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A Comparative Study of Phytoremediation of Cd and Cr in Soil Using Silica-infused *Brassica juncea L. and Vigna radiata*

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Heavy metals are added to the soil as a result of industrialization. Removing this heavy metal from the soil is a difficult procedure, and phytoremediation is an essential and effective method for remediation. Heavy metals present in the study area included are Cd and Cr. Two plants namely *Brassica juncea L.* and *Vigna radiata* were successfully grown on the soil contaminated with Cd and Cr using the Silica powder obtained from coconut husk and paddy straw is also found to have heavy metals absorption properties without decreasing the nutrient status of the soil which was observed from the study. The remediation capacity is measured using Atomic Adsorption Spectroscopy. *Brassica juncea L* remediates the heavy metals Cr (600≤ 560≤ 450 ppm) with higher efficiency while *Vigna radiate* remediates Cd with higher efficiency (450 ≤ 400 ≤ 380 ppm) respectively. The accumulation rate of these heavy metals was observed in the root and shoot growth as the metal prove to be the hyper accumulators. This paper investigated the uptake of heavy metals from roots to shoots, as well as their bioconcentration and the remediation efficiency of the p heavy metals by hyper accumulators.

With the increase in Industrialization and urbanization, the pollution by heavy metals such as arsenic, cadmium, chromium, etc accumulates in water and soil rapidly. As the heavy metals are non-biodegradable and toxic, they accumulate in the environment causing devastation to the living organisms thereby. Few heavy metals have got carcinogenic and mutagenic properties at lower concentrations. Phytoremediation is the process by which plants are used for remediating contaminated sites. *Brassica juncea L.* and *Vigna radiata* are found to have high heavy metals tolerating capacity. But plants that uptake heavy metals are slow growing and produce very little biomass and they uptake very little heavy metals in a short span. Silica obtained from coconut husk and paddy straw is also found to have heavy metals absorption properties. When silica is fused along with the Phyto remediating plant, the efficiency of the process increases. Silica powder is used in soil, while silica gel is made to float in hydroponics. The remediation capacity is measured using Atomic Adsorption Spectroscopy.

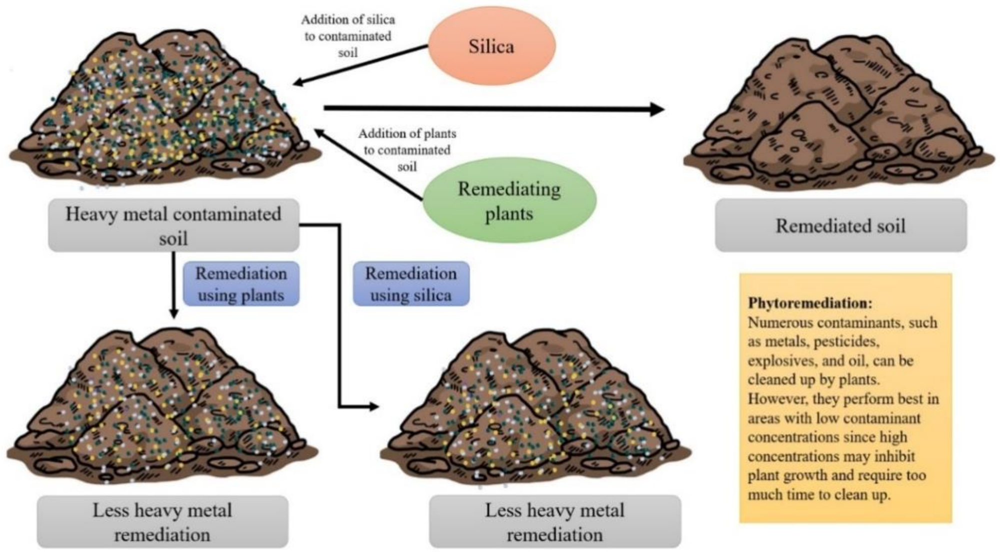

Fig. 1. Graphical abstract

Keywords: Heavy metals; phytoremediation; Brassica juncea; Vigna radiata; silica powder.

1. INTRODUCTION

Soil pollution has become a significant issue in many countries due to increased industrialization [1]. Industrial activity such as fast urbanization, and population increase have contaminated the environment and negatively impacted the quality of the air, water, and soil. Heavy metals rank first among the most important soil pollutants coming from both natural and man-made sources because of their long-term harmful effects [2]. In regions with high industrial activity, soil metal content is typically seen to increase. These places have a few times more metal build-up than pristine sites [3]. Heavy metals, unlike some biological compounds, do not degrade over time, and while they are essential to life at some levels, they become poisonous when their levels exceed the limit values [4]. It is recognized that heavy metals can be carcinogenic, teratogenic, poisonous, or lead to cardiovascular issues when they are ingested into humans at concentrations greater than the limit values recommended by the World Health Organization (WHO) [5]. As a result, metal pollution in places where there are agricultural operations is a serious concern [6]. Heavy metals, unlike other organic materials, do not decompose over time, even though they are necessary for life at particular amounts [7]. Mining, industry, and agriculture have accelerated the release of metals into ecosystems, causing serious environmental problems and posing a threat to human and animal health [8]. Excessive metal concentrations in contaminated soils can degrade soil quality and possibly contaminate the food chain. Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni), and Zinc (Zn) are the most common heavy metals found at hazardous waste sites. Industrial wastes have the potential to contaminate the groundwater and soil [9]. Around the world, the tanning business is viewed as a potential contributor to environmental pollution [10]. An important component of tannery waste is the poisonous heavy metal chromium (Cr), whose build-up in soil and water has raised considerable environmental concerns in India, notably in Tamil Nadu [11].

