Research Article

Uptake and release of chromium and nickel by Vetiver grass (*Chrysopogon zizanioides* (L.) Roberty)

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Abstract
The effectiveness of using Vetiver grass (*Chrysopogon zizanioides*) in phytoremediation of wastewater has been proven. In this study, the phytoremediation potential of *C. zizanioides* planted in Cr- and Ni-contaminated soil was evaluated through investigating the behaviors on uptake and release of metals. Three treatments: control, Cr, and Ni, with three concentrations (50, 150, and 300 ppm), were applied. The potential of *C. zizanioides* is assessed by the determination of metal uptake rate, metal release rate, bioconcentration factor (BCF), biological absorption coefficient (BAC), and translocation factor (TF). The experiment showed that Cr uptake was higher than release rate and on the other hand low in uptake and release of Ni. Accumulation of Cr and Ni was 167.8 mg kg^{-1} and 66.3 mg kg^{-1}, respectively. Excess of Cr in the soil was absorbed in high uptake rate making vetiver grass suitable for Cr phytoremediation. During 28-day uptake and 28-day release periods, it was found that BCF, BAC, and TF values in some treatments showed greater than 1 (one) and Ni-treated plants were able to translocate Ni to aerial plant parts supported by its high TF value. Low acidity of soil causes low solubility and low mobility of metals, resulting in low metal absorption. *C. zizanioides* has shown the potential as a heavy metal-tolerant species and could be potentially used as phytoremediation alternative species at least in lightly polluted areas.

Keywords Bioconcentration · *Chrysopogon zizanioides* · Heavy metals · Phytoremediation · Plant uptake · Translocation

1 Introduction

Heavy metal in wastewater presents a critical threat to our environment. Mining and manufacturing industries, such as electroplating, contribute an immense quantity of heavy metals that pollute the air, soil, and groundwater [10, 18, 22, 29]. Phytoremediation represents a promising method for heavy metal removal as it is accessible, cost-effective, and environmentally friendly for remediation of contaminated areas [33]. Two of the strategies of phytoremediation are phytoextraction and phytostabilization. Phytoextraction utilizes the ability of uptake and accumulation of metals into plant shoots, while phytostabilization utilizes the plant's ability to minimize metal mobility in contaminated soils.

In ecotoxicology, it is necessary to establish the correlations between bioavailability of metals in the environment and tissues by using bioconcentration factors and the cause of biological effects that result from metal concentration in soft tissues. The means to establish these correlations are to achieve the ultimate aims: to predict and diagnose the cause–effect of exposure to heavy metals and environmental stress and the resultant ecological and biological effects [37]. In this study, the former was focused upon.

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The use of vetiver grass (*C. zizanioides*) has been proven as an effective technique in phytoremediation. *C. zizanioides* is reported to be effective to absorb pollutants and nutrients, especially nitrogen (N) and phosphate (P) [9]. The studies conducted have also shown that *C. zizanioides* is highly tolerant to extreme soil conditions, has a long and complex rooting system, and is remarkably effective at absorbing organic and inorganic pollutants. *C. zizanioides* are also proven to be able to improve wastewater quality, such as biogas wastewater, palm oil wastewater, trichloroethylene (TCE) wastewater-contaminated soil, and batik liquid wastewater [33].

It is reported in several studies that *C. zizanioides* have a high tolerance to a broad range of heavy metals in soil. Previous studies also indicated cadmium (Cd) phytostabilization potential of *C. zizanioides*, which was found to have no significant Cd toxicity symptoms throughout the experiments, indicating high adaptability and tolerability of heavy metals [25]. Other than Cd, heavy metals such as chromium (Cr) and nickel (Ni) also pose significant concerns. Cr is a nonessential metal that can be toxic even at low concentrations, while Ni is an essential metal that can be toxic at high concentrations [4]. Accumulation of Cr in plants could reduce plant growth, induce chlorosis, and induce degradation of carotenoid; therefore, it forms ROS [21]. Excess of Ni intake could inhibit other heavy metals uptake, causing deficit which consequently inhibit plant growth. Ni excess could also interfere with antioxidant enzymes function, such as SOD, CAT, glutathione peroxidase (GSH-Px), glutathione reductase (GR), peroxidase (POD), guaiacol peroxidase (GOPX), and ascorbate peroxidase (APX). As a result, the plant's ability to fight ROS is decreased [3]. *C. zizanioides* possess high threshold levels of heavy metal compared to most vascular plants. While the threshold levels in other plants are 0.02–0.20 mg kg^{-1} and 10–30 mg kg^{-1} for Cr and Ni, respectively, the threshold levels for *C. zizanioides* are 5–18 mg kg^{-1} and 347 mg kg^{-1}, respectively [20].

The present study investigates the phytoremediation potential of *C. zizanioides* in greenhouse experiments. Cr and Ni concentrations in plants and the associated soils were analyzed. Metal uptake rate, metal release rate, bioconcentration factor (BCF), biological absorption coefficient (BAC), and translocation factor (TF) were also determined.

2 Materials and methods

2.1 Preparation and planting

Experiments were conducted in a greenhouse at the Research Unit for Clean Technology, Indonesian Institute of Sciences (LIPI) Bandung, West Java, Indonesia, without climate control. Conditions were as follows: soil temperature of 28–35 °C, room temperature of 29–40 °C, 100% relative humidity, and soil pH of 6.8–7 (Table 1). Soil was amended with low doses of urea and NPK fertilizer (ratio of urea to NPK is 1:3) in plastic pots. Only a single tuft was grown in each pot. Plants were watered regularly to maintain soil moisture.

2.2 Experimental design

A randomized complete block design with three replications and three treatments: control, Cr, and Ni, were used. Concentrations used for Cr and Ni treatments were 50 ppm, 150 ppm, and 300 ppm. Non-contaminated soil is used as control.

