



Heavy metals in a wild plant *Pogostemon cablin* growing along the highways and assessment of its phytoextraction potential for Cd, Cr, Cu, Ni and Pb

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Abstract

Due to unique ability to bio-accumulate heavy metals several plants exhibited selective bioaccumulation of heavy metals from metal contaminated soil, in their roots and shoots. In this study the bio-accumulated levels of Cd, Cr, Cu, Ni and Pb were determined in the soil, root and shoots of *Pogostemon cablin Benth*, Limaceae, grown wildy on barren land along the highways. To assess the phytoextraction potential of the *P. cablin* plant for studied heavy metals, valuable factors such as BCF (bio-concentration factors), TF (translocation factors) and BAC (biological accumulation coefficients) were evaluated by detecting the concentrations of studied heavy metals in study area soil, roots and shoots of the plant. The observed levels of tested metals in soil were found as: Cr (8.86± 0.29) > Pb (7.15 ±0.26) > Ni (3.12± 0.21) > Cu (2.57± 0.19) > Cd (0.98± 0.09, mg/Kg). Similarly, the observed levels of heavy metals in plant roots and shoots were: Cr (10.21± 0.28) > Pb (5.38 ±0.22) > Ni (2.14± 0.19) > Cu (1.92± 0.16) > Cd (1.12± 0.13) and Cr (11.03± 0.27) > Pb (3.83 ±0.14) > Ni (1.96± 0.13) > Cu (1.58± 0.11) > Cd (1.19± 0.09 mg/Kg), respectively. The soil to root bio-concentration factors BCF_{Roots} due to bio-accumulated metals in *P. cablin* were evaluated as: Cr (1.15) ~ Cd (1.14) > Cu (0.75) ~ Pb (0.75) > Ni (0.68). The root to shoot translocation factors, TF_{Shoot} were: Cr (1.08) > Cd (1.06) > Ni (0.92) > Cu (0.82) > Pb (0.71). The soil to shoot biological accumulation coefficients (BAF_{Shoot}) evaluated were: Cr (1.24) > Cd (1.06) > Ni (0.63) > Cu (0.60) > Pb (0.54). The high (>1) or moderate values of BCFs, TFs and BACs computed as above for *Pogostemon cablin* suggested that the plant has appreciable potential to absorb, bio-accumulate and translocate Cd, Ni, Cu, Cr and Pb from contaminated soil and therefore *Pogostemon cablin* plant is capable for moderate phytoextraction of Cr, Cd, Ni and Cu, from contaminated soil.

Keywords: Heavy metals bioaccumulation, *pogestemon cablin*, BCF, TF, BAC, phytoextraction

Introduction

Heavy metals are percolated to agri-soil and water bodies as a result of weathering of rocks, mining waste and metallurgical operations, washings of blast furnaces, smelting, finishing of metal and metal products, electroplating, automobile emission, burning of coal, foundries- refectories, steel - tile industries, manufacture and uses of fertilizers, industrial waste and effluents, agricultural runoff and variety of human activities [1, 2]. The higher levels of accumulated heavy metals in farm soil adversely affect soil quality causing reduced food crop production [3]. Irrigation water also transports the dissolved heavy metals to agri-fields. Metals such as copper, manganese, cobalt, zinc and chromium are essential to plant metabolism in trace amounts. Heavy metals and essential micronutrients are absorbed by the plant's roots and translocated to the stem, leaves and fruits. Several metals are essential for plant growth and human life [4]. When the concentrations of metals in plants exceed their required levels these exert toxic effects on plant growth. Some metals are toxic for plants resulting in *chlorosis*, weak plant growth, reduced nutrient uptake and reduced nitrogen fixation in leguminous plants [5]. The non-degradable nature of metals makes them persistent in ecosystem for long and to spread in ecosystems anywhere via water and air [6]. Thus, heavy metal contamination of the ecosystems may initiate harmful consequences such as reduced agricultural productivity and damaging the ecosystems. Further, on dietary consumption of heavy metal contaminated food grains and vegetables these metals are stored in delicate human organs via biomagnification causing serious health problems.