Chromium (Cr) is one of the most toxic and dangerous metals in the environment. In addition to its natural occurrence, Cr is released into the environment through a variety of industrial activities such as electroplating, tanning, polishing, painting, pigment manufacturing, and wood preservation. Higher quantities of these metals can cause metabolic abnormalities and growth suppression in most plant species, both of which can result in mortality. The degree of metal absorption by plants varies greatly between species and plant regions. Several studies have found that arsenic and chromium levels in roots are higher than in leaves or stems [12]. Though phytoremediation, using bioamendments that use harvestable parts of plants to remove toxins, provides a green and environmentally acceptable way for cleaning metal-contaminated soils and rivers, there is a risk of food chain contamination if edible crops are used for the purpose. Farmyard manure, coconut husk silica powder, poultry manure, press mud compost, and biochar have all been shown to minimize hazardous pollutants in soil environments [13]. These bio amendments provide the opportunity to increase pH, specific surface area, porous structure, surface functional groups, and the ability to be used as an adsorbent to immobilize heavy metals in soil. Pollutants are taken from plant roots and transported to shoots or other aboveground biomass such as stems, leaves, and fruits via phytoextraction Some techniques, like soil cleaning, have a negative impact on biological activity, soil structure, and fertility, while some demand expensive engineering [1].

One of the more practical and affordable ways to treat hazardous metal pollution and remove heavy metal contamination from polluted areas is phytoremediation. The process of employing green plants to eliminate pollutants from the environment is known as phytoremediation. Very few plant species-or cultivars within a species-have the ability to take in, hold down, or break down particular pollutants. Certain pollutants are only taken up and degraded by a small number of plant species. Phytoremediation, or the use of plants or plant products to stabilise or restore contaminated environments, involves three major metal-remediation strategies: phytoextraction, rhizofiltration and phytostabilization [14]. Phytoremediation can be carried out with specific plant species and kinds; certain plants are effective in breaking down organic materials, while others break down heavy metals. The region can be used as cropland or for other agricultural uses once phytoremediation is complete [15]. Therefore, the low-tech, in-place method of phytoremediation is appealing since it provides site restoration, partial decontamination, maintenance of the biological activity and physical structure of soils, is possibly affordable, unsightly, and there is a chance for bio-recovery of metals. Phytoremediation is a new method that has great potential for remediating and recovering contaminated environments. The ongoing need for contaminated site cleanup in both developed and developing countries necessitates critical, serious, and rapid study of phytoremediation as a cost-effective, promising, and novel environmental technological solution [16].

Hyperaccumulators, which make up less than 0.2 percent of angiosperm species, are woody or herbaceous plants that accumulate high concentrations of metals in their shoots (100–1,000 times higher than those found in non-hyperaccumulating species) without exhibiting any outward symptoms. This process is known as hyperaccumulation. Numerous *Brassica sp.* have been examined as possible phytoextraction plants because they are known metal accumulators [17]. Brassica plants have the potential to be used in phytoremediation due to their inherent resistance to heavy metals and high above-ground biomass output. It grows quickly, is resistant to heavy metals, and yields a significant amount of above-ground biomass. These traits have made this species the subject of numerous researches to assess its potential for phytoremediation [18]. However, it has been shown that the amount of oil generated by these plants is decreased when heavy metals, such as cadmium, are present. Bioremediation of chromium and Cadmium contaminated soils is a well-known procedure that uses biological wastes to detoxify or transform toxic Cr and Cd into less hazardous forms [19]. Despite its limitations, this technology retains appeal due to its low cost. We investigated the ability of specific crops (*Brassica juncea L.* and *Vigna radiata*) and biological wastes (Silica powder from coconut husk) to remediate contaminated soil [20]. Brassica species have demonstrated a comparatively high level of resistance to this abiotic stress, although the precise mechanism underlying this resistance is still unclear [21]. In this study, we will assess the most current findings about the mechanisms that Brassica plants use to accumulate and tolerate heavy metal stress. A food that is high in protein is the green gram [22]. It has a protein content of roughly 25%, which is about three times that of grains [23]. The goal of this study was to investigate into the phytoextraction capability of *Brassica juncea L.* and *Vigna radiata* with different bioamendments such as silica powder from coconut husk to remediate Cr and Cd from polluted soil. Furthermore, the goal of this study was to rehabilitate contaminated locations by determining suitable Phyto tolerance modifications, Cr and Cd accumulation, and translocation capacity to aerial sections of *Brassica juncea L.* and *Vigna radiata*. The goal of the current research work was to understand the toxicity and remediation level of heavy metals in Vigna radiata leaf and how to treat them (Graphical abstract).