Preparation of 1000 ppm Cr and Ni stock solution was done by dissolving 5.66 g $K_2Cr_2O_7$ (EMSURE®) and 4.48 g $NiSO_4.6H_2O$ (EMSURE®) each in 1000 mL deionized water. Preparation of 50 ppm, 150 ppm, and 300 ppm metal solutions was carried out by diluting 50 mL, 150 mL, and 300 mL of the stock solution into a 1000-mL volumetric flask each and filled with deionized water.

Treatment was carried out by pouring the solution onto the soil, marking the day as the beginning of the phytoremediation process. The plants were grown for 28 days to absorb the heavy metals (known as metal uptake period); then, the remaining plants were transferred

Table 1 Environmental condition during uptake and release period weekly

Parameter	Week							
	Uptake				Release			
	1	2	3	4	1	2	3	4
Soil temperature (°C)	32	35	29	30	28.5	29	28	29
Room temperature (°C)	37	32	31	34	40	41	29	40
Soil humidity (%)	100	100	100	100	100	100	100	100
Room humidity (%)	49	67	71	64	48	48	74	49
Soil pH	6.8	7	7	7	7	7	7	7

to non-contaminated soil and grown for 28 more days (known as metal release period).

2.3 Sampling of soil, leaves, and roots

Soil sampling was conducted at days 0 and 28 during uptake and release period. Five grams of soil was sampled from each pot and then dried until attaining a constant weight at low temperature (50 °C). Later, the samples were then digested using the wet acid digestion method [36]. Cr and Ni concentration were determined using atomic absorption spectrophotometer (AAS).

Two (2) grams of leaves was sampled from each treatment at days 0, 4, 14, and 28 during the uptake and release period. Leaves were dried in an oven at low temperature (50 °C) until they attained a constant weight. The samples were then digested until the brownish color fade [24].

Root sampling was conducted on day 28 during the uptake and release period. The roots were thoroughly rinsed with tap water and dried until attaining a constant weight at low temperature (50 °C). Dry weight biomass of the roots was measured separately for each treatment. The dried roots then digested for analysis. In addition, the elemental content of the root on day 0 of uptake period was observed using SEM–EDS. Root samples used for SEM–EDS were dried at 50 °C for 10–15 min and then cut into cross-sectional samples in liquid nitrogen, which then plated with gold plating for the analysis process.

2.4 Digestion process and determination of Cr and Ni concentration

Soil digestion was carried out using the wet acid digestion method based on [36]. One (1) gram of dried soil was added with 12 mL of HNO_3 (EMSURE®) and 4 mL of HCl (EMSURE®). The mixture was heated with a hot plate (100 °C) for 2 h. The mixture was then moved into a 100-mL volumetric flask, filtered with 0.45-µm filter paper, and diluted with deionized water.

Leaves and roots were digested using the wet digestion method based on Pequerul et al. [24] with modification. Dry samples were crushed; then, 0.1 g of the sample was added with 1 mL of 65% HNO_3 (EMSURE®) and shaken until the sample was wet. 0.8 mL of 33% H_2O_2 (EMSURE®) were slowly added to the solution and then homogenized. The sample was then heated with a hotplate at 100 °C until bubbly. After the brownish color faded in 7–8 min, the solution was cooled. It was then put into a 25-mL volumetric flask, filtered with 0.45-µm filter paper, added with 1 mL of 37% HCl (1:1) (EMSURE®), and then diluted with deionized water.

Total contents of Cr and Ni were determined using Atomic Absorption Spectrophotometer (AAS) Agilent Technologies 200 Series AA. The results obtained were converted from mg L^{-1} to mg kg^{-1}. The unit conversion was based on Loney [13]. To avoid possible contamination, all glassware and equipments used were acid-washed.

$$\frac{\text{mg}}{\text{kg}} = \left(\frac{\left[\text{concentration} \left(\frac{\text{mg}}{\text{L}} \right) \right] - \text{sample volume (L)}}{\text{dry weight of sample (g)}} \right) \times 1000$$

2.5 Data analysis

The collected data were calculated to obtain the value of bioconcentration factor (BCF) as the ratio of heavy metal concentration in the roots to the soil, biological absorption coefficient (BAC) as the ratio of heavy metal concentration in leaves to the soil, translocation factor (TF) as the ratio of heavy metal concentration in leaves to root, metal uptake rate, and metal release rate [11, 15, 37, 38].

Statistical analysis of the collected data related to the concentration of Cr and Ni from uptake and release period in plant parts (leaves and roots) was performed using IBM-SPSS version 20.0 (SPSS 2006). Data are analyzed using the independent sample *t* test (significance level of $p < 0.05$) and the Mann–Whitney *U* test (significance level of $p < 0.05$).

$$\text{BCF} = \frac{\left[\text{heavy metal}\right]_{\text{root}}}{\left[\text{heavy metal}\right]_{\text{soil}}} \quad \text{BAC} = \frac{\left[\text{heavy metal}\right]_{\text{leaf}}}{\left[\text{heavy metal}\right]_{\text{soil}}}$$

$$\text{TF} = \frac{\left[\text{heavy metal}\right]_{\text{leaf}}}{\left[\text{heavy metal}\right]_{\text{root}}}$$

$$\text{Metal uptake rate} = \frac{\left[\text{heavy metal}\right]_{\text{exposed}} - \left[\text{heavy metal}\right]_{\text{control}}}{\text{Day}(s) \text{ of metal exposure}}$$

$$\text{Metal release rate} = \frac{\left[\text{heavy metal}\right]_{\text{end of metal exposure}} - \left[\text{heavy metal}\right]_{\text{end of metal release}}}{\text{Day}(s) \text{ of metal exposure}}$$

3 Results and discussion

3.1 Cr and Ni concentration in soil

Cr and Ni concentration in soil is assessed to evaluate the bioavailability of Cr and Ni in soil (Table 2). The results obtained showed a decrease of Cr and Ni content in soil at uptake period for plants treated with

Table 2 Cr and Ni concentration in each soil treatment on days 0 and 28 (mg kg^{-1})