Normally plants bio-accumulate micronutrients as per their metabolic needs, however several plants were known to selectively accumulate much higher amounts of metals from soil. The heavy metal bioaccumulation potential of a plant is the solar driven translocation process of the plant used for ascent of sap [4]. The potential of plants to accumulate and translocate heavy metals along with micronutrients to their upper parts varied greatly with the plant, magnitude of leaf transpiration and concerned heavy metal [1]. Several plants and grasses have shown the ability to selectively bio-accumulate nutrients and heavy metals from heavy metal contaminated soils in root and tubers and subsequently translocate them to the aerial parts in varying proportions [3]. This ability of plant roots to absorb, bio-accumulate and translocate heavy metals from contaminated soil to stem and leaves have been exploited for cleaning the heavy metal contaminated soils, called Phytoremediation [7]. This is an eco-friendly

and safe method, in which the selection of plants is based on the contaminated site, nature of the contaminants, metal bioaccumulation potential and the ability of the selected plant to tolerate climatic conditions [3]. This technology generates little to no secondary waste and causes minimum environmental disturbances [1].

Phytoremediation is a promising and economically effective as well as eco-friendly green technique which decontaminates and remediates the pollutants from the biosphere [4]. In phytoremediation, the plant extracts, accumulates, transfers and stabilizes heavy metals from contaminated farm-soil, which are affected by several factors, such as the concentration of the heavy metals in soil, plant species, pH and temperature [8]. Phytoextraction is one of the types of phytoremediation in which contaminants are concentrated in the roots, stems and foliage of the concerned plant [4]. Phytoextraction encompasses the intake of heavy metals and their movement to stems, leaves, shoots and other parts. The utility of this unique technique depends on the uptake potential of plant root systems for heavy metals from soil, as well as the efficiency of bioaccumulation and translocation to aerial parts [4]. The efficiency of phytoextraction is regulated by the parameters, such as the BCF, bioaccumulation factors, TF, translocation factor and BAC, biological accumulation coefficients, hence successful phytoextraction can be achieved by improving these factors [9]. To assess the heavy metals phytoremediation potential of a plant the bio-accumulated levels of tested heavy metals and their translocation to the aerial parts of the plant under study are determined [8].

Several wild plants have shown their unique capability to selectively bio-accumulate heavy metals from contaminated soil in their underground and aerial parts in varying proportions. Due to the excellent adaptation to harsh climatic conditions, several locally, abundantly and robustly growing wild plants and grasses with considerable phytoremediation potentials for heavy metals, have found wide applications for cleanup of heavy metal contaminated soils [1, 3]. A wild and abundantly growing evergreen perennial plant *Pogostemon cablin* was selected for metal uptake and phytoextraction studies. This study was focused to evaluate the metal bioaccumulation ability of *Pogostemon cablin* growing on a heavy traffic zone of Laltappar industrial area along the Raiwala- Dehradun National Highways for Cd, Cr, Cu, Ni and Pb by analyzing the levels of studied heavy metals in soil, roots and shoots of the plant and thereby the assessment of phytoextraction ability of *P. cablin* for studied metals was computed in terms of the various BCFs (bio-concentration factors), TFs (translocation factors) and BAFs (biological accumulation coefficients) [10-13].



Photo 1: Photograph of Young *P. Cablin* collected from study area for pot culture studies

Experimental

Selection of Plant

Pogostemon cablin Benth, Lamiaceae is a very important medicinal and essential oil bearing flowering plant native to Philippines which is growing wildly in China, India, Indonesia, Malaysia, Singapore and Vietnam [12, 14]. *Pogostemon cablin* is a perennial aromatic bushy herb which grows up to 1 to 1.2 m height with an erect stem and broad leaves. The plant bears small pale pink-white flowers [15]. The leaves are used to extract essential oil, which is in great demand and has extensive applications in flavor, perfumery, cosmetic, luxury products, the food and beverage industries and the pharmaceutical and detergents and deodorants industries [18]. The plant *P. cablin* commonly called *Patchouli* is used in traditional medicinal practices in India and China as antimicrobial, antifungal, repellent and as antiviral agents [16]. The *P. cablin* essential is also used to treat colds, headaches, fever, nausea, vomiting, diarrhea, abdominal pain, insect and snake bites. It also possesses blood coagulation and fibrinolytic, antithrombotic, analgesic and anti-inflammatory activities. In aromatherapy, cablin oil is used to relieve depression, stress, calm nerves and control appetite [13]. The essential oil contains more than hundred phytochemicals, such as flavonoids, alkaloids, glycosides, terpenoids, phytosterols, flavonoids, etc. The plant is also known for perfumes, cosmetics, and incense. The plant is known for rapid multiplication and is propagated from cuttings and grafts from the mother plant [17, 18]. The leaves can be used as herbal tea for a variety of

