, 0 mM Si n = 4	m	0.12	0.04
	sd	0.05	0.00
30 µM Cu, 0 mM Si n = 4	m	0.75	0.04
	sd	0.35	0.02
0 µM Cu, 1 mM Si n = 3	m	1.23	0.00
	sd	0.32	0.00
7 µM Cu, 1 mM Si n = 4	m	0.63	0.03
	sd	0.30	0.02
30 µM Cu, 1 mM Si n = 4	m	0.48	0.08
	sd	0.19	0.01

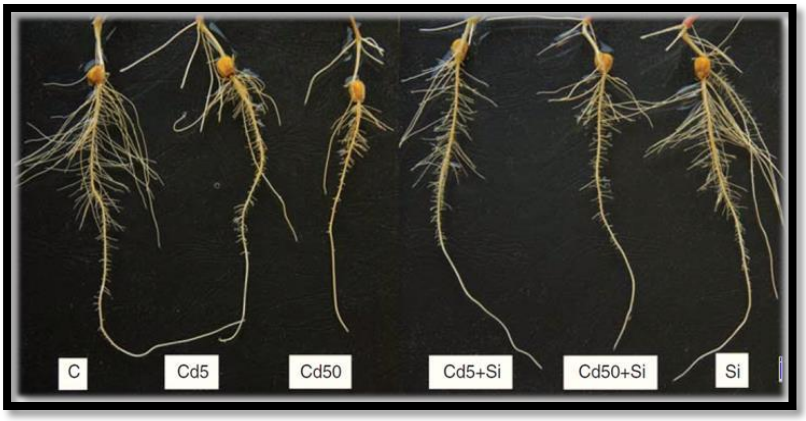


Cu] in solution µMBars showing sd of four replicates, P ≥ 0.05

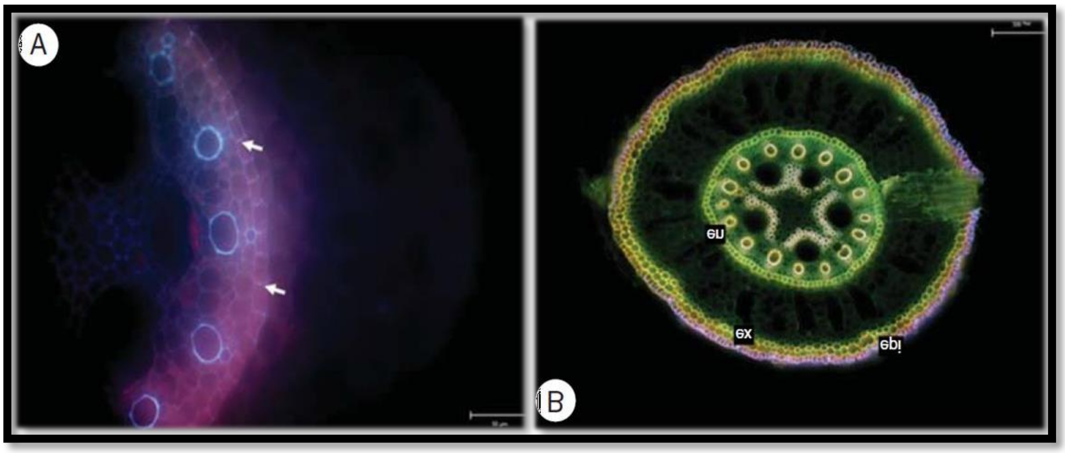
Figure 12: Effect of silicon on wheat (Triticum turgidum L.) seedlings' absorption of Cu bycomplex formation

5. Root architecture modification

Effect of silicon on root modification and cadmium uptake in young maize plants: In order to assess the impact of Si on Cd uptake and cellular distribution in connection to the growth of root tissues, Vaculik *et al.* (2012) performed a hydroponic experiment on a maize plant. Compared to controls, the addition of Si improved seminal roots' branching. Increased Cd treatment was favourably linked with the Cd concentration in maize roots. Compared to control plants, roots treated with Cd5 closer to the root apex, Cd5 formed suberin lamellae and casparian bands in particular.Individual endodermal cells began to suberize farther away from the root apex in Si-treated roots than in control roots. When compared to untreated rice plants, Si enhanced the endodermal and exodermal root tissues' suberization and lignification.Exodermis is less effective than endodermis at blocking apoplasmic Cd transfer (Fig : 13).