Treatment	Cr				Ni			
	Uptake		Release		Uptake		Release	
	0	28	0	28	0	28	0	28
Control	17.46	0.00	0.00	3.84	12.05	4.61	0.00	8.55
50 ppm	63.86	28.14	0.00	4.92	37.35	35.98	0.00	23.05
150 ppm	122.97	92.73	0.00	6.53	82.05	156.37	0.00	7.95
300 ppm	70.94	209.50	0.00	5.21	19.29	257.94	0.00	10.70

50 ppm Cr, 150 ppm Cr, and 50 ppm Ni. Heavy metal content in soil decreased from 63.9 to 28.1 mg kg^{-1} (by 55.9%), 123.0 to 92.7 mg kg^{-1} (by 24.6%), and 37.4 to 36.0 mg kg^{-1} (by 3.7%), respectively. However, plants treated with 300 ppm Cr, 150 ppm Ni, and 300 ppm Ni showed an increase of Cr and Ni concentrations in its soil content varying from 70.9 to 209.5 mg kg^{-1} (by 66.1%), 82.1 to 156.4 mg kg^{-1} (by 47.5%), and 19.3 to 257.9 mg kg^{-1} (by 92.5%), respectively. Cr and Ni accumulated in the treated soil were higher than that of the control soil. Cr concentration in soil of plants treated with 150 ppm and 300 is above the normal concentration range (12–44 mg kg^{-1}) and is within the range of the critical concentration (75–100 mg kg^{-1}), meaning that plants are in a Cr-induced stress condition [26]. The same plants were treated with 150 ppm and 300 ppm Ni, which also contained Ni higher than the normal concentration range (1–20 mg kg^{-1}) but within the critical range (100 mg kg^{-1}). This means that plants treated with 150 ppm and 300 ppm Ni are in a Ni-induced stress condition [26]. Even though plants were under Cr and Ni stress, several studies reported that *C. zizanioides* could survive under the highest levels of contaminants reported in the literature, which are 2290 mg kg^{-1} and 100 mg kg^{-1}, respectively, for Cr and Ni [5].

The remaining plants were then transplanted to non-contaminated soil (metal release period). The results showed that the initial Cr and Ni concentration in all treatments was 0.0 mg kg^{-1}. After 28 days of observation, the results showed an increase in all treatments varying from 4.9 mg kg^{-1}, 6.5 mg kg^{-1}, and 5.2 mg kg^{-1}, respectively, for Cr and 23.1 mg kg^{-1}, 8.0 mg kg^{-1}, and 10.7 mg kg^{-1}, respectively, for Ni. Cr and Ni concentrations in treated soil are similar to non-contaminated soil and are within the range of published values [26].

These results indicate that *C. zizanioides* exhibited the ability to reduce Cr concentration in soil through a high absorption process, especially for 50 ppm and 150 ppm treatment. On the other hand, the ability to release Cr is relatively low. In addition, plants treated with Ni showed a relatively low absorption process for 50 ppm treatment, and Ni released by plants in all treatments was relatively low. *C. zizanioides* treated with 300 ppm Cr, 150 ppm Ni, and 300 ppm Ni were not able to absorb excess Cr and Ni in the soil as indicated by the increasing heavy metal concentration in soil at the end of the uptake period.

Theoretically, Cr and Ni concentration in soil in this study could reach up to 2500 mg kg^{-1}, 7500 mg kg^{-1}, and 15,000 mg kg^{-1} for 50, 150, and 300 ppm, respectively. This turned out to be inconsistent with the results obtained on day 0 (beginning of metal uptake period), where the results obtained showed much lower metal concentration. One of the factors that affected the availability of heavy metal in the soil is acidity. Acid soils tend to make metals more soluble and mobile [12]. Soil pH in this study ranged between 6.8 and 7.0, thus making it a neutral soil (Table 1). Because of low acidity, this type of soil has low solubility and mobility of heavy metals, causing uneven distribution of heavy metals so the obtained concentration has not represented the real concentration.

Chrysopogon zizanioides root on day 0 of uptake condition (Fig. 1) reported to have high quantities of C and O, which was 56.5% and 41.0%, respectively, and low amount of K 1.1%. The concentration of Ni, Mg, Al, P, S, and Cl recorded was 0.3%, 0.1%, 0.04%, 0.3%, 0.3%, and 0.5%, respectively. The element distribution in the roots is reported to be evenly distributed as shown in Fig. 2. Analysis of SEM–EDS is acted as a preliminary analysis to detect whether Ni and Cr were observed in the root samples or not. From the result, it is reported that there were only Ni detected and no Cr in the roots. The presence of Ni indicates that Ni is an essential heavy metal for plants [3], and the absence of Cr is beneficial for the experiments as it would not affect the result of Cr accumulation in plant parts.

3.2 Accumulation of Cr in leaves

Figure 3a shows the total accumulation of Cr in leaves throughout the experiments. Overall, Cr concentration showed an increase throughout the uptake period. The highest Cr concentration is contained by leaves on day 14. Compared to control plants, treated plants tend to have higher Cr concentrations, indicating that Cr excess in soil

