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Phytomining Potential of Jatropha curcas and Sansevieria trifasciata for Chromium (Cr) and Vanadium (V) Uptake from Red Mud Amended with Sludge-Manure Mixture

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Abstract. The rapid growth of the alumina industry has significantly increased red mud production, with each ton of alumina yielding 0.8 to 1.5 tons of this byproduct. Red mud is a highly alkaline residue produced during bauxite refining, containing various metals including chromium (Cr) and vanadium (V), which pose significant environmental risks if not properly treated. Effective management and valorization of red mud are essential to mitigate environmental contamination and exploit its economic potential. Phytomining, a bioremediation strategy utilizing hyperaccumulator plants, offers a promising method for extracting economically valuable metals from red mud. This study investigates the phytomining capacity of *Jatropha curcas* and *Sansevieria trifasciata* to uptake Cr and V from red mud amended with a 5% sludge-manure mixture. The experiment was conducted over a 28-day period, during which both species were cultivated in red mud media with the amendment. The phytomining capacity of the plants was determined by measuring the metal accumulation, analyzed on days 0, 14, and 28 using acid digestion and ICP-OES analysis. Results showed that both plant species preferentially accumulated metals in their root systems rather than in their aerial parts. *Jatropha curcas* absorbed 1.6 mg/kg of Cr and 2.9 mg/kg of V, while *Sansevieria trifasciata* exhibited higher uptake, with 2.5 mg/kg of Cr and 4 mg/kg of V. These findings highlight the phytomining potential of these species in recovering valuable metals from red mud.

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1 Introduction

Mining is an industrial activity that processes raw materials extracted from the earth, such as oil, natural gas, and mineral ore. Bauxite mining holds a prominent position within Indonesia's mining sector. One of the by-products of bauxite ore processing is red mud, a highly alkaline residue. Annually, bauxite processing generates approximately 70 million tons of red mud worldwide, as 1 ton of bauxite processing results in 0.8 to 1.5 tons of red mud [1]. In Indonesia, the alumina extraction plant located in Tayan, West Kalimantan, has a production capacity of 300,000 tons of alumina per year, generating between 240,000 and 450,000 tons of red mud annually [2]. The high iron oxide content in red mud gives it a distinct red color, while its high alkalinity (pH of 11-12) and concentrations of sodium and aluminum make it hazardous to the environment if not managed properly. According to Indonesian Government Regulation No. 18 of 1999 concerning Hazardous and Toxic Waste Management, red mud falls under the category of hazardous and toxic waste due to its high alkalinity, which poses risks to all forms of life [3]. Red mud contains iron oxide, quartz, sodium aluminosilicate, titanium dioxide, calcium carbonate/aluminate, and sodium hydroxide, as well as trace amounts of hazardous heavy metals such as chromium and vanadium [4].

One promising approach to red mud treatment is phytoremediation, a method that uses plants to remove heavy metals from the environment. The phytoremediation mechanism involves plants absorbing, degrading, excreting, and stabilizing pollutants such as heavy metals. Typically, plants used in phytoremediation accumulate heavy metals through their roots [5]. However, phytoremediation also produces waste in the form of used plants that have absorbed heavy metals. To address this challenge, an advanced extension of phytoremediation, called phytomining, has been developed. Phytomining focuses on cultivating, harvesting, and processing hyperaccumulator plants to recover valuable metals, creating potential for economic gain [6]. The phytomining process involves producing bio-ore, which can then be treated through pyrolysis, followed by smelting or acid leaching, and ultimately, metal extraction by solvent extraction. This eco-friendly approach has advantages for extracting single or multiple metals and is more cost-effective than conventional ore mining. Phytomining technology can also contribute to economic development and infrastructure improvement in existing mining regions [6][7].