Scale = 10 mm

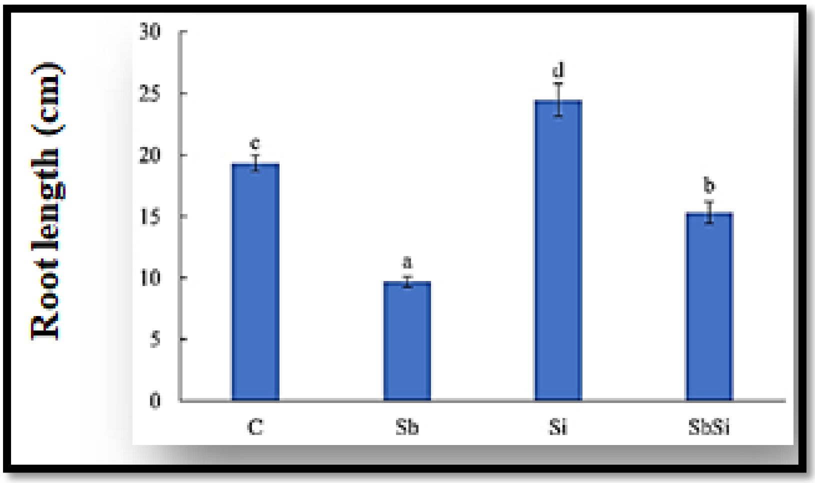


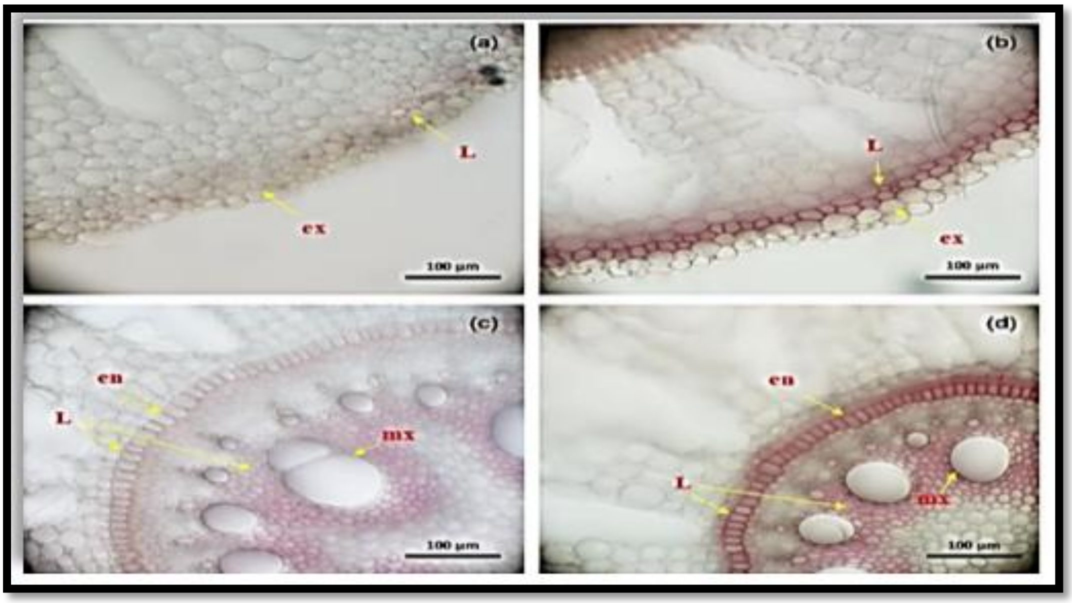
(A) Young root cross- section of Maize (scale bar = 50 mm).
(B) A cross-section of youngmaize plants' basal region (scale bar =200 mm).

