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Identification and remediation strategies for chromium to mitigate food chain contamination

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Abstract

Chromium (Cr) metal is crucial for industrial development specially steel, wooden and tannery; contributing significant revue in Indian economy. These industries are generating huge volume of waste, creating Cr pollution reduced the soil health parameters over a untreated water irrigation. Chromium is a heavy metal that can contaminate soil, water, and ultimately affect the food chain. It exists in two main forms: hexavalent chromium (Cr-VI), which is more toxic and mobile, and trivalent chromium (Cr-III), which is less toxic. However, it is more challenging, when the different industrial effluents merged at a common point and cause multi-metal toxicity. Mustard and spinach crops have been studied for their potential to accumulate and remediate chromium from contaminated environments. In this backdrop, different experiments were conducted to identify the Cr toxic level, immobilization of Cr with different metals, phytoremmedation and measurement of indices for quantify the Cr toxicity potential. These studies involved the graded application of Cr (0, 50 and 100 mg kg^{-1} soil), cations (sodium, calcium) and anions (sulphate and chlorides) spiked in Indian vertisol. Mustard (*Brassica juncea*) and spinach (*Spinacia oleracea*) were used as test crops in these experiments. Different indices (BCF, TE, TF and Cr removal) were computed to identify the metal toxicity level and formulated the phytoremediation strategies. These studies are very much important for formulating Cr remediation strategies for tannery irrigated areas.

Keywords: *Chromium, geo-accumulation indices, mustard, phytoremedition indices, soil health parameters*

Introduction

Heavy metal pollution presents a global challenge, capturing the attention of both researchers and policymakers who seek solutions for its mitigation across various ecosystems. Generally, heavy metals refer to those metals and metalloids with atomic densities exceeding 5 kg m^{-3} or atomic numbers surpassing calcium as defined by many researchers (Saha *et al.*, 2017). The primary sources of heavy metals in the environment from both natural geological processes and human activities. However, recent increment in heavy metal concentrations can be attributed predominantly to anthropogenic actions such as urban and industrial waste discharge, fossil fuel combustion, mining activities, utilization of heavy metal-contaminated fertilizers, and the use of polluted water for agricultural purposes (Minhas *et al.*, 2021). Concurrently, the scarcity of freshwater has emerged as a critical global challenge in the 21st century, compelling farmers to resort to using subpar water sources for irrigation, particularly in peri-urban areas. Here, industrial effluents and sewage water contaminated with high levels of heavy metals, including Cr, lead (Pb), zinc (Zn), cadmium (Cd), among others, are commonly utilized. The composition and concentration of heavy metals in these effluents vary depending on the industrial activities and local lifestyle factors (Rajendiran *et al.*, 2015). Persistent use of such effluents leads to a significant accumulation of these metals in agricultural soils, eventually entering the human food chain through the consumption of heavy metal-contaminated plant materials. However, the bioavailability and uptake of these metals by plants are influenced by several factors such as soil metal content, pH, Eh (redox potential), moisture content, presence of organic substances, and other elements in the rhizosphere (Saha *et al.*, 2017). Heavy metals pose severe risks to plant health and ecosystem functioning. Excessive Zn in soil can result in leaf edge browning and stunted growth, while excessive Cr can induce necrosis and root xylem blockage in plants, ultimately leading to plant decay. Even small amounts of Cd in soil can impede the growth and development of plants during early stages (Coumar *et al.*, 2016). Furthermore, these metals alter soil ecology, diminishing microbial diversity (Casida *et al.*, 1964), and consequently reducing plant growth and biomass yield.