Numerous studies have demonstrated the capability of certain plants to accumulate heavy metals. *Jatropha curcas*, for example, has been effectively selected for remediating heavy metal-contaminated soils, particularly those contaminated with nickel (Ni), lead (Pb), and cadmium (Cd). Its ability to absorb these metals also makes it suitable for remediating soils contaminated with arsenic (As), chromium (Cr), and zinc (Zn). Studies have shown that *Jatropha curcas* can accumulate lead (Pb) at a concentration of 11.4913 mg/kg from coal waste [8]. Similarly, *Sansevieria trifasciata* has shown a notable ability to accumulate heavy metals; it can accumulate lead (Pb) at concentrations of up to 418 mg/kg in leadcontaminated soils, with the highest Pb concentration found in the roots [9]. Furthermore, research has shown that *Sansevieria trifasciata* is capable of accumulating copper (Cu) from soils contaminated by copper and brass smelting industry waste at a concentration of 12.76 mg/kg [10].

In this study, fresh red mud samples were obtained from West Kalimantan, Indonesia. This study investigated phytomining potential of *Jatropha curcas* and *Sansevieria trifasciata* in absorbing chromium (Cr) and vanadium (V) from red mud. The plants were grown in a red mud substrate amended with manure-sludge mixtures. The addition of manure was intended to improve the physical, chemical, and biological properties of the soil, thus enhancing soil fertility and replacing essential nutrients. The addition of sludge aimed to enrich plant nutrients and utilize readily available domestic sludge [11][12].

2 Materials and Method

2.1 Sample collection and preparation

The red mud sample was collected from West Kalimantan, Indonesia. Fresh red mud was chosen due to its higher heavy metal content, which is advantageous for maximizing the yield of heavy metals obtained through the phytomining process. The red mud was dried under direct sunlight for approximately 12 hours and subsequently sieved using a 10-mesh sieve prior to mixing. This sieving process ensured that the particles were of uniform size, promoting a homogeneous mixture and consistent distribution of red mud with the amendments to be added.

2.2 Phytomining experiment

In this study, toxicity tests were conducted to evaluate the feasibility of using *Jatropha curcas* and *Sansevieria trifasciata* for phytomining in a medium comprising 95% red mud and 5% manure-sludge. The primary parameters evaluated included the concentrations of vanadium (V) and chromium (Cr), with additional parameters such as pH and electrical conductivity (EC). Moisture content, density, light intensity, temperature, and soil texture also monitored to provide a comprehensive environmental assessment. The phytomining process spanned 28 days, during which metal content analyses were conducted on days 0, 14, and 28 to observe metal accumulation in plant tissues over time.

2.3 Metal extraction

Vanadium and chromium levels were determined through the acid digestion method and analyzed using Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES), following the Indonesian National Standard (SNI) 8910:2021 for environmental testing. This analysis aimed to assess residual metal levels in the soil as well as metal uptake in plant organs (roots, leaves, and stems).

To further understand plant performance and efficiency in metal uptake, the study calculated the metal tolerance index (MTI), translocation factor (TF), and bioaccumulation factor (BF), following methodologies proposed by previous studies [19][20]. These indices enabled a quantitative assessment of metal accumulation patterns and offered valuable insights into the potential of *Jatropha curcas* and *Sansevieria trifasciata* for phytomining applications in red mud.

3 Result and discussion

3.1 Plant propagation

Propagation aims to multiply the plants that are used in this research, it is allowed to prepare the number of plants that will be used on phytomining test. Through this process many aspects are being observed, such as measurements of stem height and root length. Plant generative phase is also observed in this phase, such as growth of flower as a reproduction organ [21]. Plant propagation is carried out at least one month before the plant reaches optimum size for further care [22]. During this process, plants of the same age and similar height will be selected for running phytomining test.

Jathropa curcas was measured on the first day of propagation, it shows 10 cm based on stem length of cuttings. This process occurs for 50 days, during this time *J. curcas* not showing neither new shoots nor flowers during observation. This result matches with previous research which states *J. curcas* having a vegetating phase at least for 6 months [23]. Based on Figure 1 it shows the growth curve of *J. curcas* after 50 days of observation. It shows that *J. curcas* is still on vegetative phase with an average growth rate of 4-4 cm per week.