- epi = epidermis;
- ex = exodermis;
- en = endodermis

Figure 13: Effect of Silicon on root Modification and uptake of Cadmium in Young Maize Plants

By altering the root architecture, si can reduce antimony phytotoxicity in giant reed(Arundo donax L.) Shetty *et al.* (2021) carried out a greenhouse experiment to test the gigantic reed's tolerance to Sb toxicity and the ability of Si to lessen its phytotoxicity. Sb very slightly boosted root lignification when compared to control plants, but it significantly deepened endodermal layer lignification, proto and early metaxylem vessels, and lignified central pith, were identified in SbSi treated roots considerably compared to plants treated with Sb, closer to the root apex (Fig : 14). The fact that Si-enhanced lignification of root structures likely restricts transfer of Sb tothe shoot further explains why SbSi treated plants have lower Sb concentrations in their shoots(Fig :15).





Lignifications (red color)a,b=30%, c,d=90% of root length
(L lignification, ex exodermis, en endodermis, mx meta xylem)
C = Control, Sb = Sb 20 mg L, Si = 1 mM,SbSi = Sb 20 mg L + Si 1
MmMeans ± SE (n = 3). $p < 0.05$.

Figure 14: Effect of Si in Reducing Phytotoxicity caused by Antimony in Gigantic Reed (ArundoDonax L.) by Changing Root Architechture