digestive ailments. The *P. cablin* oil is used to treat fungal skin infections, dandruff, and eczema [16]. India is a potential grower in the global patchouli oil market with focus to promote cultivation strategies of patchouli plant and is expected to become the second largest producer of patchouli oil in the world [18].

Sampling and pre-treatment of soil samples

The selected area for this study was a barren land near heavy traffic zone of Laltappar industrial area along the Raiwala- Dehradun National Highways. Five representative soil samples were collected from the study site at the depth of 5- 30 cm. The non-soil particles such as stones etc. were removed from soil samples. The collected soil samples were air dried for 8-10 days, followed by oven drying at 100^o C for 24 hours. The dried samples were finely grinded separately to obtain fine particles and stored in clean and dry plastic bottles, to be used for determination of studied metals.

Sampling and pre-treatment of plant samples

To estimate the bio-accumulated levels of Cd, Cr, Cu, Ni and Pb in *Pogostemon cablin*, nearly 6-7 months old plant samples were rooted out during mid July, 2017 from soil of natural habitat carefully, so as to get the plant samples with fully intact root system. The collection of samples was performed in accordance with standard methods [19]. The decayed parts of the samples of *P. cablin* were discarded and kept in unused and clean poly bags and brought to the laboratory, where samples were washed carefully with tap water 2-3 times to remove dust and soil particles. Then the samples were washed 2-3 times with distilled water and placed over clean filter paper sheets on a table top to make samples moisture free. The semi-dried plant samples were separated into roots and shoots and collected on separate clean filter paper sheets first dried in air for one week in a dust free chamber and then oven dried for a few hours at 80^oC to a constant weight. Dried samples of roots and shoots were finely grinded to fine powder and stored separately in labeled sample bottles.

Digestion of the soil and plant samples

To estimate the levels of Cd, Cr, Cu, Ni and Pb bio-available in soil samples, 1.0 g of the finely grinded soil samples were digested separately with HNO₃ –HCl–HClO₄ mixture (5:1:1) for few hours to get transparent extracts, which was filtered and diluted to a volume of 100 mL with double distilled water [20]. However, to estimate the bio-accumulated levels of metals in *P. cablin*, 1.0 g of the grinded samples of roots and shoots were subjected to nitric acid - perchloric acid (5:1, v/v) digestion following the standard methods [19], for few hours to get a transparent light-colored liquid, which was then filtered in 100 mL volumetric flasks and made up to the mark with double distilled water.

Estimation of Metals in soil and plant parts

The levels (mg/Kg,dw) of Cd, Cr, Cu, Ni and Pb present in the transparent extracts of soil samples and in the root and shoot extracts of *P. cablin* were determined on PerkinElmer Analyst-200 Model, Atomic Absorption Spectrophotometer, using an air-acetylene flame, by following the standard procedure, using an air-acetylene flame [19]. Various standard stock solutions of metal ions used in the analysis of metals were from *Sigma-Aldrich*, which were diluted to required concentrations for preparing various working standards. All the estimations were run in triplicate. All chemicals, reagents and solvents used were of analytical grade. Double distilled water was used for all purposes.

Results and discussion

The concentrations of Cd, Cr, Cu, Ni and Pb found in the soil extracts and in the root and shoot extracts of *Pogostemon cablin* are presented in Table- 1.