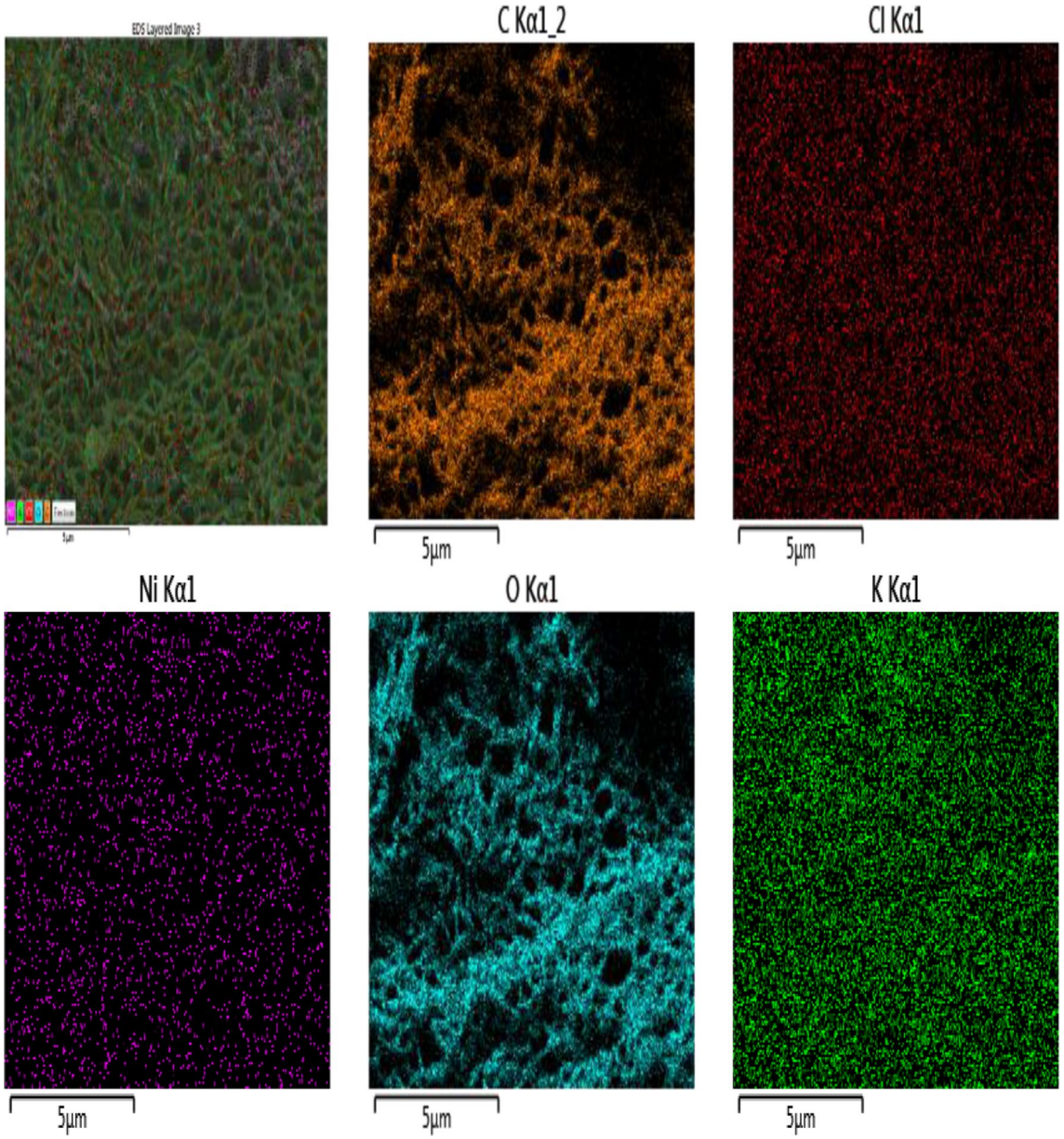

Fig. 1 Mapping of the elemental content distribution in *C. zizanioides* roots on day 0 of metal uptake period

is gradually absorbed and translocated to aerial plant parts. Cr concentration in plants treated with 150 ppm and 300 ppm experienced a significant decrease on day 28. This may be due to excessive Cr accumulation by plants, causing metal saturation which then inhibits Cr absorption [19]. Several studies showed that *C. zizanioides* is the most Cr-tolerant plant among 36 plant species, regardless of Cr forms and rates. The plants can accumulate very high concentration of Cr varying from 404 to 1750 mg kg^{-1} for Cr(III) and up to 10,000 mg kg^{-1} in the shoots but died a few days later after exposure of Cr(VI) at a concentration of 500 mg kg^{-1} in the soil [28, 35].

After the plants were transplanted into non-contaminated soil, Cr concentration in each treatment tended to decrease and reached the lowest concentration on day 28 (Fig. 3b). Control plants had a very low Cr concentration when compared to treated plants. This tendency of decreasing concentration may be due to the extracted part that is the young leaves. Ordinarily, Cr accumulation occurs in the roots, which are then translocated into stems and leaves. In leaves, Cr is largely accumulated in the mature leaves rather than the young ones, which will be shed to reduce the metal that is absorbed by plants.

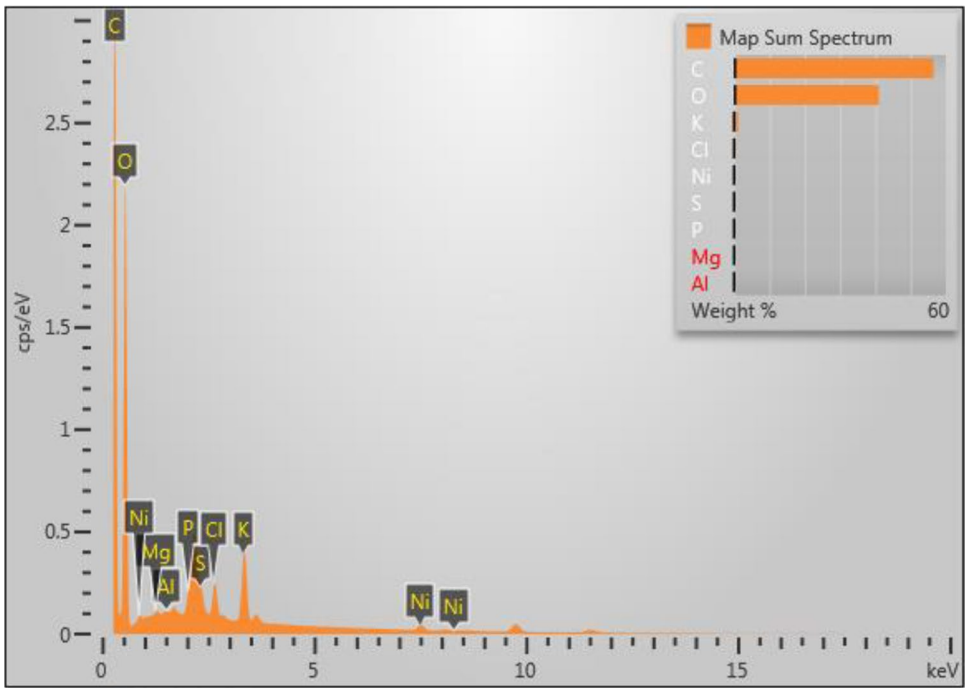

Fig. 2 EDS peaks of elements in *C. zizanioides* roots on day 0 of metal uptake period

This is one of the plant strategies to reduce metal concentration in their bodies [19].