2. MATERIALS AND METHODS

2.1 Description of the Study Area and Initial Characteristics of Soil

The effect of several bioamendments and plants on Cr and cd bioavailability was investigated in a pot culture experiment at the National Agro Foundation Research and Development Centre in Chennai, India (12°.98′84.01″ N, 80°.22′26.4″ E). To test metal accumulation and phytoremediation of Cr and Cd-contaminated soils, two plant species, *Brassica juncea L.* and *Vigna radiata*, were planted. According to the treatment schedule, silica powder was administered and uniformly blended. A specified amount of water was given to each pot on a regular basis to compensate for moisture loss. Soil and plant samples were taken at the end of the experiment for various analyses. The physical properties such as bulk density was analysed using the wet cylinder method. And physicochemical properties such as soil reaction (pH) were analysed using potentiometry-soil water suspension of 1:2:5 ratio, Electrical conductivity (EC) was analysed using conductometry-soil water suspension of 1:2:5 ratio, and the chemical properties such as Organic carbon was analyzed using chromic acid wet digestion method, available nitrogen was analyzed using Alkaline permanganate method, Available Phosphorous was analysed using Calorimetry method, Available Phosphorous was analyzed using Neutral normal ammonium acetate method, Exchangeable Ca and Mg were analyzed using Neutral normal ammonium extract-versenate titration method, the total Cr content was analyzed by digestion with aquaregia and available Sulphur was analyzed using 0.15 percent $CaCl_2$ Turbidimetry method [20].

2.2 Methods Used to Analyse the Parameters of Soil

2.2.1 Soil sample collection and analysis

Soil samples were collected from the pot culture experiment at fortnightly intervals on the 0th, 10th, 15th, 30th, and 40th days. Soil samples were collected and dried for 2-3 days before being powdered, sieved (2 mm sieve), sealed in a polyethylene cover, and analyzed. pH was determined using a pH meter [19], EC using a conductivity meter [19], and organic carbon using a wet digestion method [24], total Cr content digestion with aqua regia (USEPA 1979), and speciation of Cr by the sequential extraction method (Noble and Hughes 1991).

The important characteristics of silica powder are listed in Table 1. Initially 200 g of soil was taken in plastic pots and the 5g silica powder was added to the soil uniformly according to the treatment. Then 2.83 g of $k_2cr_2o_7$ was added in 1000 ml distilled water to make a Cr stock solution of 1000ppm. Similarly 2.83 g of $Cdcl_2$ was added in 1000 ml distilled water to make a Cd stock solution of 1000 ppm.

The soil in the pot was then treated with a 500-ppm aqueous solution of $K_2cr_2o_7$ and 500 ppm of an aqueous solution of $Cdcl_2$. Following that, two seedlings of local types obtained from a nearby nursery were placed into each container. Finally, watering and weeding were done as needed. The experiments were replicated three times in the order in Table 3.

2.2.2 Plant collection and analysis

On the 40th day, the plants were harvested and split into roots, shoots, and leaves for analysis. The samples were dried in a 65 °C oven to achieve constant weight, and the dry weight of each component was recorded. Finally, the dried plant samples were crushed and digested in 10 mL with a di-acid mixture (9 HNO3:4 HClO4), and the Cr and Cd concentration were measured using an atomic absorption spectrophotometer (Varian Spectra AA220). Plant height (cm), root length (cm), and shoot length (cm) were all measured.

2.2.3 Bioconcentration Factor (BCF) and Translocation Factor (TF)

BCF is the ratio of Cr and Cd content in plant tissue to soil concentration. The plant's propensity to acquire heavy metals is referred to as BCF. BCF>1 implies substantial metal accumulation in the shoot. The ratio of a plant's ability to extract heavy metals from the root to the shoot is expressed as TF, TF shows heavy metal build-up in the root and vice versa.

BCF= Cr in the roots (mg kg^{-1})/Cr in the soil (mg kg^{-1}).
TF= Cr in stover/stalks (mg kg^{-1})/Cr in roots (mg kg^{-1}) (mg kg^{-1}).
EF= Cr in stover/stalk (mg kg^{-1})/Cr in soil (mg kg^{-1}) (mg kg^{-1}), similarly values are calculated for Cd contaminated soil.