Table 1: Levels (mg/Kg, dw ± σ) of metals in soil, roots and shoots of *Pogostemon cablin*

Metals	Concentration in Soil (n = 5)	WHO Limits Soil (mg/Kg)	Concentration in		WHO Limits, Plants (mg/kg)
			Roots (n = 5)	Shoots (n = 5)	
Cadmium	0.98± 0.09	1.00	1.12±0.13	1.19±0.09	0.01
Chromium	8.86± 0.29	50.00	10.21±0.28	11.03±0.27	1.30
Copper	2.57± 0.19	20.00	1.92±0.16	1.58±0.11	10.0
Nickel	3.12± 0.21	20.00	2.14±0.19	1.96±0.13	10.0
Lead	7.15 ±0.26	10.00	5.38±0.22	3.83±0.14	2.0

Metal levels in soils

The agri-soil inherently contained several heavy metals in addition to micronutrients and humus produced by decomposition of plant parts and animal matter, which is essential to the fertility of soil [1]. The input of street runoff during heavy rain and regular percolation of waste water of diverse sources to agri-soils may raise the influx of heavy metals many fold in the soil [3]. Only, the bio-available fraction of the concerned heavy metal in soil solution near the plant roots are absorbed by the plant roots, which depends on the levels of metals in soil and morphology of the concerned plant [21]. The bioaccumulation of heavy metals by plants depends upon temperature, moisture, organic matter and pH of soil [9]. Plants growing in metal-polluted sites exhibit altered metabolism, growth reduction, lower biomass production and metal accumulation. Various physiological and biochemical processes in plants are affected by metals [22]. The concentration of studied heavy metals (Table-1, Fig.-1) observed in soil samples was: Cr (8.86± 0.29) > Pb (7.15 ±0.26) > Ni (3.12± 0.21) > Cu (2.57± 0.19) > Cd (0.98± 0.09, mg/Kg, dw). The observed mean concentration of all the studied metals found in soil samples

were lower than WHO limits set for soil, while the mean levels of Cd was closer to the WHO limits of 1.00 mg/Kg. On comparing these findings with the earlier studies reported by Huang *et al.*, 2019, the observed mean concentration of Cd (0.12) found in soil samples was lower than our results and also WHO limits set for soil; on the other hand the mean concentrations of Cu (17.18), Cr (22.8) and Pb (39.83mg/Kg) were much higher than the present findings, while the mean level of Pb was higher than WHO limits set for soil [13].