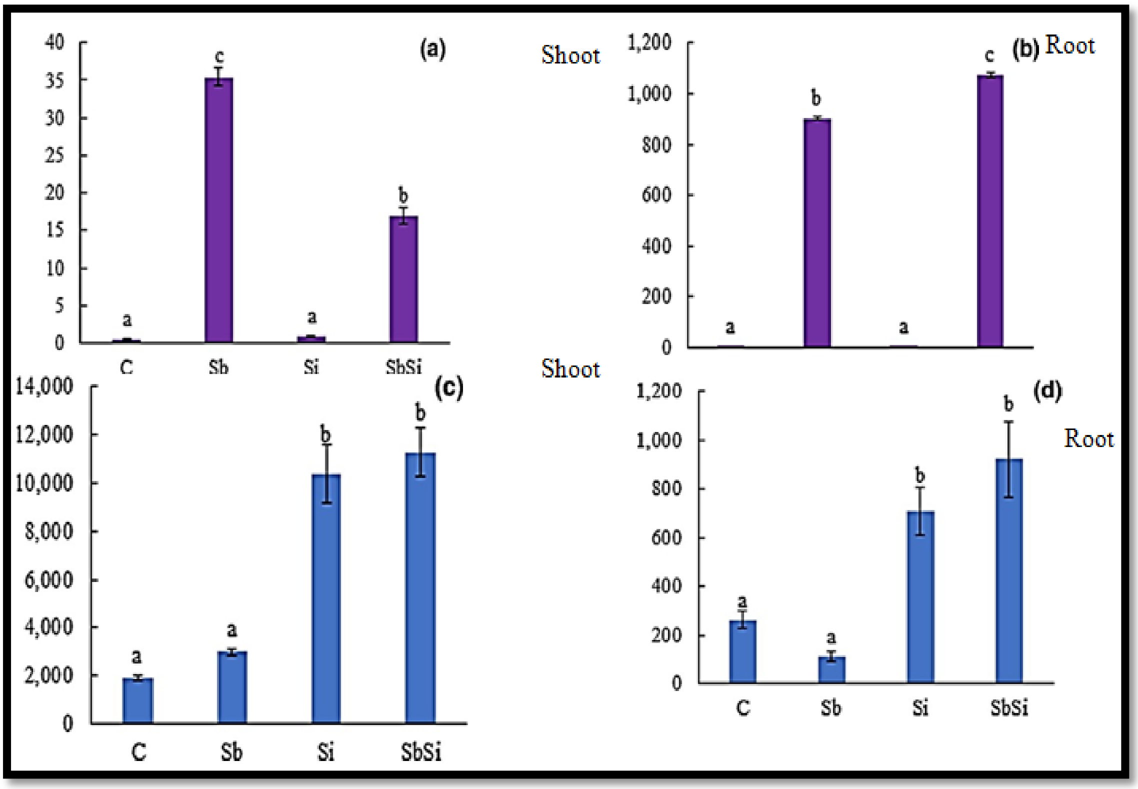
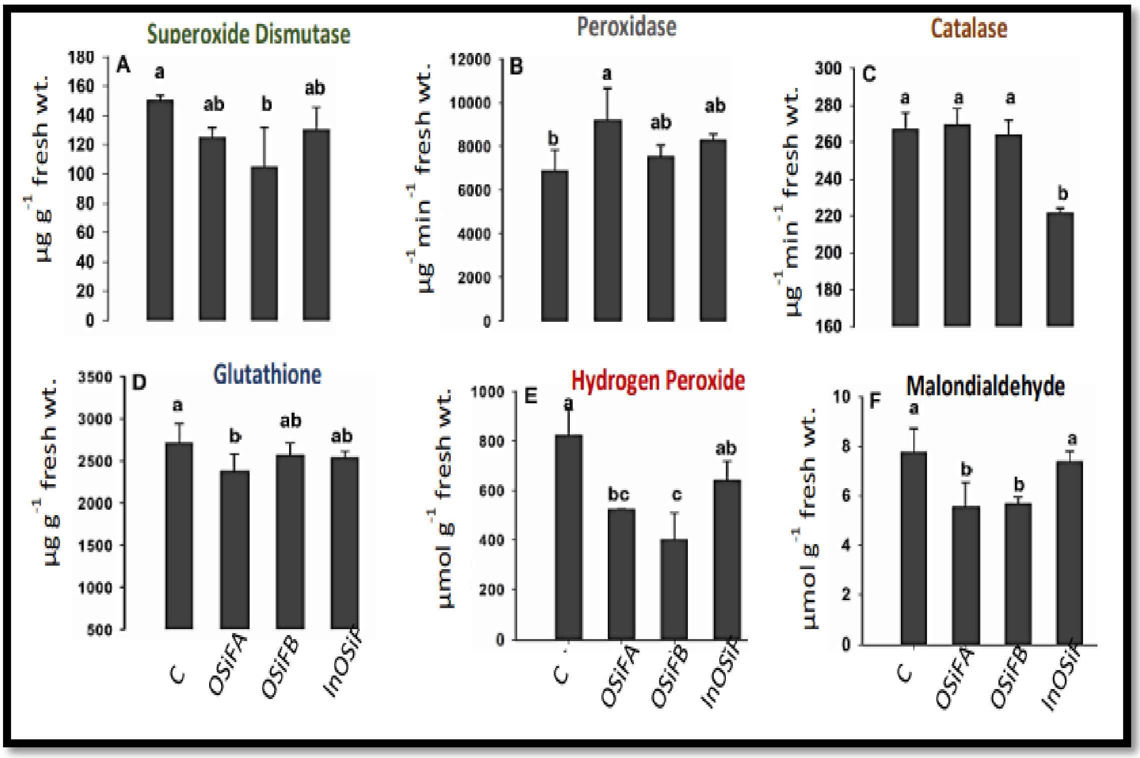


Figure 15: Effect of Si in Alleviating Antimony Phytotoxicity in Giant Reed (*Arundo Donax* L.) by Changing Root Architechture

Given that the roots of SbSi plants contained more Sb than the roots of Sb treated plants, the addition of Si to Sb treated plants promoted root lignification, possibly as a defensive reaction. The lignification of root structures with Si enhancement, which is expected to obstruct Sb translocation to the shoot, provides another explanation for the reduced Sb concentration in theshoots of SbSi treated plants.