On day 4, Cr concentration has increased in 150 ppm and 300 ppm treatment (Fig. 3a). This may be caused by the ability of plants to carry out a detoxification mechanism through the synthesis of phytochelatins. As a result, plants can survive, accumulate metals, then store them in their vacuoles, hence increasing the absorption ability [23]. On the other hand, Singh et al. [30] stated that stress due to Cr can reduce plant biomass. This was proved by the results exhibiting an increase in leaf biomass after 28 days of exposure to heavy metals.

3.3 Accumulation of Ni in leaves

Ni accumulation in leaves is shown in Fig. 4a. Obtained results exhibited an increase in Ni concentration throughout the uptake period. Plants treated with 50 ppm and 300 ppm were reported to accumulate the highest concentration on the last day of this period. This indicates that exposure duration affects the accumulated concentration of Ni in the leaves. In 150 ppm treatment, Ni reached the highest concentration at day 14, which was 25.1 mg kg^{-1}. Ni concentration in control plants was relatively low compared to that of treated plants. The decreasing Ni concentration in plants treated with 150 ppm at day 28 may be due to excessive accumulation of Ni by plants, causing metal saturation which then inhibits the absorption of these metals [19]. Studies conducted by Truong [35] reported a high Ni accumulation in shoots (448 mg kg^{-1}), which, when compared to the recent findings, showed a huge difference, meaning that *C. zizanioides* is able to accumulate higher Ni concentrations than the results of this experiment.

Accumulation of Ni showed a decrease over the time at release period. Plants treated with 50 ppm and 150 ppm had the lowest concentration on day 28, which was 6.2 mg kg^{-1} and 6.4 mg kg^{-1}, respectively. The treatment using 300 ppm metal contains a lower concentration of Ni at day 14, which was 14.4 mg kg^{-1}. The control plants tended to have a very low concentration of Ni when compared to treated plants.

It is possible that the reduction of the Ni concentration in leaves was due to the extraction of plant samples. Samples used in the experiments were young leaves, which may contain a lesser concentration of Ni. Several studies showed that plants accumulate high quantities of heavy metals in plant roots. Heavy metals were then translocated from roots to leaves, favoring the mature leaves that will be shed later. This is one of the plant strategies used to excrete metals accumulated in its body [3]. Chen et al. [3] also stated that stress due to exposure to Ni can reduce the total dry weight accumulation in roots and stems, as well as the total plant biomass. This is due to poor plant development and reduced supply of nutrients to the reproductive parts of the plant. The statement was supported by the results obtained, which showed a decrease in biomass produced by the plants after 28 days at the uptake period.

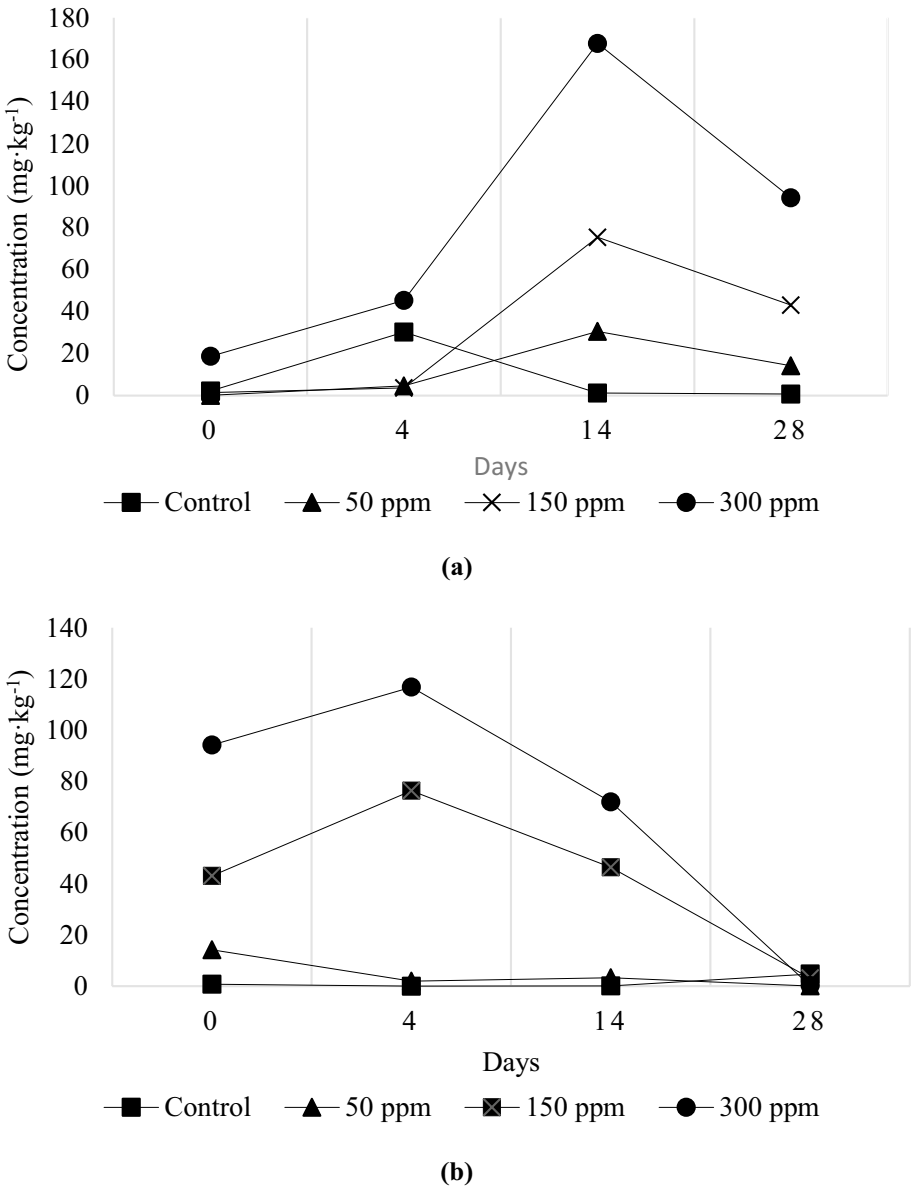

Fig. 3 Cr concentration in leaves (mg kg^{-1}) **a** metal uptake condition and **b** metal release condition