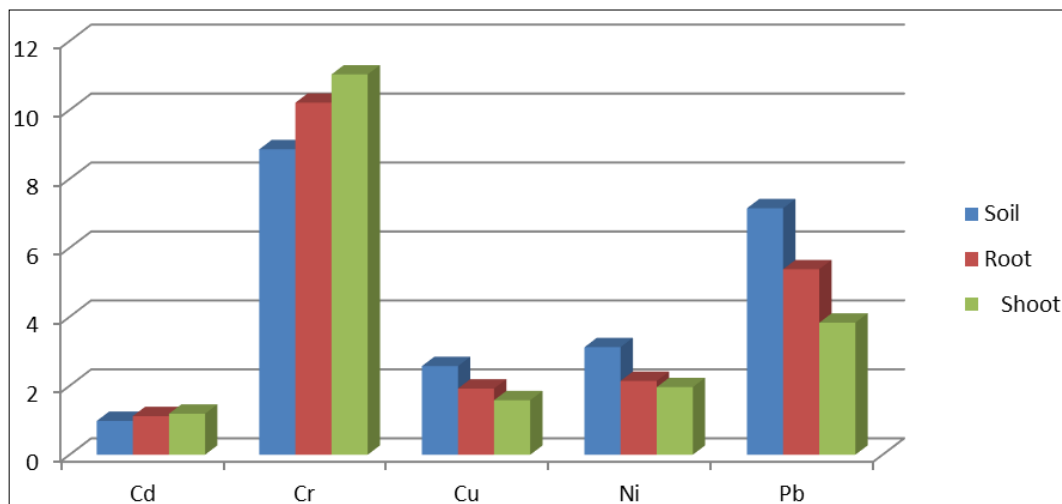


Fig 1: The levels of metals in soil, roots and shoots of *Pogostemon cablin*

Soil to plant metal uptake and accumulation in roots and shoots of *P. cablin*

The plant's root system has the unique ability to bio-accumulate micronutrients as aqueous solutions from farm soil to achieve perfect growth [4]. During this process, in addition to essential micronutrients, plant root system also facilitates the absorption of some other bio-available metals including heavy metals present around the soil solution near the plant roots in soil [1]. The cell sap containing micro-nutrients etc. are then translocated to the aerial plant parts through phloem which is facilitated suction generated by the leaf transpiration [4]. The accumulation of heavy metals in plants is related to their bio-availability in the soil solution and its pH. Plants growing in metal-polluted sites exhibit altered metabolism, growth reduction, lower biomass production and metal accumulation. Various physiological and biochemical processes in plants are affected by metals [22]. The absorption of heavy metals from farm soil and their translocations to the stem and leaves and their subsequent entry and storage via food chain to the consumer's sensitive organs exert various adverse consequences [21]. *Pogostemon cablin* is an important plant used to absorb cadmium from polluted land, because of its high plant biomass and highest Cd concentration which can be translocated to plant leaf [12].

In present findings (Table-1, Fig.-1) the overall bio-accumulated levels of Cd, Cr, Cu, Ni and Pb found collectively, in the roots and shoots of *Pogostemon cablin* were found as: Cr (23.24) > Pb (9.21) > Ni (4.10) > Cu (3.50) > Cd (2.16 mg/Kg, dw). While the bio-accumulated levels of studied metals in the roots of *P. cablin* were: Cr (10.21±0.28) > Pb (5.38±0.22) > Ni (2.14±0.19) > Cu (1.92±0.16) > Cd (1.12±0.13) and in shoots were: Cr (11.03±0.27) > Pb (3.83±0.14) > Ni (1.96±0.13) > Cu (1.58±0.11) > Cd (1.19±0.09 mg/Kg,dw). The bioaccumulation levels of Cd, Cr and Pb were many times higher than WHO limits of 0.01, 1.30 and 2.0 mg/Kg, respectively set for plants. When these results are compared with the earlier findings, we found that the mean levels of bio-accumulated Cd, Cr, Cu and Pb reported by Huang *et al.*, 2019 in *P. cablin* whole plant were as: Cr (12.64) > Cu (11.50) > Pb (1.64) > Cd (0.18) [13]. Thus, the mean values of bio-accumulated Cd, Cr and Cu were higher than WHO limits set for plants, however, the mean levels of Pb in *P. cablin* was lower than the WHO limit. Further, the bio-accumulated levels of Cd reported by Elly *et al.*, 2018, in roots, stem and leaves of *P. cablin* varied as: (0.03 – 0.12), (0.03 – 0.09) and (0.03 – 0.05 mg/Kg), respectively, The mean concentration of twenty determinations of Cd in root, stem and leaf of *P. cablin* were 0.078, 0.057 and 0.032mg/Kg, respectively. All these levels of Cd were higher than WHO limit of 0.01 mg/Kg set for plants [12].

Quantification of bio-accumulation and translocation

Heavy metals when absorbed by plant root cells along with the essential micronutrients entered to root xylem and translocated to stem, leaf and fruits in varying proportions [4]. The translocation of heavy metals along with the micronutrients to the aerial parts is facilitated by leaf transpiration which creates suction in the phloem column. To quantify the bio-accumulation and translocation and thereby phyto-extraction potential of *P. cablin* for heavy metals were computed in terms of the (BCFs) bio-concentration factors, (TFs), translocation factors and bio-accumulation coefficients (BACs). The BCF was used to compute the efficiency of a plant to bio-accumulate and magnify the heavy metals from soil [9]. Similarly, the translocation factor (TF) was used to estimate the efficiency of the plant understudy to translocate heavy metals from its root to shoot [9]. On the other hand the BAC signifies the efficiency of a plant to bio-concentrate heavy metals from soil to the shoots [23, 24]. The computed values of various BCFs, TFs and BACs due to accumulated Cd, Cr, Cu, Ni and Pb in *P. cablin* are compiled in the Table-2.