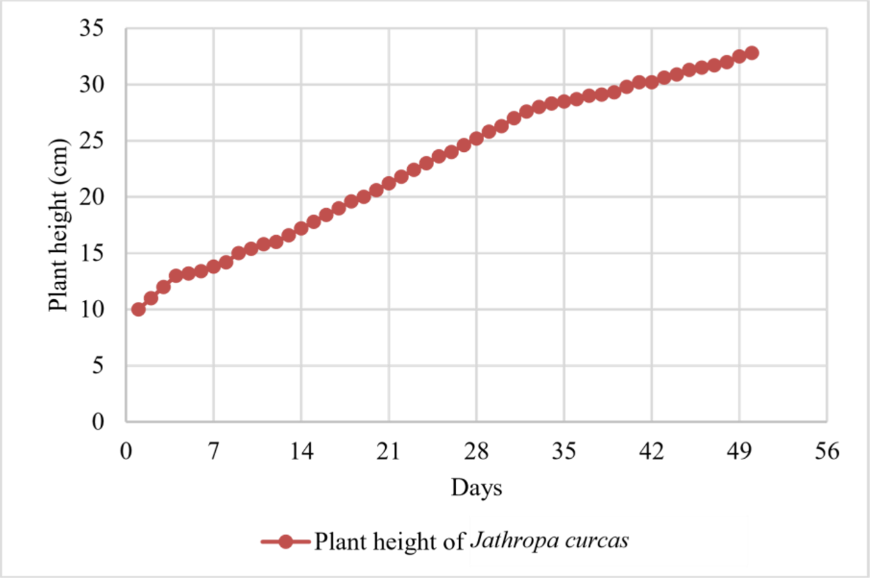


Figure 1. Growth rate of *Jatropha curcas*

Sansevieria trifasciata cuttings used on propagation being measured and shown 45 cm on stem length. Same with the other plant, S. trifasciata propagation is carried out for 50 days. Through observation, neither new shoots nor flowers were shown during the process. It seems this plant has a slow growth rate when compared to *J. curcas*. There's only 1 mm addition on stem length that've been observed on the 30th day. This result is relevant to previous research states if *S. trifasciata* shoots growth rate only growth by only 1-2 mm. Figure 2 shows *S. trifasciata* growth rate during propagation phase.

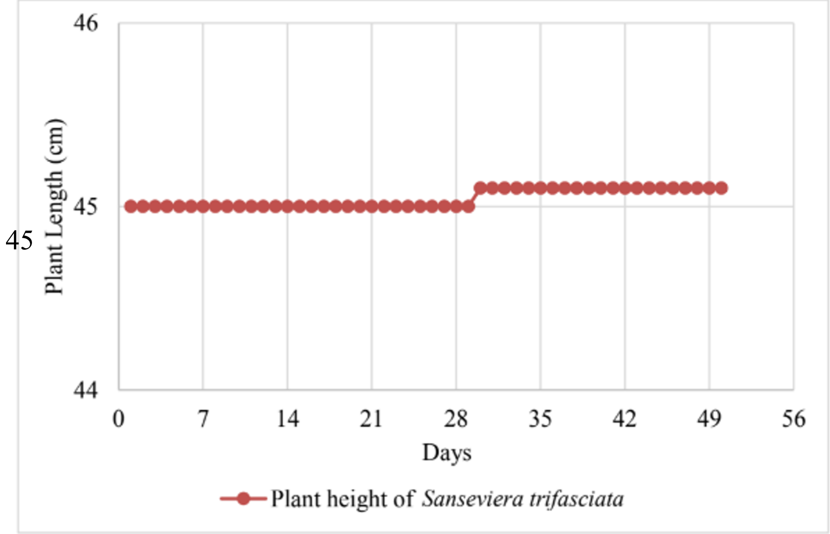


Figure 2. Growth rate of *Sansevieria trifasticiata*

3.2 Toxicity testing

J. curcas and *S. trifasciata* are tested on several mixture media to determine minimum concentration of stimulants required for survival on red mud media. This testing is on laboratory scale, and is expected to be applied to red mud land covering hectares. Thus, this test aims to determine the minimum concentration of stimulants to improve critical conditions on red mud land without reducing the suitability of application in the field. Both *J. curcas* and *S. trifasciata* are tested on the same media mixture, which uses 0%, 5% and 10% concentration of manure and sludge stimulant mixture. Both plants showed death in media with 0 % stimulant, while in media with 5 % and 10 % stimulant the plants remained alive until the 17th day. The results of this toxicity test can be seen in Table 1.