In the peri-urban regions of Kanpur, farmers are utilizing industrial effluents or a mixture of household effluents and industrial waste for vegetable cultivation (Dotaniya *et al.*, 2017). They hold the belief that these effluents can serve as both water and nutrient sources for their crops. However, the presence of significant quantities of trace metals such as Cr, Zn and Cd, alongside various cations and anions in these effluents, cannot be disregarded. Each metal exhibits unique behavior within living systems, contingent upon its inherent properties and chemical characteristics (Dotaniya *et al.*, 2019). Given that these effluents contain multiple metals as constituents, there is a possibility of interactions among them. Researchers have investigated the interactions between two metals and their effects on plant growth and metal accumulation. However, information regarding the interaction of multiple metals and their influence on crop growth and metal uptake from the soil remains scarce. Therefore, studying the interactions among these metals is essential for comprehending their behaviors and impacts on both soil and plant systems. Generally, industrial wastes contain a substantial amount of organic matter (OM) and contribute significantly to soil organic carbon (SOC) when added to soil (Dotaniya *et al.*, 2023). However, they also contain notable quantities of hazardous heavy metals such as Cr, Cd, Zn, and Pb, which are released into the soil. These heavy metals are known to be toxic to soil microbes and may impede the growth and development of microbial populations (Dumat *et al.*, 2006). Soil biological activity is considered a crucial indicator of soil health, with soil microbes playing active roles in nutrient transformation, OM mineralization, and other ecological services. Soil contamination with heavy metals may disrupt soil microbe-mediated processes and further degrade soil health.

Therefore, it is evitable to study source, cause and effect of heavy metals contamination in soil to effectively prevent, remediate and manage the soil from any adverse effect and loss. This kind of information will be really useful in making policy guidelines and management of contaminated areas. Thus, the current investigation carried out during 2014-2018 at ICAR-Indian Institute of Soil Science, Bhopal, India, aimed to study the interactive effects of Cr with metals, cations and anions; and their impact on soil health parameters and remediation indices in spinach and mustard crops.

Material and Methods

Identification of Cr toxicity

Soil, tannery effluents and groundwater samples were collected from different agricultural fields located at Kanpur (26°46' N and 80°35' E). It is a tannery irrigated belt of Kanpur, Uttar Pradesh. Soils were collected randomly from the effluent irrigated fields and non-effluent irrigated fields. Soil sampling was carried out from 0-15 cm depth using a tube auger. The samples were collected by adopting simple random sampling technique. The pH, texture and EC of effluent, soil and groundwater were determined as per the standard methods (Singh *et al.*, 2005). Geo-accumulation index (I_{geo}) is widely used for assessing heavy metal contamination in sediments (Chabukdhara and Nema, 2012) and trace metal pollution in agricultural soils (Wei and Yang, 2010). The geo-accumulation index, in the present study, was calculated and classified as per following formula described by Muller (1969).

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n}$$

Where, C_n is the soil trace metal concentration and B_n is geochemical baseline. The soil sample with ≤0 value indicates unpolluted and classified under class I. Similarly, 0-1, 1-2, 2-3, 3-4, 4-5 and >5 indicates unpolluted to moderate polluted (class II), moderate polluted (class III), moderate to heavily polluted (class IV), heavily polluted (class V), heavily to extremely polluted (class VI) and extremely polluted (class VII), respectively.

Chromium immobilization by using cations and anions in spinach

The bulk soil was collected from the research farm ($26^0$16” N latitude and $77^0$36” E longitudes, soil type vertisol) of ICAR-Indian Institute of Soil Science, Bhopal and subsequently, was air dried in shade, ground and passed through a 2 mm sieve. The physico-chemical properties of experimental soil were determined as per standard procedure described in Singh *et al.* (2005). The experimental soil was clay loam in texture with pH (8.07); EC (0.54 dS m^{-1}); organic carbon (0.48%), available N, P, K and S were 180 kg ha^{-1}, 8.23 kg ha^{-1}, 192 kg ha^{-1}, 9.9 mg kg^{-1}, respectively.

Immobilization with cations (calcium and sodium): The experiment was conducted in black soil with spinach crop. Chromium was applied at 0, 50, and 100 mg kg^{-1} through $K_2Cr_2O_7$ and calcium (Ca) in 0, 2, 4 *mM* kg^{-1} was applied through $CaCl_2$; and sodium (Na) was applied at 0, 40, 80 *mM* kg^{-1} through NaCl.

Immobilization with anions (chloride and sulphate): The three levels of each Cr, Cl^- and SO_4^{2-} were applied in combination with three replications. Chromium was applied at 0, 50, and 100 mg kg^{-1} through $K_2Cr_2O_7$ and chloride in 0, 25, 50 *mM* kg^{-1} was applied through KCl; and sulfate was applied at 0, 4, 8 *mM* kg^{-1} through K_2SO_4. In both experiments, the variation of K in different treatment combinations was balanced through KNO_3 application and similarly N through application of urea.