2.2.4 Evaluation of chlorophyll content

Leaves were collected separately from the seedlings grown in control and heavy metal contaminated soil. The leaf tissues where placed in a glass beaker with 8 ml of acetone and 2 ml of ethanol for 18 hours in darkness. After 18 hours, the chlorophyll a and chlorophyll b was analysed at 665 nm and 649 nm respectively using UV spectrophotometer and absorbance were noted as mentioned in the formula for the estimation of chlorophyll content as,

C_a=13.95A_{665} – 6.88A_{649}
C_b= 24.96A_{649} -7.32A_{665}

2.2.5 Calculation of germination percentage, vigour index

The seedling which had the maximum length was taken out gently without disturbing the plants.Roots by adding water to the soil. The roots were washed using distilled water. The seedlings were kept on a paper and the root length and shoot length was measured by using 30mm scale. Germination percentage was calculated by initially counting the number of seeds sprouted after being sown and the vigor index was also calculated by using the below formula:

Germination percentage = (Number seeds sprouted / Total number of seeds sown) x 100Vigor index= Germination % × mean of seedling length (root + shoot)

Table 1. Methods used to analyse the parameters of the soil

Parameters	Method
Total N	Diacid extract (5:2- H2SO4 : HClO4)- semi automatic kjeldahl distillation method
Total P	Triacid extract (9:2:1- HNO3: H2SO4 : HClO4) Vanadomolybdate yellow colour method
Total K, Na	Triacid extract- neutralized with ammonia- Flame photometer
Total Cr	Atomic Absorption spectrophotometer (triple acid extract)
Total S	Diacid extract (9:4- HNO3: HClO4)- Turbidimetric method

2.3 Statistical Analysis

Statistical software SPSS Version 22 was used to analyze experimental data from the experiment to identify the effect of treatments and factorial completely randomized design (pot culture experiment). The F test employed a significance level of 0.05. Panse and Sukhatme proposed and calculated the variance analysis (1967). A simple Pearson correlation analysis was also performed to examine the link between soil characteristics and crop yield when treated tannery effluent at various dilutions was combined with amendments (Blyth 1994).

3. RESULTS AND DISCUSSION

3.1 Characteristics of Soil and Bioamendments

The experimental soil had a pH of 7.01 and an EC of 0.642 dS m^{-1}, and the other characteristics are listed in Table 2. After the addition of Bioamendments the pH of the soil varied between 6.03 and the EC of the soil varied between 0.668 dS m^{-1}. The organic carbon of the bioamendments added soil was found to be 6.06%. Physiochemical characteristics of bioamendments.

3.2 Changes in the pH and EC of soil after the Addition of Bioamendments

The adsorbent properties and ionization level of metal ions in aqueous solutions are affected by the pH of the solution. The pH of the soil was significantly modified as a result of the addition of bioamendments. In soil with *Brassica juncea and Vigna radiata*, the pH ranged between 7.34-7.45 and 7.06-8.01. The most significant factor that affects plant heavy metal uptake is soil pH. EC ranged from 0.311 to 0.301 in the soil during the experiment with *Brassica juncea L.* in the experiment with Green gram, the EC ranged between 0.311 to 0.309. EC value increased with the presence of heavy metals, but in the trials after being remediated by plant and soil, the EC value showed a gradual decrease in the soil, enunciating the effective remediating capacity of the plant and the Bioamendments. Effect of Bioamendments on EC of Cr and Cd contaminated soil with *Brassica juncea L.* and *Vigna radiate.* According to this study, the pH of the soil was alkaline in the control soil and soils with lower quantities of heavy metals in all the treatments. The pH increased as the metal content increased. The pH of the soil gradually increased in the crops from 0 to the 40th day. The bioamendments had a significant effect on soil pH. Initially, in *Brassica juncea L.* The pH of the chromium-contaminated soil was 6.099, and cadmium contaminated soil the pH of the soil was 6.134. After the addition of bioamendments, the pH of the soil was found to be 6.99 and 7.21 respectively. Similarly, in soil remediated by Green gram, the initial Ph of the soil before the addition of amendment was found to be 6.099 in Cr-contaminated soil and 6.134 in Cd-contaminated soil. After the addition of amendments, the Ph value increased by 6.98 and 7.13 respectively. As the pH rises, the soil becomes alkaline, and metal ion bioavailability falls. Lower pH is good for metal availability but bad for plants (Hutchinson et al. 2007). Effect of Bioamendments on pH of Cr and Cd contaminated soil with *Brassica juncea L.* and *Vigna radiata.*

3.3 Estimation of Organic Carbon in the Soil after the Addition of Bioamendments

Soil Organic Carbon (SOC) has been demonstrated to have a significant influence on SOC in soil bioamendments. Initially, the SOC was found to be highest (0.26%) in the silica-amended soil and lowest (0.13%) in the control soil (T_1). Organic carbon bioamendments are injected into the soil and interact with microorganisms to supplement and make available other nutrients to plants (Barajas-Aceves 2005). However, in the *Brassica juncea L.* the maximum SOC (0.71%) was recorded in the soil amended with silica powder (T_2) and the smallest (0.46%) in the control soil (T_1). Similarly in Green gram the maximum SOC (0.75%) was recorded in the soil amended with silica powder and in control the smallest (0.49) was recorded (Table 2). As a result, silica powder is more likely to act as a soil conditioner and nutrient transformation catalyst than as a primary source of nutrients [18], who observed a significant decrease in SOC of the the organic manure-amended soils due to the C mineralization and its respective losses, which indicated that metals were less, likely to be bound to organic matter to form metal-chelate complexes. Thus, the metals occurred mostly in the available form readily take-up and accumulated in plants.