Table 2: Various BCFs, TFs and BACs due to accumulated heavy metals in *P. cablin*

<i>Pogestemon cablin.</i>	Cd	Cr	Cu	Ni	Pb
BCF _{Root}	1.14	1.15	0.75	0.69	0.75
TF _{Shoot}	1.06	1.08	0.82	0.92	0.71
BAC _{Shoot}	1.06	1.24	0.61	0.63	0.54

Bio-concentration factors (BCFs) of heavy metals in *P. cablin*

BCF is one of the important parameter which signifies the metal uptake, their movement and bio-accumulation in plant tissues, thereby assessment of phytoremediation potential of plant species under study [25]. A bio-concentration factor (BCF) is the capability of a plant under study to bio-accumulate heavy metals from soils in plant parts [26]. The value of BCF signifies the metal uptake potential of a plant under investigation. The BCF is usually computed as the ratio of the observed concentration of a metal in plant roots and the concentration of that metal found in soil [9]. The bio-concentration factors are usually computed by using following relation:

$$BCF = \frac{\text{Concentration of a metal in plant or plant parts}}{\text{Concentration of that metal in soil}}$$

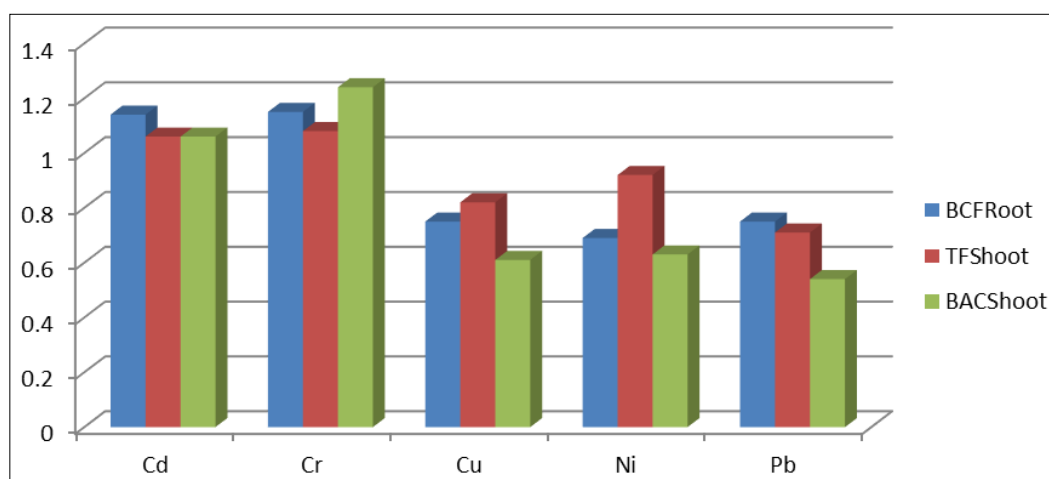
Bioconcentration factors vary with plant to plant and metal to metal and normally determined by important variables such as soil pH, the bio-availability of tested heavy metals, climatic and biological conditions, as well as the morphological components of the plant, such as its biomass as high biomass favors heavy metal bio-accumulation. The soil to root bio-concentration factors BCF_{Roots} evaluated due to bio-accumulated Cd, Cr, Cu, Ni and Pb in *P. cablin* presented in Table-2, Fig-2 were: Cr (1.15) ~ Cd (1.14) > Cu (0.75) ~ Pb (0.75) > Ni (0.68). These values of BCF_{Roots} concluded that among the studied heavy metals Cr and Cd registered highest bio-accumulation in *P. cablin* from high traffic zones National Highways soil, while Ni registered the lowest accumulation and Cu and Pb recorded moderate accumulation. The mean values of BCFs for *P. cablin* reported by Huang, *et al*, 2019, were as: Cd (2.01) > Cu (0.92) > Cr (0.61) > Pb (0.48)^[13]. These findings differed with our results in the order of BCF_{Root} for Cu, Cr and Pb and the BCF_{Root} of Cd (2.01) was much higher than our result (1.14) and the BCF_{Root} of Cr (0.61) was lower than our results, 1.15. Similarly, the BCF of Cu (0.92) was higher as compared to our result (0.75) and the BCF of Pb (0.48) was much lower than our result (0.75).