6. **Controlling antioxidant enzymes: Wheat (*Triticum aestivum* L.) antioxidant response and the comparative effectiveness of organic and inorganic silicon fertilizers:** The byproducts of peroxidation under stress are hydrogen peroxide (H2O2)and malondialdehyde (MDA), which can seriously harm the cell membrane system. When compared to the control, both Si fertilisers considerably reduced the amount of H2O2 and MDA present in wheat. In comparison to CK and InOSiF, OSiFs considerably reduced their H2O2 levels by 36%-51% and 18%-31%, respectively, and their MDA by 27%-28% and 23%-25%, respectively. By achieving a balance between the osmotic pressure of the environment and the osmotic strength of the cytoplasm and vacuoles, Superoxide Dismutase (SOD) and Catalase(CAT) together transformed superoxide radicals and H2O2 into H2O and produced more Glutathione (GSH) for plant cells protection (Fig : 16).



Mean (n=3) ± SD; $p < 0.05$
CK = Control
OSiFA = Organosilicon fertilizer A, OSiFB = Organosilicon fertilizer BInOSiF = Sodium silicate with common fertilizer

Figure 16: Comparison of the Effects of Organic and Inorganic Silicon Fertilisers on the Production of Antioxidants in wheat (Triticum Aestivum L.)

According to Farooq *et al.* (2013), application of Si lessens Cd toxicity in cotton by lowering the levels of malondialdehyde and hydrogen peroxide and increasing the activity of antioxidant enzymes. Although Cd does not directly produce ROS, it nevertheless triggers an oxidative burst by interfering with the body's defences against free radicals, which boosts MDA levels because lipid peroxidation. This is one of the main mechanisms underpinning the stress that Cd causes in plants (Fig :17).