Table 1. *Jatropha curcas* and *Sansevieria trifasciata* toxicity test Stimulant = manure + sludge.

Plant	Media Mixture	Observation Results
Jatropha curcas	Red mud 100%	The plant dies on the 4th day, marked by wilting leavles and drying stems.
	Red mud 95% + stimulant 5%	The plant still is alive on the 17th day, indicated by the leavles still being fresh and green
	Red mud 90% + stimulant 10%	The plant still is alive on the 17th day, indicated by the leavles still being fresh and green
Sansevieria trifasciata	Red mud 100%	The plant dies on the 4th day, marked by wilting leavles and drying stems.
	Red mud 95% + stimulant 5%	The plant still is alive on the 17th day, indicated by the leavles still being fresh and green
	Red mud 90% + stimulant 10%	The plant still is alive on the 17th day, indicated by the leavles still being fresh and green

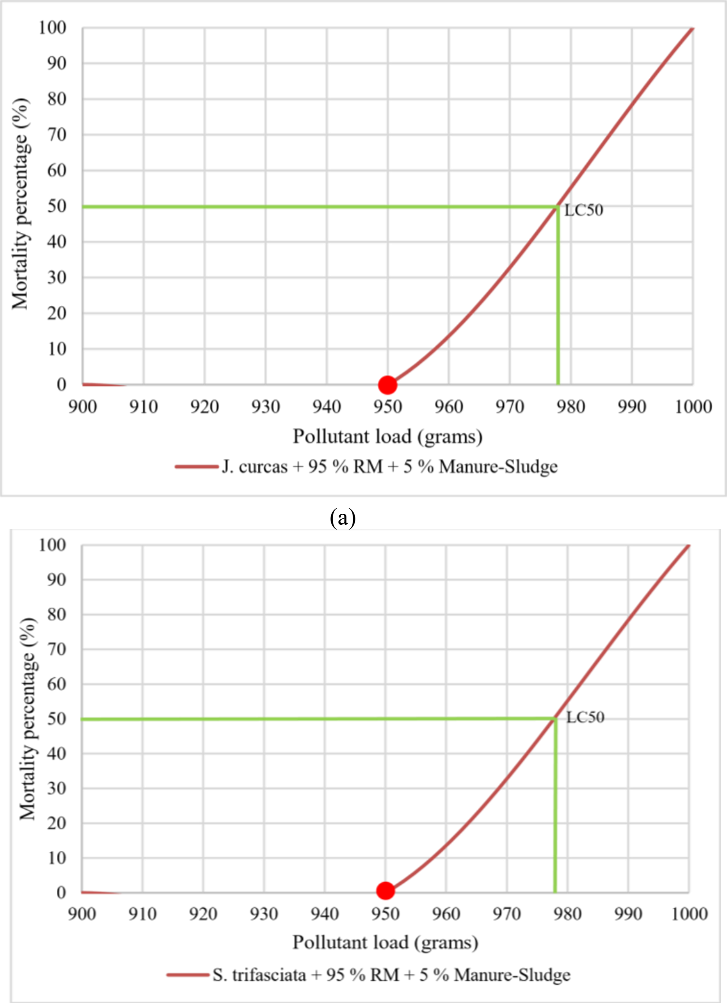
The determination of the Lowest Observed Effect Concentration (LOEC), No Observed Effect Concentration (NOEC), LC50 (the concentration at which 50 % of the test population dies or shows lethal effects), and Maximum Acceptable Toxicant Concentration (MATC) was conducted. Based on the results obtained, the LOEC value indicating a toxic effect on both plants was 1000 grams of red mud, while the NOEC value, which showed no toxic effect on either plant , was 950 grams of red mud. The accepted MATC of red mud for both plants were 974.68 grams, and the LC50 value causing 50 % mortality in the test samples was 975 grams of red mud. The results of these determinations are presented in Table 2.