Crop cultivation

After application of respective treatments, pots were kept to attain equilibrium for a month period. After one-month period, the Cr concentration in the soil was measured. Again, the soil in each pot was mixed thoroughly and filled. The spinach variety '*Palak All*

Green' was used as a test crop (5 plants pot^{-1}). The recommended doses of fertilizers were applied uniformly in each pot. Full dose of P and K and half dose of N were applied at the time of seed sowing and remaining half of the N was applied in later stages into two equal splits (at 15 and 30 DAS). Pots were irrigated with deionized water (300 ml each irrigation) as when required. The fully matured above ground biomass of the crop was harvested. The plant roots were separately collected, and properly washed sequentially with mild acid and distilled water to remove the adhered soil particles and other contaminations. Both shoot and root portions were oven dried at 60°C. The dry matter yields were recorded and the plant samples were ground and kept in air tight plastic bags for heavy metals determination.

Identification of phytoremediation indices

The Cr concentration in the filtrate was measured in inductively coupled plasma - optical emission spectrometry (ICP-OES, Perkin). The flow rate of instrument was maintained at 80 ml per minute. The analyzed data was further used in computation of bioconcentration factor, translocation factor and translocation efficiency and crop removal using the formulae given as below:

Bioconcentration factor (BCF): It is defined the contamination removal capacity of the plant was calculated as per the formula given by Zhuang *et al.* (2007):

$$\text{BCF} = \frac{\text{Cr in harvested tissue (mg kg}^{-1}\text{)}}{\text{Cr in soil (mg kg}^{-1}\text{)}}$$

Here, Cr in harvested tissue is a concentration of Cr in harvested plant parts (root, shoot) and Cr in soil is total applied Cr levels of respective treatments.

Translocation factor (TF): It is transfer of Cr metal ions from root to shoot and is quantified by the formula proposed by Padmavathiamma and Li (2007) and Adesodun *et al.* (2010):

$$\text{TF} = \frac{\text{Cr}_{\text{shoots (mg kg}^{-1}\text{)}}}{\text{Cr}_{\text{roots (mg kg}^{-1}\text{)}}}$$

Translocation efficiency (TE) is calculated with the help of the formula described by Meers *et al.* (2004):

$$\text{TE (\%)} = \frac{\text{Cr}_{\text{content in shoots (mg kg}^{-1}\text{)}}}{\text{Cr}_{\text{content in the whole plant (mg kg}^{-1}\text{)}}} \times 100$$

Crop removal represented the Cr removal capacity of the crop with respect to contamination level. It is calculated as per given formula.

$$\text{Cr removal (\%)} = \frac{\text{Total Cr uptake by plant (mg kg}^{-1}\text{)}}{\text{Total Cr applied to the soil (mg kg}^{-1}\text{)}} \times 100$$

Phytoremediation potential of mustard

The field experiment was conducted in sewage irrigated areas near Bhopal city, India. *Patranala* (sewage carrying natural channel), is the major source of irrigation water in several surrounding villages. On the basis of survey on intensity of sewage utilization for crop cultivation, two experiments at Islamnagar village and one experiment at Bheropura village were conducted. In the investigation, the phytoremediation trials were performed in different locations using four mustard varieties namely NRCDR 2, NRCHB 101, RH 749 and RH 119.

Metal analysis

The dried plant materials were ground, and 0.5 g was placed in a conical flask with 5 mL of nitric acid and left overnight for pre-digestion. The next day, 10 mL of a di-acid mixture (HNO_3:$HClO_4$: 9:4 ratio) was added, and the mixture was heated on a hot plate at 105°C for digestion. The digested plant material was then extracted, brought to the desired volume, and filtered using Whatman No. 42 filter paper (Saha *et al.*, 2017). After that metal concentration in extractant from plant samples were measured with the help of ICP-OES. Metal uptake and metal transfer factor were calculated as per the formula given below:

$$\text{Metal uptake (µg plant}^{-1}\text{)} = \text{Metal concentration in plant (µg g}^{-1}\text{)} \times \text{biomass (g plant}^{-1}\text{)}$$

$$\text{Metal transfer factors (TF)} = \frac{C_{plant}}{C_{Soil}}$$

where, C_{plant} and C_{soil} are the plant and soil concentrations of heavy metal, respectively.