Alleviation of cadmium toxicity by Si in oxidative stress condition in cotton

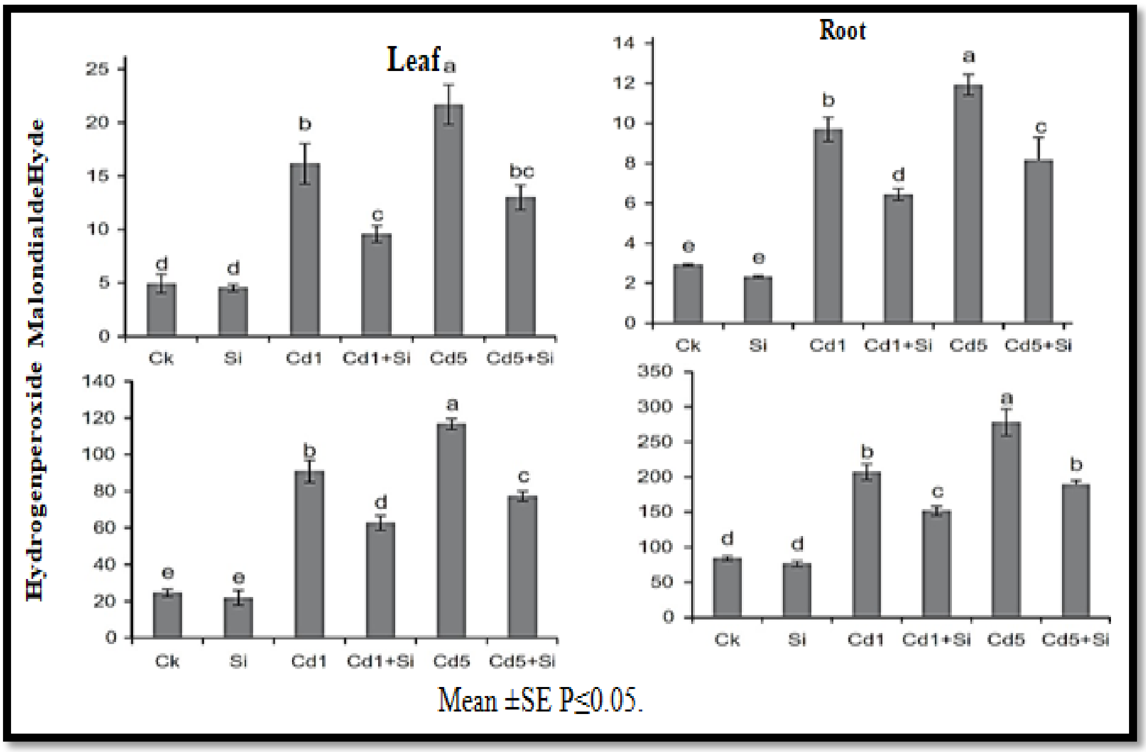
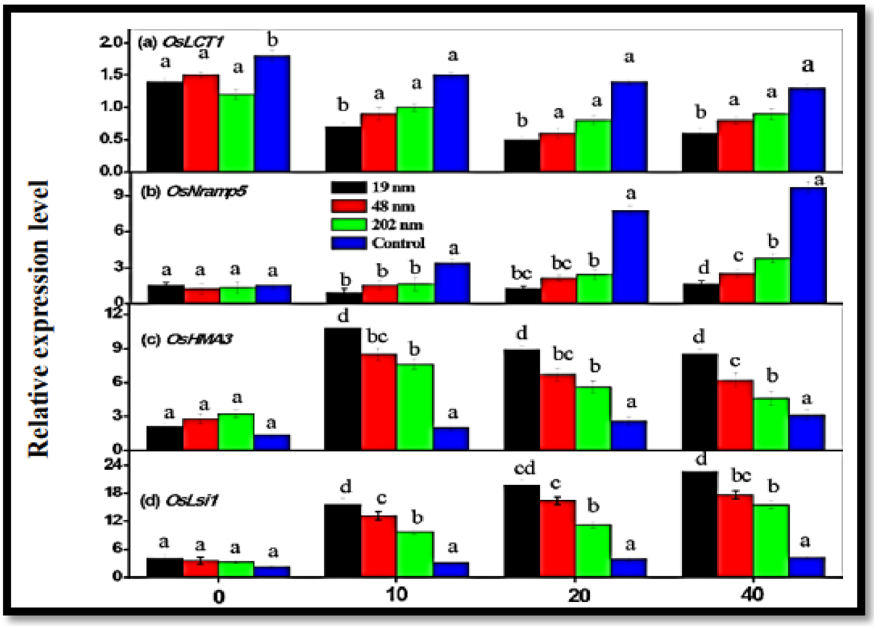


Figure 17: Alleviation of Cadmium Toxicity by Si in Oxidative Stress Condition in Cotton