3.4 Changes in Water-Soluble Chromium and Cadmium: *Brassica juncea L.* and *Vigna radiata*

Chromium is water soluble, and the use of bio-additions resulted in significant variations in the concentration of water-soluble Cr and Cd. Water soluble Cr ranged from 500 ppm in control and 260 nm in the soil remediation with *Brassica juncea L.* along with silica powder. And in Cd-contaminated soil, the initial value of water-soluble Cd in control was found to be 500 ppm and, in the soil, remediated by *Brassica juncea L.* along with silica powder the value of Cd was found to be 280 ppm. The concentration of H_2O-soluble Cr and Cd steadily reduced from the 0th to the 40th day. The use of bioamendments resulted in significant variations in the concentration of water-soluble Cr and Cd. Water soluble Cr ranged from 500 ppm in control and 280 nm in the soil remediation with green gram along with silica powder. And in Cd-contaminated soil, the initial value of water-soluble Cd in control was found to be 500 ppm and, in the soil, remediated by Green gram along with silica powder the value of Cd was found to be 290 ppm. The concentration of H_2O-soluble Cr and Cd steadily reduced from the 0th to the 40th day. All things considered, it has been found that the addition of silica to the modified transition metal ions and compounds resulted in an increase in their stability and longevity as an adsorbent due to their nanoscale particle morphologies. When altered with various types of silica, iron metal and its oxides in particular have demonstrated remarkable adsorption capabilities for the chromium ions. The reason for this is because silica keeps them from clumping together and offers them sturdy support [25].

3.5 Biotransformation and Bioavailability of Cr in Contaminated Soil

Chemical bioavailability is a current notion to reduce chemical availability even when in touch with soil. Metal speciation describes the several forms in which an element can be found. As a result, understanding metal speciation in soils is critical for better understanding its transit and interaction. Diverse water sources and amendments influence Cr and Cd speciation in the current study via variations in soil chemical properties and metal adsorption, complexation, and chelation [26] Surface complexation or adsorption onto soil particles to change the water-soluble fraction into fractions with poorer solubility. Numerous stabilising substances, including compost, silica and biochar, have been investigated for the treatment and management of soil system heavy metal pollution [27]. With the addition of compost, the plant bioavailability of the metal was decreased due to the organic functional groups that were thought to be significant in lowering the concentration of the dissolved Cd [28].

Table 2. Characteristics of initial soil

Parameters	Soil	Parameters	Bio amendment
Soil type	Clay loam	pH	7.09±0.15
Bulk density (mg m^{-3})	1.05	EC (dSm^{-1})	3.25±0.08
pH	7.0±0.15	Total Nitrogen (mg kg^{-1})	1.08±0.03
Electrical conductivity (dSm^{-1})	0.540±0.01	Total Phosphorous (mg kg^{-1})	9.35±0.21
Organic matter (%)	0.94±0.02	Total Potassium (mg kg^{-1})	0.1±0.009
Nitrate Nitrogen (mg kg^{-1})	64.6±1.06	Total Nickel (mg kg^{-1})	16.89±0.10
Available phosphorous (mg kg^{-1})	22.63±0.20	Total Lead (mg kg^{-1})	26±0.53
Exchangeable potassium(mg kg^{-1})	425±4.90	Total Chromium (mg kg^{-1})	BDL
Exchangeable calcium (mg kg^{-1})	2605±5.42	Total Cadmium (mg kg^{-1})	4.46±0.04
Exchangeable magnesium(mg kg^{-1})	820±4.66	-	-
Available sulfur(mg kg^{-1})	44.5±0.89	-	-
Available manganese(mg kg^{-1})	9.31±0.20	-	-
Available copper(mg kg^{-1})	2.33±0.04	-	-
Available boron(mg kg^{-1})	0.5±0.005	-	-
Total chromium(mg kg^{-1})	BDL	-	-
Total cadmium (mg kg^{-1})	BDL	-	-
Cation exchange capacity (Cmol (p+) kg−1)	21.40±0.33	-	-

BDL below detectable limit (below 0.1 ppm)

Table 3. Arrangement of the plants in series for pot experiment

Brassica juncea	T1(Control)- uncontaminated soil	T2 (500 ppm of Cr + 5 Kg of Silica powder)	T3 (500 ppm of Cd + 5 Kg of Silica powder)
Vigna radiata	T1(Control)- uncontaminated soil	T2 (500 ppm of Cr + 5 Kg of Silica powder)	T3 (500 ppm of Cd + 5 Kg of Silica powder)