Statistical analysis

The experiment was conducted in a completely randomized design for pot experiment and randomized complete block design with three replications. Dry matter yield, Cr concentration and uptake kinetics and phytoremediation indices were statistically examined using a factorial design were kept as suggested by Panse and Sukhtame (1967). Statistical Package SPSS (Version 10.0; SPSS Inc., Chicago, IL, USA) software was used to perform analysis of variance (ANOVA). The mean data for all the parameters was obtained, and critical differences in mean values were used to compare and interpret the treatments at $p \leq 0.05$.

Results and Discussion

Identification of chromium toxicity classes

The escalating heavy metal contamination levels in agricultural fields have resulted in higher geo-accumulation index (I_{geo}) values (Table 1). The I_{geo} values for all heavy metals investigated in this study exceeded 0, indicating soil contamination by heavy metals, although the degree of contamination varied depending on the type of metal. For instance, the I_{geo} values for Cu, Pb, Ni, Zn, and As fell within the range of 0-1, indicating contamination levels ranging from unpolluted to moderate for these metals. However, for Cd and Cr, the I_{geo} values were 1.49 and 4.32, respectively, signifying moderate contamination for Cd and an extreme level of contamination for Cr. The utilization of tannery effluent for irrigation may have contributed significantly to the accumulation of Cr in the soil. Additionally, substantial amounts of other metals, particularly Cd, may have originated from other wastewater discharged into the channels carrying tannery effluents. The significant presence of heavy metals, other than Cr, may have originated from additional industrial effluents discharged into the same sewage channel (Gurjar and Yadav, 2013). Although the heavy metal concentrations in the majority of groundwater samples were within safe limits according to USEPA standards (2009) suggesting that tannery effluent irrigation did not contaminate the groundwater, leaching of heavy metals from the soil likely contributed to increased groundwater heavy metal concentrations (Ball and Izbicki, 2004). Furthermore, the shallow water table in the Indo-Gangetic Plains, typically not exceeding depths of 4-6 meters, may exacerbate this leaching process (Rattan *et al*., 2005). Of all the industrial effluents studied, tannery effluent was identified as the most hazardous pollutant affecting water body quality (Parithabhanu and Khusnumabegam, 2013). Singh *et al.* (2001) reported elevated Cr levels in groundwater samples from the carpet industrial area of eastern Uttar Pradesh, indicating metal leaching from the industry. It has been established that Cr (VI) exhibits higher mobility compared to Cr (III), with the latter being preferentially retained by the soil. Soil carbon mineralization and enzyme activities serve as reliable indicators of soil biological activity. Doelman and Haanstra (1984) observed a reduction in microbial respiration rates in soil with increasing concentrations of heavy metals such as Cr, Ni, Cu, and Pb. The addition of heavy metals to soil induces quantitative and qualitative changes in microflora composition and enzymatic activity (Tabatabai and Bremner, 1969). The effects of heavy metals on microorganisms and soil enzymes are contingent upon both the physico-chemical properties of the metals and the soil itself.

Table 1: Geo-accumulation index

Elements	Value	Class	Description
Cu	0.22	II	Unpolluted to moderate polluted
Cd	1.49	III	Moderate polluted
Pb	0.95	II	Unpolluted to moderate polluted
Cr	4.32	VI	Heavily to extremely polluted
Ni	0.47	II	Unpolluted to moderate polluted
Zn	0.84	II	Unpolluted to moderate polluted
As	0.46	II	Unpolluted to moderate polluted