Root to shoot translocation factors due to studied metals in *P. cablin*

Translocation factor (TF) is one of the important indicators which signify heavy metal transfer from plant roots to the above ground parts, stem and leaves [9]. Thus, TF is the quantification of the capability of a plant to transfer heavy metal understudy from plant roots to shoots. TFs are evaluated as the ratio between the observed concentration of a heavy metal in the shoots of a plant and the concentration of that heavy metal found in the roots of that plant by following the relation:

$$TF = \frac{\text{Concentration of a metal in the stem or leaf or shoot of the plant}}{\text{Concentration of that metal in the roots of the plant}}$$

The various values of root to shoot translocation factors, TF_{Shoot} computed for Cd, Cr, Cu, Ni and Pb in *P. cablin* (Table-2, Fig.-2) were: Cr (1.08) > Cd (1.06) > Ni (0.92) > Cu (0.82) > Pb (0.71). Thus, soil to shoot translocation factors of studied heavy metals were found as: Cr > Cd > Ni > Cu > Pb, the translocation of Cr being the highest and Pb the lowest. When these findings were compared with that reported by Elly *et al.*, 2018, it was noticed that root to stem, root to leaves and root to shoot translocation factors for Cd were, TF_{Stem} (0.73), TF_{Leaves} (0.41) and TF_{Shoot} (1.14) [12]. Thus the root to shoot translocation factor for accumulated Cd in *P. cablin* computed from the findings of Elly *et al.*, 2018 was comparable with TF_{Shoot} reported by us for Cd [12].

**Fig 2:** Various BCFs, TFs and BACs due to accumulated heavy metals in *P. cablin*

Soil to shoot biological accumulation coefficients (BAC)

The biological accumulation coefficient is a measure of the magnitude of accumulation of heavy metals in the aerial parts of the concerned plant and higher values (>1) of computed BAF_{Shoot} signify the efficiency of metal uptake potential and accumulation of heavy metals from soil to the plant shoot. The biological accumulation coefficients (BAC) were introduced as a new factor to quantify the assessment of phyto-remediation potential of a plant for heavy metals from contaminated soil by Cui *et al.*, 2007 and Li *et al.*, 2007^[23, 24]. The soil to shoot biological accumulation Coefficients of heavy metals were computed as ratio of heavy metal observed in shoots and in soil, as first introduced by Li *et al.*, 2007 and Cui *et al.*, 2007 as follows^[23, 24].

$$BAC = \frac{\text{Concentration of metal in the shoots of the plant}}{\text{Concentration of that metal in concerned soil}}$$

The soil to shoot biological accumulation coefficients (BAF_{Shoot}) evaluated for Cd, Cr, Cu, Ni and Pb in *P. cablin* (Table-2, Fig-2) were: Cr (1.24) > Cd (1.06) > Ni (0.63) > Cu (0.60) > Pb (0.54). The BAF_{Shoot} computed for Cd and Cr were >1 and the BAF_{Shoot} for Cu, Ni and Pb were <1, therefore *P. cablin* accumulates the tested heavy metals considerably. The values of BAC for accumulated Cd and Cr in *P. cablin* both were >1, suggesting that the plant efficiently bio-accumulated Cd and Cr, while Cu and Ni registered moderate accumulation and Pb the lowest. The computed values of BAC for Cd, Cr, Cu and Ni also suggested that the plant *P. cablin* can be used for efficient phytoextraction of Cd and Cr and moderate phytoextraction of Cu and Ni from contaminated soil.