3.6 Effect of Cr and Cd on *Brassica juncea L.* and *Vigna radiate* Height and Root Length

Heavy metal phytotoxicity and severe sterility of contaminated soils were the principal limiting factors for plant development (Norwood et al., 2013). *Brassica juncea L*. has a plant height of 5 to 8 cm. The highest plant height, 8 cm, was reported at T1 (Uncontaminated soil), followed by T3 (Cd contaminated soil), while the lowest plant height, 5 cm, was recorded in T2 (Cr contaminated soil). In Green gram, the plant height ranges from 18.5 cm to 29.3 cm. The highest plant height, 29.3 cm, was reported at T1 (Uncontaminated soil), followed by T3 (Cd contaminated soil), while the lowest plant height, 18.5 cm, was recorded at T2 (Cr contaminated soil). Plant growth is affected by the uptake of heavy metals. Heavy metals hinder the uptake of essential nutrients from the soil such as sulfur, boron, phosphorous, etc decrease the height of the plants. The no. of seedlings was found higher in T1 in both plants and low in T2 in both plants. This signifies the uptake of Cr to be higher compared to Cd by the plants. Vigour index of *Brassica juncea L*. and Vigour index of Green gram (Table 4). Seed germination is the first physiological process affected by Cr (VI). Symptoms of Cr and Cd phytotoxicity include inhibition of seed germination or of early seedling development, reduction of root growth, leaf chlorosis and depressed biomass. Low concentrations shows growth promotory and higher concentrations shows germination inhibitory effect in four varieties of *Vigna radiata*. Some heavy metals are essential micronutrients for plants but their excess may result in metabolic disorders and growth inhibition in most of the plant species (Table 4). Similar experiments were carried out in green gram under the influence of mercury [29,30].

The ability of a seed to germinate in a medium containing Cr and Cd would be indicative of its level of tolerance to this metal [31]. The highest risk for human health is when plants develop tolerance mechanisms against metals and when those plants are incorporated into the food chain.

3.7 Estimation of Chlorophyll Content

The chlorophyll contents were removed from the leaves which turned the acetone ethanol mixture green in color, the chlorophyll content decreased in T_2 as the metal uptake by plants hinders the supply of nutrients to the plants, thus affecting the chlorophyll content. In *Brassica juncea,* chromium-contaminated soil the chlorophyll content ranged between 3.1862 and 2.1743 in Green gram the chlorophyll content ranged between 3.2034 and 2.1976. The chlorophyll content of plants is given in Fig. 4. According to similar research, plants cultivated in mine soils had lower levels of carotenoid and chlorophyll than plants grown in soil contaminated with Cr. In comparison to the control, the amount [31]. of chlorophyll had gradually decreased as the concentration of lead increased. As the level of Cd increased, the carotenoid content of seedlings that were 25 and 45 days old gradually decreased. According to reports, this decrease may be the result of metal interference with pigment metabolism [32].

3.8 Estimation of Nutrient Status of the Soil

The following results were obtained for the sulphur content in the soil with heavy metals using UV spectrophotometer for *Vigna radiata and Brassica juncea L.* and are given in Table 5. There is not much decrease in the concentration of sulphur in both the plants. There are no significant changes in the concentration of sulphur content in the soil. The plants uptake the heavy metals and trace amount of sulphur are taken up by the plants. The concentration of sulphur has reduced from 24.7% in T_1 to 23.1% in T_2 in *Brassica juncea*, while the concentration decreases from 24.5 in T_1 to 24.0 in T_2 in green gram.

There is no significant change in the concentrations of phosphorous in the soil. The heavy metals hinder the uptake of phosphorous by the plants. In *Brassica juncea L.* the Phosphorous uptake by plants ranges from 2.09 mg/Kg in T1 to 2.0 in T_3, while in Green gram the Phosphorous content ranged from 2.09-2.06 mg/Kg, demonstrating no significant change

Table 4. Biometric observation of Brassica juncea and Vigna radiata with effect of heavy metals

Trails		G%		Vigour index		Seed index		Root length (cm)		Shoot length (cm)		Total plant height (cm)	
Brassica juncea	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***
BT1R1	GT1R1	30%	80%	150	2000	3	8	2.3	3.3	5.9	26	8	29.3
BT2R1	GT2R1	50%	60%	325	1758	4	6	3.2	2.9	3.3	16	6.5	18.9
BT3R1	GT3R1	100%	50%	800	925	10	5	2	4	3	21	5	25

Table 5. Soil Nutrient status of Brassica juncea and Vigna radiata

Trails	Calcium		Magnesium		Sodium		Potassium		Sulphur		Boron		Phosphorous	
	Brassica juncea	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***	***Brassica juncea***	***Vigna radiata***
T_1	1380.6	1353.0	426.9	426.1	148.8	195.3	157.4	147.3	24.5	24.5	1.08	1.08	2.09	2.09
T_2	1367.1	1349.2	419.7	426.0	148.1	195.2	156.8	143.6	24.0	24.2	0.58	0.59	2.08	2.09
T_3	1388.7	1378.9	398.5	399.2	146.3	187.4	147.8	139.2	23.1	24.0	0.56	0.55	2.0	2.06