Effect of anions and cations on phytoremediation indices

The combined application of Cr and Cl^- at various levels showed a non-significant effect on both spinach shoot and root dry weight compared to Cr application alone. However, the application of Cl^- (50 *m*M kg^{-1}) alongside 50 mg Cr kg^{-1} soil had a significant impact on root dry weight compared to the combined application of 25 *m*M kg^{-1} Cl^- and 50 mg Cr kg^{-1} soil. In the presence of Cl^-, the Cr concentration and uptake in spinach shoot decreased at lower Cr levels (50 mg Cr kg^{-1} soil) but increased at higher Cr levels (100 mg Cr kg^{-1} soil) when Cl^- was present. Additionally, the application of sulfur (S) with Cr led to a reduction in both root and shoot dry weight, as well as the concentration and uptake of Cr in both root and shoot, BCF, and crop removal. However, the TF and TE were significantly increased (Table 2). When 4 to 8 *m*M S kg^{-1} was applied with 50 mg kg^{-1} Cr, there was a significant reduction in shoot dry weight (5.2%), with a higher percentage of reduction (5.4%) observed when Cr was applied at 100 mg kg^{-1}. The reduction in dry weight was more pronounced for the roots compared to the shoots. Furthermore, the Cr concentration significantly decreased due to the application of S (4 and 8 *m*M kg^{-1}) along with 50 mg kg^{-1} Cr, from 13.70 µg g^{-1} to 12.92 and 11.14 µg g^{-1}, respectively.

The concentration of Cr in the shoot was unaffected by the application of elevated Cr levels. However, the application of Cr levels ranging from 50 to 100 mg kg^{-1} significantly increased the Cr concentration in the roots from 47 to 54 µg g^{-1}. The combined application of Cr and Na did not affect the dry weight of spinach shoots and roots. Increasing the application rate of sodium reduced the biomass weight of both roots and shoots in all treatment combinations. Elevated levels of Cr (50 to 100 mg kg^{-1}) with lower levels of sodium significantly affected the Cr concentration in the shoots, whereas higher levels of sodium (40 and 80 *m*M kg^{-1}) did not impact the Cr concentration. However, in the roots, increasing the sodium level from 0 to 80 *m*M kg^{-1} reduced the Cr concentration from 67.34 to 29.42 µg g^{-1} in pots with 50 mg kg^{-1} applied Cr. Elevated concentrations of calcium also did not affect the Cr concentration in spinach shoots, except at Cr level 50 with calcium levels up to 2 *m*M. Conversely, in the roots, increasing calcium levels with a Cr level of 100 mg kg^{-1} soil increased the Cr concentration. However, at Cr levels of 50 mg kg^{-1}, the application of Ca up to 2 *m*M increased Cr uptake, while further increasing calcium levels (2 to 4 *m*M) decreased Cr uptake, from 0.118 to 0.069 mg pot^{-1}. Total Cr uptake also significantly improved with the combination of higher doses of Cr along with calcium application (Table 3). Similar BCF, TF, and TE were both unaffected by Ca application at higher Ca levels; whereas at lower Cr levels, an increase in Ca levels from 0 to 2 *m*M reduced both TE and TF. Increasing calcium levels did not affect Cr crop removal by spinach crop. However, increasing Cr levels in conjunction with Cl$^-$ levels resulted in reduced Cr uptake under multi-metal stress conditions (Bajwa, 2002). Similar experimental work conducted by Ali *et al.* (2012) demonstrated that the application of Cr with salinity *via* NaCl decreased the concentrations of Cr, Fe, and other metals in barley crops. The escalating stress induced by high Cr concentrations, along with other ionic ions, disrupted the plant's uptake pattern of other metals and significantly reduced essential plant nutrient mechanisms such as Fe, Mn, and Zn (Orlovsky *et al*., 2016). Elevating S levels through SO_4^- along with Cr ions in CrO_4^- reduced Cr root adsorption, yet a fraction of Cr was still taken up by the plant through mass flow. Poor Cr translocation from root to shoot was observed in this experiment with lower Cr application rates in spinach crops. Similar outcomes were reported in barley (Ali *et al.,* 2012), mung bean (Banerjee *et al.*, 2008), and rice (Zeng *et al.*, 2009). This phenomenon could be attributed to Cr immobilization in the vacuoles of root cells and rapid reduction of hexavalent Cr into trivalent Cr within cells (Dotaniya *et al.*, 2018). At higher Cr levels (100 mg kg^{-1}) with increased salinity ions, Cr uptake was enhanced and accumulated in the shoot. Similar findings were observed in barley by Ali *et al.* (2012), where they noted an increase in Cr concentration in the shoot with elevated salinity levels. Increasing the concentration of mineral salts such as Ca, K, and Mg reduced Cr uptake in the root and shoot of barley under Cr-contaminated soils (Ali *et al.*, 2012). Rios *et al.* (2010) reported that the application of heavy metals in soil reduced the uptake rate of minerals in lettuce plants due to an antagonistic relationship between Ca and selenium. Increasing Ca concentration through external application in soil, which could easily reach equilibrium due to the higher concentration of Ca already present in the soil, did not exhibit antagonistic effects in all treatments. Simulation modeling has predicted that the application of mineral nutrients adversely affects the kinetics of heavy metals in soil and influences the concentration in the root and shoot of many crops (Misle, 2013). The interaction between metals influenced other parameters like BCF, translocation factor (TF), TF and Cr removal (%). This indicates that a higher concentration of one metal can nullify the effect of another metal with a lower concentration, but competition among metals occurs when they are applied in higher doses. The interactive effects of various metal cations affect the uptake of metals from soil to plant roots and within the plant system (Coumar *et al.*, 2016). Furthermore, the removal mechanism of metals from contaminated soil using a macrofungus, *Galerina vittiformis*, revealed that metal accumulation in the fruiting body occurred in the order Pb(II)>Cd(II)>Cu(II)>Zn(II)>Cr(VI) from 50 mg kg^{-1} soil (Damodaran *et al.*, 2013).