Assessment of phytoremediation potentials of *P. cablin*

Phytoremediation is carried out in situ for selective removal of heavy metals from metal contaminated soil by growing metal tolerant plant species in that soil, which absorbs, bio-accumulates and then trans-locates the target heavy metals to its above ground parts. Phytoextraction is a kind of the phytoremediation which concentrates the heavy metals and other contaminants in the roots, stems and leaves of the plant under study, the target contaminants can be collected by harvesting the whole plant^[1, 4]. The overall success of phytoextraction is directly related to the bioavailability of the metals in soil, characteristics of soil, morphology of the plant species and the biomass yield of plant shoots^[10, 27]. Phytoextraction potential of a plant species can be quantified by evaluating the bio-concentration factors, translocation factors and biological accumulation coefficients for each studied metals by observing the efficiency of the absorption, accumulation and translocation of heavy metals in that plant^[9]. Plants with high BCF and TF values (>1) have the potential to be used in phytoextraction. On the basis of the higher values (>1) of BCF, TF and BAC, the potential of the plant under study for phytoextraction and phytostabilization can be evaluated^[9, 24]. As per the Table-1 and 2, *P. cablin* accumulates and translocates Cr (1.15) > Cd (1.14) > Cu (0.75) ~ (Pb (0.75) in its areal parts suggesting the efficient phytoextraction of Cr and Cd and moderate phytoextraction of Cu and Pb from the concerned soil. Thus, for efficient phytoextraction *P. cablin* registered high and moderate BCF, TF and BAC values, which are facilitated by the plant's deep roots, fast growth, robust, high biomass and considerable ability to absorb and accumulate Cd, Cr, Cu, Ni and Pb in the stem and leaf of the plant. The ability of *P. cablin* (patchouli) to absorb Cd can be measured through the high plant biomass and high Cd concentration which can be translocated to leaf organs^[12].

Conclusion

Heavy metal contamination of the soil may degrade the ecosystem and health problems to the consumers due to dietary intake of heavy metal contaminated food grains. Phytoremediation is selective removal of heavy metals from metal contaminated soil by cultivating locally abundantly growing metal tolerant plants on the polluted soil aiming to concentrate the targeted heavy metals in their roots, tubers and above ground parts through bio-absorption, bio-accumulation and translocation i.e. phytoextraction. In this study, *Pogostemon cablin* Benth, Lamiaceae was selected to assess its phytoextraction potential for Cd, Cr, Cu, Ni and Pb. The *P. cablin* is a medicinal and essential oil bearing plant called *Patchouli* and used in traditional medicinal practices in India and China. The phytoextraction potential of *Pogostemon cablin* growing on barren land along the National Highways was assessed for Cd, Cr, Cu, Ni and Pb by determining their concentration in soil of study area and in the roots and shoots of the plant. The observed levels of studied metals in the soil, plant roots and shoots were as: Cr (8.86±0.29) > Pb (7.15 ±0.26) > Ni (3.12± 0.21) > Cu (2.57± 0.19) > Cd (0.98± 0.09) and Cr (10.21±0.28) > Pb (5.38±0.22) > Ni (2.14±0.19) > Cu (1.92±0.16) > Cd (1.12±0.13) in the roots and Cr (11.03±0.27) > Pb (3.83±0.14) > Ni (1.96±0.13) > Cu (1.58±0.11) > Cd (1.19±0.09 mg/Kg,dw), respectively. The phytoextraction potential of the *P. cablin* was assessed in terms of the bioconcentration factors (BCF), translocation factors (TF) and Biological accumulation coefficients (BAC). The soil to roots BCF_{Root} for studied metals were computed as: Cr (1.15) ~ Cd (1.14) > Cu (0.75) ~ Pb (0.75) > Ni (0.68) and root to shoot TF_{Shoot} for these metals were: Cr (1.08), Cd (1.06), Ni (0.92), Cu (0.82) and Pb (0.71). While the computed soil to shoot, BAC_{Shoot} were: Cr (1.24) > Cd (1.06) > Ni (0.63) > Cu (0.60) > Pb (0.54). Most of the values of BCF, TF and BAC computed as above were either >1 or moderate, suggested that *P. cablin* has appreciable potential for absorption, bioaccumulation and translocation i.e. Phytoextraction of Cd, Cr, Ni and Cu from contaminated soil.

Acknowledgement

The authors are thankful to Dr. S. K. Dabral, former head, department of Chemistry, Pt. L. M. S. Govt. Post Graduate College (Autonomous College) Rishikesh, Dehradun, Uttarakhand, India for valuable suggestions.

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