Table 2. Toxicity test result .

Plant	Stimulant (%)	Red mud (%)	d (Test pollutant load grams)	n (Number of test leaves)	r (Test leaf mortality)	P1 (% survival)	P2 (% live mortality)	LOEC	NOEC	LC50	MATC
J.curcas	0%	100 %	1000	6	6	0,0	100,0	1000	950	975	974,68
	5%	95%	950	3	0	100,0	0,0				

	10%	90%	900	3	0	100,0	0,0				
S. Trifasciata	0%	100 %	1000	4	4	0,0	100,0	1000	950	975	974,70
	5%	95%	950	6	0	100,0	0,0				
	10%	90%	900	4	0	100,0	0,0				

The results presented in Table 2 and Table 3 are depicted in an S-shaped toxicity curve. The x-axis of this curve represents the pollution load (in grams), while the y-axis represents the mortality rate of the tested plants. The green line in this graph represents the LC50 value at 975 grams, and the red point indicates the pollutant load at 950 grams of red mud. This curve is used to determine the red mud concentration for phytomining testing. Based on the graphs in Figure 3, a planting medium composition of 950 grams of red mud with the addition of 5 % manure - sludge and 5 % was selected .



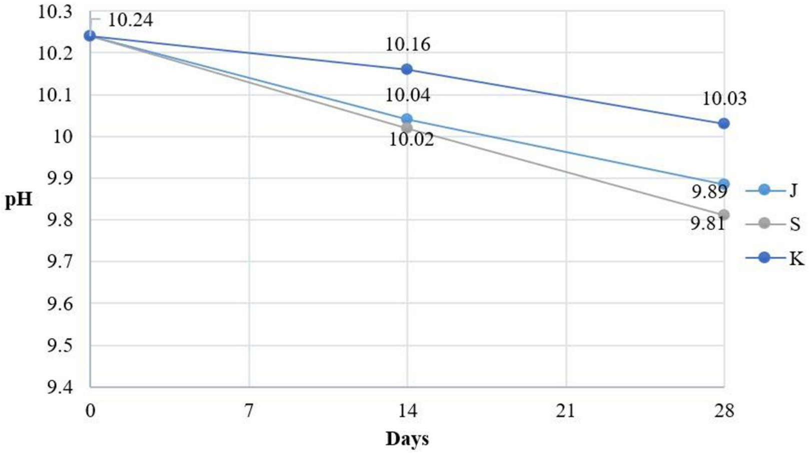
(a)

(b)

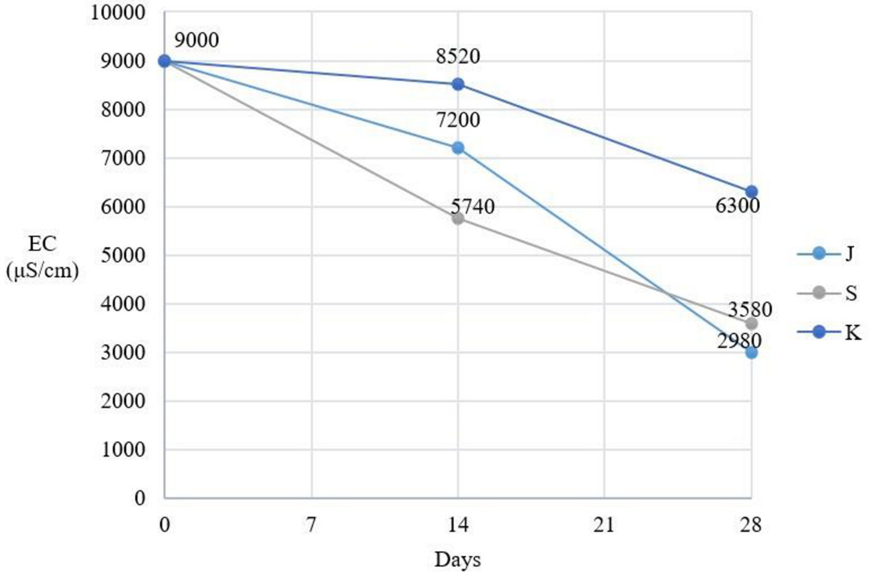
Figure 3. Toxicity s-curve of (a) *J. curcas* and (b) *S. trifasciata*