Table 2: Interactive effects of Cr and S concentration on spinach

Treatment		Dry weight (g pot^{-1})		Cr concentration (µg g^{-1})		Cr uptake (mg pot^{-1})			BCF	TF	TE (%)	Crop removal (%)
Cr (mg kg^{-1})	S (*m*Mol kg^{-1})	Shoot	Root	Shoot	Root	Shoot	Root	Total				
50	0	14.12a	2.79a	13.70a	67.34b	0.193ab	0.188a	0.381a	0.810a	0.204b	10.15b	0.76a
50	4	10.21b	1.60a	12.92a	44.10cd	0.135bc	0.071b	0.206b	0.570b	0.296ab	14.73ab	0.41a
50	8	9.68b	1.93a	11.14b	31.63e	0.106c	0.061b	0.167b	0.428c	0.353a	17.56a	0.33a
100	0	13.96a	2.67a	14.33a	77.49a	0.198a	0.208a	0.407a	0.459c	0.184b	9.17b	0.41a
100	4	9.74b	1.80a	12.16a	46.32c	0.118c	0.081b	0.199b	0.293d	0.262ab	13.06ab	0.20a
100	8	9.21b	2.50a	14.76a	38.09d	0.137abc	0.089b	0.225b	0.264d	0.396a	19.70a	0.23a

*Means with the same letter are not significantly different column wise based on Tukey grouping at $p = 0.05$

Phyotemedition of metal through mustard

There was significant difference among the varieties with respect to dry matter production. The highest mean dry biomass was recorded in mustard variety NRCHB

Table 3: Interactive effects of Cr and Ca concentration on dry weight, Cr concentration & uptake, BCF, TF, TE and crop removal

Treatment		Dry weight (g pot^{-1})		Cr concentration (µg g^{-1})		Cr uptake (mg pot^{-1})			BCF	TF	TE (%)	Crop removal (%)
Cr (mg kg^{-1})	Ca (*m*Mol kg^{-1})	Shoot	Root	Shoot	Root	Shoot	Root	Total				
50	0	11.76a	1.72a	17.41a	43.70d	0.203a	0.076c	0.279ab	1.222a	0.472a	30.76a	0.139ab
50	2	10.92a	2.39a	12.12b	48.79c	0.137b	0.118ab	0.254ab	1.218a	0.267b	20.75b	0.127ab
50	4	11.68a	1.44a	12.62ab	48.38c	0.147ab	0.069c	0.217b	1.220a	0.290b	20.89b	0.108b
100	0	10.92a	2.14a	12.87ab	53.94ab	0.150ab	0.111b	0.262ab	0.668a	0.244b	19.51b	0.131ab
100	2	10.72a	2.55a	15.48ab	51.99b	0.176ab	0.126ab	0.302a	0.675a	0.314b	23.53b	0.151a
100	4	10.23a	2.19a	15.66ab	56.31a	0.164ab	0.141a	0.305a	0.720a	0.318b	23.71b	0.152a