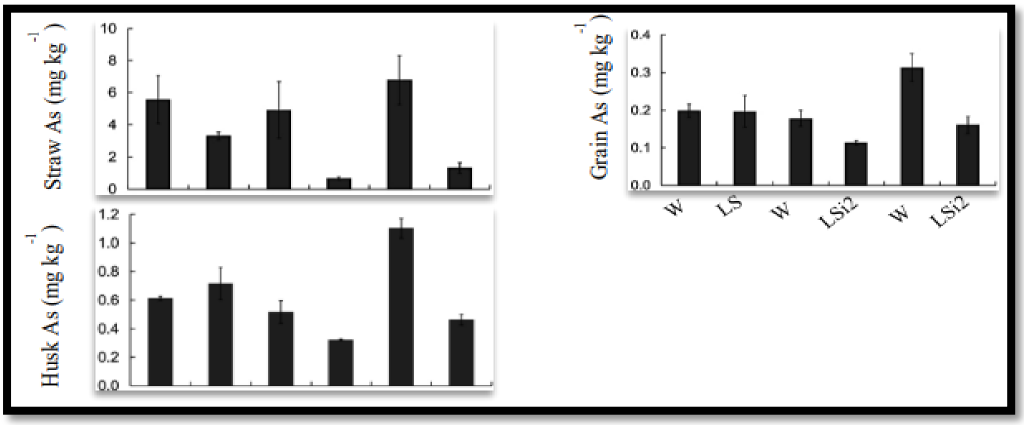
7. **Up and down-regulation of gene expression responsible for heavy metals and metalloid uptake, accumulation and transportation to plants: Through the expression of genes, silica nanoparticles reduce the toxicity of cadmium in rice cells** According to Cui *et al.* (2017), silicon nanoparticles can lower the absorption of Cd into rice grains and phloem by 16.7% to 64.3% above control by decreasing the expression of the OsLCT1 low affinity cation transporter. SiNPs decreased the gene expression for uptake of Cd and Cd transport (OsLCT1 and OsNramp5), but they increased the expression of the genes for Cd transport into the vacuole (OsHMA3) and Si uptake (OsLsi1). These findings show that the presence of SiNPs boosted Si absorption capacity by at least 1.87 times and decreased capacity of Cd uptake, which jointly reduced the toxicity of Cd in rice (Fig :18).



Means ± SD (P < 0.05). Cd^{2+} concentrations in 10, 20 and 40 μm 1.0 mM SiNPs sizes of 19 nm, 48nm, and 202 nm

Figure 18: Cadmium Toxicity is reduced in Rice Cells by Silica Nanoparticles by GeneticExpression

Effect of silicon transporters on rice's ability to absorb, accumulate, and transport heavy metals: Three mutant cultivars of rice were grown in a experiment on soil with a total As level (5.3 mg/kg) to investigate the role that the Lsi1 and Lsi2 transporters play in the As accumulation in rice. Ma *et al.* (2008). As concentrations in straw were decrease in all three mutants than in the wild type, with the two lsi2 mutants having concentrations that were just 13–19% of the equivalent wild-type rice. In contrast, the grain As concentration in both lsi2 mutants was considerably (P 0.01) lower than that of wild-type rice, being 63% and 51% of the corresponding wild-type rice, respectively (Fig: 19).



Means ± SD (*n* = 3).

Figure 19: Impact of Silicon Transporters on Heavy Metals Uptake, Accumulation, and Transportation by Rice

VI. CONCLUSIONS

1. To reduce the threats to the environment and human health caused by acidic soil contaminated with several metals, fly ash and steel slag application may be a viable option.
2. Si application changes soil pH , microbial community etc which reduce the available form of heavy metals and metalloid
3. Si application enhance formation of phytochelatins, oranic and inorganic ions which can form complex with heavy metals and metalloid and reduce their availability in plants
4. Most SiNPs alleviate heavy metals and metalloid toxicity by concentrated on the cell walls and bind them to prevent entering into the cell.
5. Si application enhanced root lignification as a defence reaction restrict the heavy metals and metalloid translocation to the shoot
6. Applying Si lowering reduces the uptake and buildup of metalloids and heavy metals via decreasing ROS damage through improved antioxidant enzyme activity.
7. Si application can reduce plant heavy metals and metalloid uptake by stimulating the Si transporter (OsLsi1); and inhibiting the heavy metal transporters.

VII. FUTURE PROSPECTS

1. To assess the viability in application of Si for the cleanup of metal-contaminated soils, extensive field tests are needed
2. To clarify the potential coexistence of Si and Cd in the endodermis of roots or in phytoliths of shoots, additional research is necessary
3. More research should be done on the Si-NPs dispersion and plant migration, as well asthe potential impact of microbial communities in the soil's rhizosphere
4. Further investigation at the transcriptome level is necessary to determine the specific mode of action and underlying mechanism of Si-mediated regulation of antioxidant enzymes in plants under abiotic stress conditions
5. Finding the allelic differences in LSi1 and LSi2 that prefer uptake of silicon over arsenite requires additional research

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