3.3 pH and EC effect on phytomining

The parameters observed in this phytomining test included the chromium (Cr) and vanadium (V) metal content in plants, pH, and electrical conductivity (EC). pH is closely related to the bioavailability of Cr and V metals. Cr tends to be bioavailable in acidic conditions at pH below 5.6 [26]. The release of acids, such as citric, tartaric, and oxalic acid, can lead to metal binding due to chelate formation, which aids in the bioavailability of heavy metals in plants [27] . Unlike Cr , V is more bioavailable in alkaline conditions [28] The two types of plants used in this study have different optimal pH ranges for heavy metal absorption. *J. curcas* optimally absorbs heavy metals at a pH of 5-6.5, while *S. trifasciata* is more optimal in the pH range of 5.5-8.5 [29, 30]. Based on observations, there was a decrease in pH in the planting mediu. This decrease was caused by CO_2 gas activity in the soil, where CO_2 reacts with water to form carbonic acid [31]. This carbonic acid is responsible for the pH reduction in the planting medium. In the control reactor, there is a decrease in pH due to the activity of local microorganisms in the stimulant and planting medium that produce CO_2, as their primary product of metabolism. Figure 4 below shows the pH values in the test reactors.



(a)



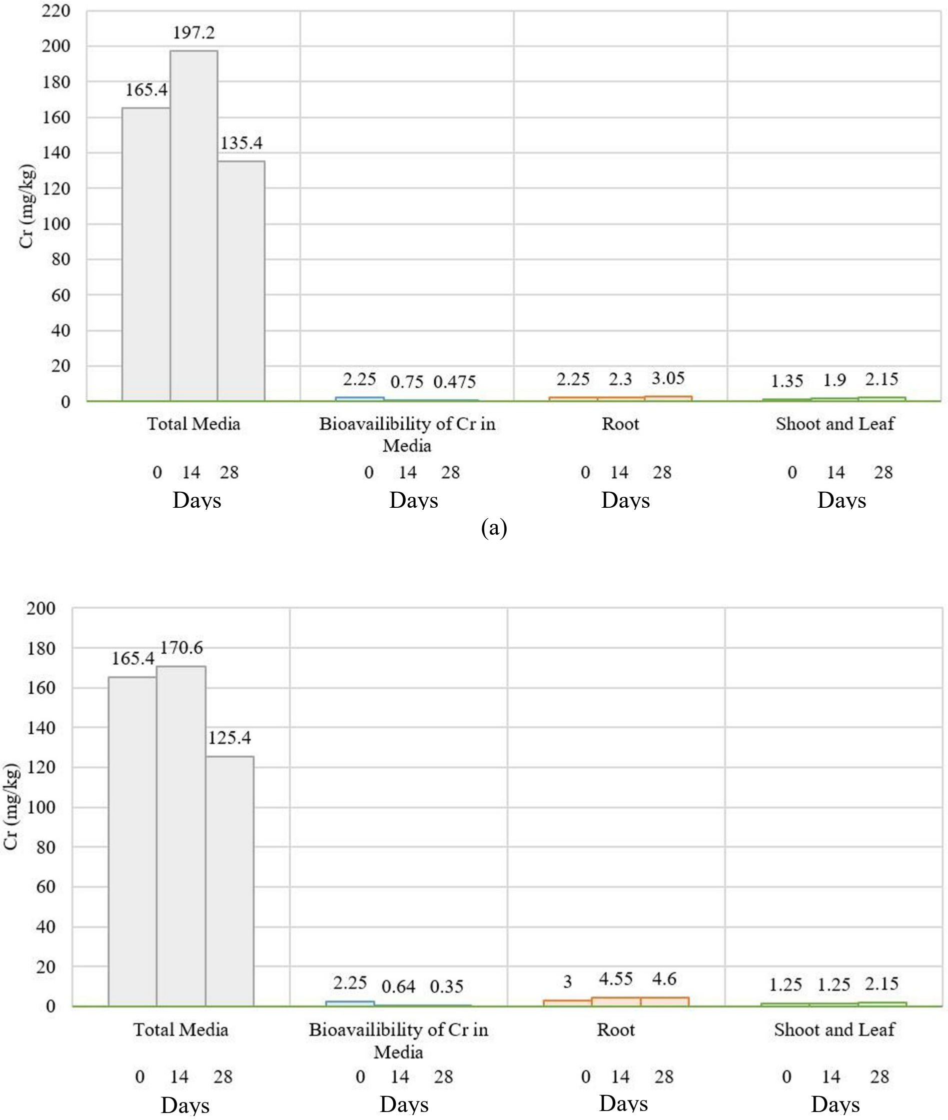
(b)