3.4 Uptake rate and release rate

The uptake and release rate of Cr and Ni in all treatments tended to fluctuate (Table 3). Cr uptake rate in all treatments tended to have a higher value when compared to its release rate, apart from 50 ppm treated plants at days 4 and 28 and 300 ppm treated plants at day 28. On the other hand, the Ni uptake rate was higher on some treatment (150 ppm at days 14 and 28 and 300 ppm at days 4, 14, and 28). Meanwhile, 50 ppm Ni-treated plants reported a higher release rate except for day 28.

According to Chen et al. [3], uptake and release rates are affected by the availability of heavy metals in soil, plant metabolism, soil acidity, the presence of other metals, and the composition of soil organic matter. Soil pH that allows metal absorption to be carried out ranges from 3.9 to 5.7. Referring to this value, the soil pH in this study (Table 1) did not allow the metal absorption process to be optimum because the pH value is more alkaline, which was in the range of 6.8–7.

Cr uptake rate in this study demonstrated a higher value, while Ni uptake rate exhibited a lower value when compared to its release rate. High uptake rate in plants is proven to represent an essential trait as a phytoremediation agent [3, 17]. In this context, *C. zizanioides* is proven to be useful as an alternative to phytoremediation in Cr-contaminated areas. This finding is supported by the characteristics of *C. zizanioides*, which have a deep and extensive root penetration system, a good nutrient

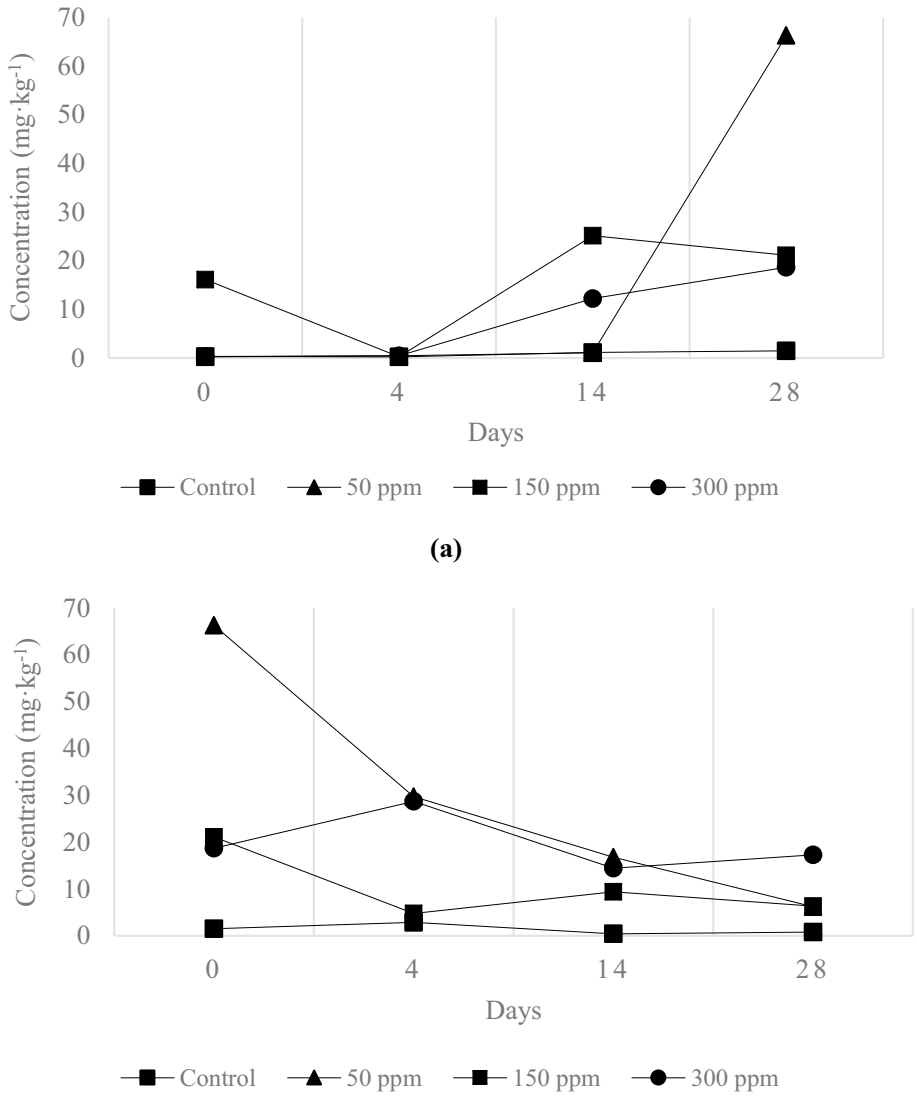

Fig. 4 Ni concentration in leaves (mg kg^{-1}) **a** metal uptake condition and **b** metal release condition

Table 3 Metal uptake rate and release rate in vetiver (*C. zizanioides*)

Day	Treatment (ppm)	Cr		Ni	
		Uptake rate (mg kg^{-1} d^{-1})	Release rate (mg kg^{-1} d^{-1})	Uptake rate (mg kg^{-1} d^{-1})	Release rate (mg kg^{-1} d^{-1})
4	50	−6.40	3.07	0.05	9.15
	150	−6.64	−8.32	0.01	4.09
	300	3.78	−5.64	0.05	−2.51
14	50	2.09	0.78	−0.01	3.54
	150	5.30	−0.24	1.71	0.84
	300	11.90	1.59	0.79	0.30
28	50	0.48	0.51	2.31	2.15
	150	1.51	1.43	0.70	0.53
	300	3.34	3.36	0.61	0.05

absorption ability, and a high tolerance for environmental stress conditions [9].