Fig. 2. Biometric observations of *Brassica juncea* and *Vigna radiata*

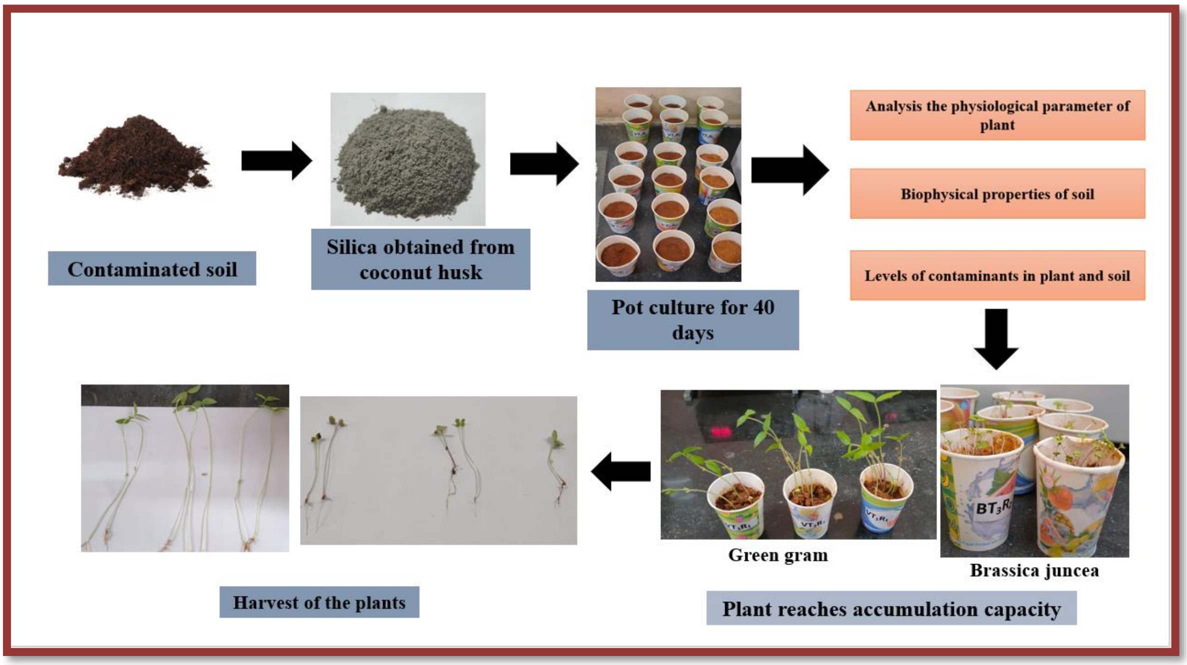

Fig. 3. Pictorial representation of the overall process of Remediation by *Brassica juncea* and *Vigna radiata* along with silica

in its uptake by the plants. Boron content in the soil decreases by 10%. Boron is the essential nutrient required by the plants in their healthy growth. But since plant uptakes a lot of heavy metal it hinders the uptake of boron by the plants. There are no significant changes in the concentration of Calcium, Magnesium, Sodium, and potassium in the soil for both plants [33]. Due to heavy metal uptake by the plants and silica, it resists the adsorption of these micro elements that is required for the healthy growth of the plant. Hence the growth of plants is affected. Similarly, the quantities of sulphur, phosphorus and potassium in the two mine soils varied from low to medium. According to [34] potassium is necessary for the growth and reproduction of plants in a sustainable manner. In soil nutrient remediation, organic matter and TN content had a favourable connection [35]. The nitrogen level of the compost increased due to the breakdown of protein and other organic materials. However, adding silica powder can improve the soil's effective nutrient level by increasing the variety and number of microorganisms present. Because of the addition of silica powder may improve the availability and migration rate of phosphorus in the soil. Consequently, the development of phosphate complexes can be encouraged by increasing the amount of compost applied, which lowers the rate at which soil phosphorus is retained [36,37].