*Values followed by different letters or no same letter/letters in common column wise are significantly different at $p = 0.05$ level of significance

Table 4: Effect of mustard varieties on metal uptake

Variety	Cu	Cd	Pb	Cr	Ni	Zn	Mn
	(µg plant ^{1})						
NRCDR2	155.42d	1.54b	1.53a	24.28c	2.83d	5.66d	160.01c
NRCHB 101	479.74a	2.80a	1.10b	38.11a	9.96a	26.67a	538.31a
RH 749	340.46b	0.80c	0.56c	17.66d	3.36c	9.91c	417.41b
RH 119	276.47c	1.42b	1.12b	30.29b	6.22b	15.19b	103.03d

*Mean data of all locations; the different letter in the same column represents statistically significant differences between treatments ($p = 0.05$)

101 with 44.7 g plant^{-1}. The mean biomass of other mustard varieties produced was 42.8 g plant^{-1} by RH 749, 38.0 by RH 119 and 34.1 g plant^{-1} by NRC DR 2, respectively. Among the three locations, total metal removed by the mustard cultivars were in the pattern of Islamnagar-I > Bheropura > Islamnagar-II for Cu, Cd and Zn; Bheropura > Islamnagar-I > Islamnagar-II for Cr, Pb and Ni; Islamnagar-II >Bheropura > Islamnagar-I for Mn. Different varieties had performed differently regarding metal uptake (Table 4).

However, at higher levels of all these metals, there might be competition among them, resulting in a reduction of Cr uptake. Therefore, this phenomenon, wherever applicable, could be very useful in phytoremediation of contaminated soils. There were significant differences among the varieties with respect to dry matter production, except between RH 749 and RH 119. This difference might be attributed to genetic potential differences among the varieties. Similar findings of yield differences among cultivars of different crops are well established and reported by different researchers (Qdir *et al.*, 2004). The nutrient acquisition capacity of cultivars, through the release of chelating agents and ion-specific transporters, helps in promoting plant growth and producing higher biomass (Van Ginneken *et al.*, 2007). The influence of soil fertility on biomass production was found to vary between different locations, likely due to differences in soil physico-chemical properties resulting from sewage water irrigation. The importance of soil fertility in crop production is a well-established fact, with fertile soils producing more crops than less fertile soils (Havlin *et al.*, 2013). This could be attributed to the application of FYM, which mediated an increase in dry matter yield and a decrease in Cr concentration. This suggests that using FYM in the soil reduced the bioavailability of Cr (Kumar *et al.*, 2020). Similar findings demonstrating improvements in dry matter yield in metal-contaminated soils with FYM application have been reported (Koka *et al.*, 2019). Additionally, the Cr concentration in both shoot and root portions significantly decreased from 5.62 to 3.43 µg g^{-1} and 23.12 to 13.77 µg g^{-1}, respectively, due to the application of FYM at 5 g kg^{-1}. This reduction could be attributed to the immobilization of Cr by FYM (Ramya *et al.*, 2019).

Conclusion

Heavy metal toxicity is limiting the crop yield potential and plant nutrient dynamics in soil. It was observed that application of marginal quality natural resources accumulated significant amount of toxic metals in soil over a period. Different experiments were conducted to see the effect of Cr and different metals on soil health parameters, plant physiological attributes, metal interaction and uptake kinetics, immobilization of Cr in soil and remediation process by Indian mustard. In nutshell, long-term application of tannery effluent accumulated 25-30 times more Cr than tube well irrigated; sulphate and calcium metals reduce the Cr uptake in spinach. As a phytoremediation crop, Indian mustard should be used in metal contaminated fields for reducing heavy metal concentration. This study is very much useful for scientific management of Cr; and also creating awareness among the peoples for safe application of metal contaminated water and growing non-food crops in metal contaminated soils.

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