3.5 Phytoremediation potential of vetiver (*C. zizanioides*)

The use of *C. zizanioides* as a phytoremediation agent in this study can be evaluated by several indexes, such as bioconcentration factor (BCF), biological absorption coefficient (BAC), and translocation factor (TF) [11, 14, 15, 38]. Bioconcentration factor (BCF) is an indicator of the translocation process of available metals from soil to plants. Biological absorption coefficient (BAC) is an indicator of accumulated levels of metals in plants. Translocation factor (TF) is an indicator of the translocation ability of metal from roots to shoot [11, 16]. Plants used for phytoextraction generally have BCF and TF values > 1 (Yoon et al. 2006). Plants used for phytostabilization have values of BCF > 1 and TF < 1 [14]. On the other hand, plants with BAC and TF values > 1 have the potential to be hyperaccumulator plants [11]. According to Baker and Brooks (1989) in Yoon et al. [38], hyperaccumulator plants can accumulate Cr and Ni as much as > 1000 mg kg^{-1}.

All Cr-treated plants at the uptake period showed a significant difference in Cr accumulation in leaves and roots. At the release period, only Cr accumulation in roots showed significant differences. All Ni-treated plants showed a significant difference in the accumulation in the roots and only the 300 ppm treated plants showed a significant difference in the accumulation in the leaves. Only the 300 ppm treated plants at the release period showed to be significantly different in the leaves. Plants given Cr treatment showed that Cr was largely accumulated in the roots, except for 150 ppm and 300 ppm at the uptake period. In contrast, plants given Ni treatment showed that Ni was largely accumulated in the leaves. This indicates that Cr is generally retained in the roots, while Ni is effectively translocated into the aerial part of the plants. Similar findings indicated that heavy metal content was highly accumulated in the vetiver roots. Generally, metal uptake was higher in vetiver root than in the shoot due to the plant root structure that can form a high surface area and due to restricted heavy metal translocation from root to shoot [31]. High Ni accumulation in the aerial part of the plants indicated a high translocation ability. Previous studies [31] also reported that essential elements (Mn and Zn) were largely accumulated in the shoot than root due to restricted accumulation in the roots for some metal elements required for plant growth.

In this study, only BCF value at uptake period from 300 ppm Cr was > 1, while other treatments were < 1. Only BAC value from 50 ppm Ni was > 1. TF values from 150 ppm Cr, 300 ppm Cr, 50 ppm Ni, and 150 ppm Ni were > 1 (Tables 4, 5). Previous studies reported BCF, BAC,

Table 4 Cr concentration in soil, leaves, and root in vetiver (*C. zizanioides*) with BCF, BAC, and TF values

Period	Soil (mg kg^{-1})	Leaves (mg kg^{-1})	Root (mg kg^{-1})	BCF	BAC	TF
50 ppm						
Uptake						
Control	0.00	0.76* ± 0.82	0.33* ± 0.57	0.53	0.50	0.94
Treated	28.14	14.20* ± 2.77	15.05* ± 0.00			
Release						
Control	3.84	4.72 ± 5.11	0.11 ± 0.19	0.04	0.01	0.24
Treated	4.92	0.05 ± 0.01	0.22 ± 0.38			
150 ppm						
Uptake						
Control	0.00	0.76* ± 0.82	0.33* ± 0.57	0.39	0.46	1.20
Treated	92.73	43.04* ± 1.54	35.96* ± 0.33			
Release						
Control	3.85	4.72 ± 5.11	0.11* ± 0.19	0.75	0.48	0.63
Treated	6.53	3.11 ± 0.87	4.90* ± 0.98			
300 ppm						
Uptake						
Control	0.00	0.76* ± 0.82	0.33* ± 0.57	0.06	0.45	7.71
Treated	209.50	94.22* ± 1.85	12.21* ± 0.19			
Release						
Control	3.84	4.72 ± 5.11	0.11* ± 0.19	2.89	0.04	0.01
Treated	5.21	0.19 ± 0.00	15.04* ± 0.57			

*Indicating a statistically significance different ($p < 0.05$)

Table 5 Ni concentration in soil, leaves, and root in vetiver (*C. zizanioides*) with BCF, BAC, and TF values

Period	Soil (mg kg^{-1})	Leaves (mg kg^{-1})r	Root (mg kg^{-1})	BCF	BAC	TF
50 ppm						
Uptake						
Control	4.61	1.48 ± 1.33	1.19* ± 1.14	0.17	1.84	10.78
Treated	35.98	66.29 ± 0.76	6.15* ± 0.63			
Release						
Control	8.55	0.79 ± 0.71	0.85 ± 1.25	0.05	0.27	5.63
Treated	23.05	6.19 ± 0.07	1.10 ± 0.96			
150 ppm						
Uptake						
Control	4.61	1.48 ± 1.33	1.19* ± 1.14	0.03	0.13	4.17
Treated	156.37	21.10 ± 2.22	5.06* ± 1.40			
Release						
Control	8.55	0.79 ± 0.71	0.85 ± 1.25	0.09	0.80	8.46
Treated	7.95	6.35 ± 0.67	0.75 ± 0.66			
300 ppm						
Uptake						
Control	4.61	1.48* ± 1.33	1.19* ± 1.14	0.08	0.07	0.92
Treated	257.94	18.65* ± 2.80	20.37* ± 0.87			
Release						
Control	8.55	0.79* ± 0.71	0.85 ± 1.25	0.18	1.61	8.90
Treated	10.70	17.28* ± 2.59	1.94 ± 1.39			