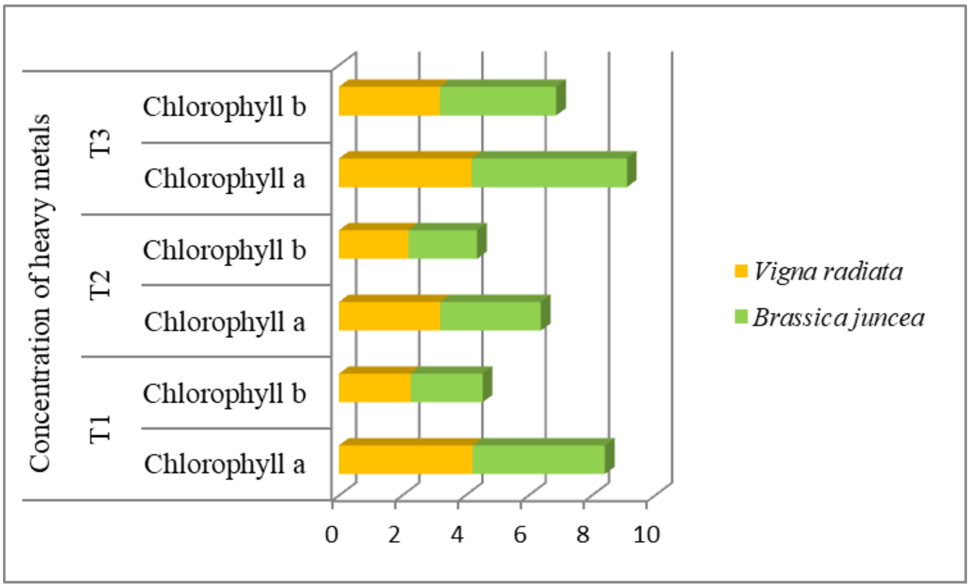

Fig. 4. Chlorophyll content of *Brassica juncea* and *Vigna radiata*

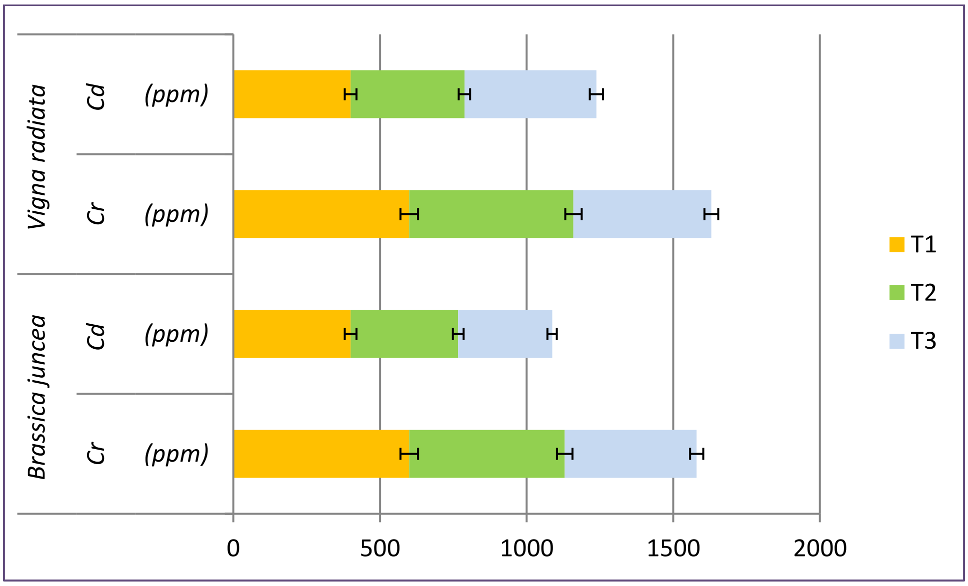

Fig. 5. Remediation capacity of *Brassica juncea* and *Vigna radiata*

3.9 Heavy Metal Content in *Brassica juncea L.* and *Vigna radiata*

The remediation efficiency of *Brassica juncea* and *Vigna radiata* with silica and the remediation efficiency of Green gram and Green gram with silica were evaluated. The graphical representation of the remediating capacity of *Brassica juncea* and *Vigna radiata* along with silica (Fig. 5). Similarly, among, the species used for chromium phytoremediation we find *Pluchea indica* and *Cynodon dactylon, Phragmites australis, Typha angustifolia, Pterocarpus indicus* and *Jatropha curcas*. The maximum chromium concentration in the dry shoot matter of the hyperaccumulator *Prosopis laevigata* reached 5.5 mg g^{-1}. However, it is very important to identify new feasible hyperaccumulators or accumulators of Cr as the groundwork for the successful phytoremediation of Cr contaminated soils [36,38].

The heavy metal uptake by *Brassica juncea* is more efficient than green gram. The concentration of heavy metals has decreased by 30% by Green gram and 50% by *Brassica juncea L.* and silica. The chromium content in soil is greater than Cadmium and Nickel. Green gram reduces the heavy metal by 20% and 40% with silica. Pictorial representation of the overall process of Remediation by *Brassica juncea L.* and *Vigna radiate* along with silica. The BCF is a key indicator for evaluating the ability of plants to extract heavy metals. The values of remediation efficiency of different plant (*S. plumbizincicola*) in soil, the results indicated the plants showed higher potential for Cd phytoextraction in Cd-contaminated soil [39-41].

4. CONCLUSIONS

As phytoremediation is a cost-effective and natural method, steps are taken in using plants as a remediating agent. Phytoremediation is a solar-powered, environmentally friendly technology that is well-liked by the locals. In the near future, it is anticipated that heavy metal phytoextraction will be a financially viable method for agro mining. Comparing the remediation study between *Brassica juncea* and *Vigna radiate. Brassica juncea L.* proves to have better-remediating capacity than green gram. In this study, Cr was found to be in greater concentration in the soil sample, followed by Cd. Silica proved to have more remediating capacity than the plants. More than 50% of the metals were remediated by the plants with silica powder. One of the most crucial processes for the tolerance of *Brassica juncea* appears to be the chelating of heavy metals especially of Cr and *Vigna radiata* of Cd. This is because this organic acid may be involved in chelating the metals, which facilitates their translocation and accumulation in the shoots and lessens their toxicity. This conclusion is supported by the evidence that exogenous application of citrate to a contaminated medium enhances both plant tolerance and heavy metal uptake. The study is comparative to find the efficiency of plants infused with silica in up taking heavy metals. The remediated plants are further used for the production of Biofuels.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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