*Indicating a statistically significance different ($p < 0.05$)

and TF values of Cr for *C. zizanioides* grown on mine-soil were 0.95, 0.79, and 0.83, respectively. On the other hand, BCF, BAC, and TF values of Ni were 0.93, 0.43, and 0.46, respectively. The data indicated that Cr and Ni accumulated by plants were largely retained in the roots [2]. When compared to findings in this study, it showed a higher result in some treatments, which indicated an effective heavy metal translocation from root to shoot by plants, as shown by general TF values > 1. BCF and BAC reveal efficient uptake of heavy metals by root and shoot. A higher BCF value indicates that the root parts of the plants accumulated higher heavy metal concentration than the shoot parts. In addition, BAC values reported by Tariq et al. [34] for *C. zizanioides* were 0.31 and 0.26 for Cr. Findings in this study showed a similar result to the previous studies, which were < 1. Plants treated with 50 ppm Cr at the uptake period showed a high Cr accumulation supported by its high Cr absorption ability (55.9%) (Table 2). Plants treated with Cr in this study could not be categorized as hyperaccumulators due to accumulation by plants that only attained up to 167.8 mg kg^{-1}. *C. zizanioides* treated with 50 ppm Cr showed a high Cr accumulation ability supported by its high Cr absorption ability (55.9%) (Table 2). Plants treated with 50 ppm Ni showed a hyperaccumulator ability seen from BAC and TF values > 1. However, plants could only accumulate up to 66.3 mg kg^{-1} of Ni, which was far below the criteria for hyperaccumulator species, so plants could not be categorized as hyperaccumulators.

At the release period, only BCF values from 300 ppm Cr were > 1. Only BAC values from 300 ppm Ni showed to be > 1. In addition, TF values from all Ni-treated plants were > 1 (Tables 4 and 5). When compared to previous findings [2], the recent findings showed a higher BCF, BAC, and TF values in some treatments. Plants treated with 300 ppm Ni showed a potential hyperaccumulator ability as supported by its BAC and TF values > 1. However, accumulation in plant parts had not yet reached the criteria for hyperaccumulator species, which only accumulate up to 28.7 mg kg^{-1}, so plants still could not be categorized as hyperaccumulator species. Nonetheless, *C. zizanioides* indicated a high translocation of Ni when given 50 ppm and 150 ppm treatments at uptake period and 300 ppm at release period, as shown by TF values > 1.

According to Maiti (2003) in Ramachandra et al. [26], the normal concentration of Cr in plants ranges from 0.03 to 14 mg kg^{-1}, while the critical concentration range is 5–30 mg kg^{-1}. The normal concentration of Ni in plants ranges from 0.02 to 5 mg kg^{-1}, while the critical concentration ranges from 10 to 100 mg kg^{-1}. When compared with the recent findings, all treated plants accumulated higher Cr and Ni concentration than their normal concentrations. This indicates that *C. zizanioides* treated with various concentrations of Cr and Ni demonstrated the ability

to tolerate these metals (heavy metal-tolerant species) but did not reach the hyperaccumulator concentration. Research conducted by Patandungan et al. [23] on Cd-contaminated soil reported the ability of *C. zizanioides* to accumulate Cd, which also could not be categorized as a hyperaccumulator plant because it could only accumulate up to 0.298 mg kg^{-1}.

Rice (*Oryza sativa*) comes from the same family as vetiver, so its ability to absorb, accumulate, and translocate heavy metals can be used as a comparison. Based on previous studies, it is reported that most heavy metal accumulation by rice is found in roots, followed by stems, then grains. The accumulation of Cr and Ni due to excessive metal absorption in the soil causes the concentration of these two metals to increase in rice grains. Although the accumulation is not as high as in the roots, the presence of Cr and Ni in rice grains is a potential threat to human health [7, 8, 27, 32].

From the experiment, it could not be concluded whether *C. zizanioides* can be used for phytoextraction or phytostabilization. This may be due to the uneven distribution of heavy metals in the soil, so that absorption by plants has not occurred optimally and only some of the heavy metals available can be absorbed and accumulated by the plant roots. This may also cause the concentration of Cr in the soil at 300 ppm treatment and the concentration of Ni in the soil at 150 ppm and 300 ppm treatments to increase after 28 days of exposure to heavy metal wastewater. This statement is also supported by the research conducted by Patandungan et al. and Ambarwati and Bahri [1, 23] who stated that *C. zizanioides* demonstrate great potential in processing heavy metal wastewater so that further research is needed. Research by Danh et al. [6] also showed that vetiver was able to accumulate heavy metals in higher amounts than other plants. To overcome this problem, research can be carried out in a longer time, so the results obtained can represent the ability of vetiver to both absorb and release heavy metals maximally.

4 Conclusion

Chrysopogon zizanioides was found effective in removing heavy metals (Cr and Ni) depending on the concentration of heavy metals, which affect the uptake rate, release rate, and metal accumulation in plant parts. Plants treated with a high concentration of heavy metals showed a decrease in absorption ability due to metal saturation in plants. Plants treated with Cr showed a high uptake rate when compared to its release rate, while plants treated with Ni showed a low uptake and release rate. A high Cr uptake rate indicates that *C. zizanioides* can be potentially used as a phytoremediation agent supported by its characteristics, i.e., deep and extensive root penetration system, good nutrient absorption ability, and high tolerance for environmental stress conditions. The uptake and release rate of *C. zizanioides* in this study tend to fluctuate because of the varying concentrations given, which affecting the bioavailability of heavy metals in the soil. Low solubility and mobility of Cr and Ni in soil due to low soil acidity also affect metal uptake and release rate. The accumulated metals in plant parts showed a different result for Cr and Ni. Cr was largely accumulated in the roots, while Ni was largely accumulated in the leaves. This indicates that Cr is retained in the roots, while Ni is effectively translocated into aerial plant parts. The evaluated values of BCF, BAC, and TF in this study only showed several treatments to be > 1. None of the treatments during 28-day uptake and 28-day release periods demonstrated the potential to be used for phytoextraction, phytostabilization, or as a hyperaccumulator species. Nevertheless, findings from this study have demonstrated the potential use of *C. zizanioides* as heavy metal-tolerant species due to its ability to accumulate higher Cr and Ni concentrations above their normal concentration range. *C. zizanioides* also presented the potential as an alternative species for phytoremediation at least in lightly polluted areas.

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Compliance with ethical standards

Ethics approval and consent to participate Not applicable.

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