Figure 4. (a) pH and (b) EC value on phytomining reactorsı . J : *Jatropha curcas* + 95 % red mud + 5 % manure – sludge; S : *Sanseıviera trifasciata* + 95 % red mud + 5 % manure sludge; K: 95 % red mud + 5 % manure – sludge.

The EC value was one of the indicators observed in this test, where a decrease in EC value indicates optimal nutrient absorption by plants [32]. This EC value is highly dependent on the quantity of ions or mineral salts present in the soil [33]. The decrease in EC value is influenced not only by nutrient absorption by the plants but also by the addition of stimulants to the planting medium The addition of stimulants such as manure and sludge increases soil porosity, facilitating water flow within the medium. This water flow results in a reduction of EC due to the leaching of ions in the soil, as these ions are carried away with the water , reducing their concentration in the soil [34]. Therefore, the EC reduction is a positive indicator in this test. The decrease in EC value in the control reactor was caused by the watering process, which was also conducted on the control reactor , leading to ion leaching in the planting medium. Figure 4b shows the EC measurements in the experimental reactors.

3.4 Metal content of V and Cr in plant tissue

Heavy metals present in soil are transferred to plants through transformation processes that are closely related to bioavailability, which determines the case with which heavy metals can be absorbed by living organisms. When the bioavailability of a metal is high, heavy metals are more readily absorbed by plants [35]. According to the results obtained , the bioavailable Cr content in red mud was 2.25 mg/kg, which increased to 165 mg/kg after the addition of a 5 % manure - sludge stimulant. In *J. curcas*, the initial Cr content was 2.25 mg/kg in the roots and 1.35 mg/kg in the aboveground parts of the plant. *S. trifasciata* had an initial Cr content of 3 mg/kg in the roots and 1.25 mg/kg in the aboveground parts. Plants grown in normal soil generally contain 1-5 mg/kg of Cr in their dry weight [36]. The Cr content in soil and plants throughout the testing process is shown in Figure 5. There was a decrease in bioavailable Cr on days 14 and 28, indicating Cr uptake by plants in the reactor. By day 28, the reduction reached 0.475 mg/kg for *J. curcas* and 0.35 mg/kg for *S. trifasciata*. The Cr concentration in both the roots and aboveground parts of the plants increased; in *J. curcas*, the Cr concentration in the roots reached 3.05 mg / kg and in the aboveground parts reached 2.15 mg/kg by day 28. Meanwhile, in *S. trifasciata*, the Cr concentration reached 4.6 mg/kg in the roots and 2.15 mg/kg in the aboveground parts .

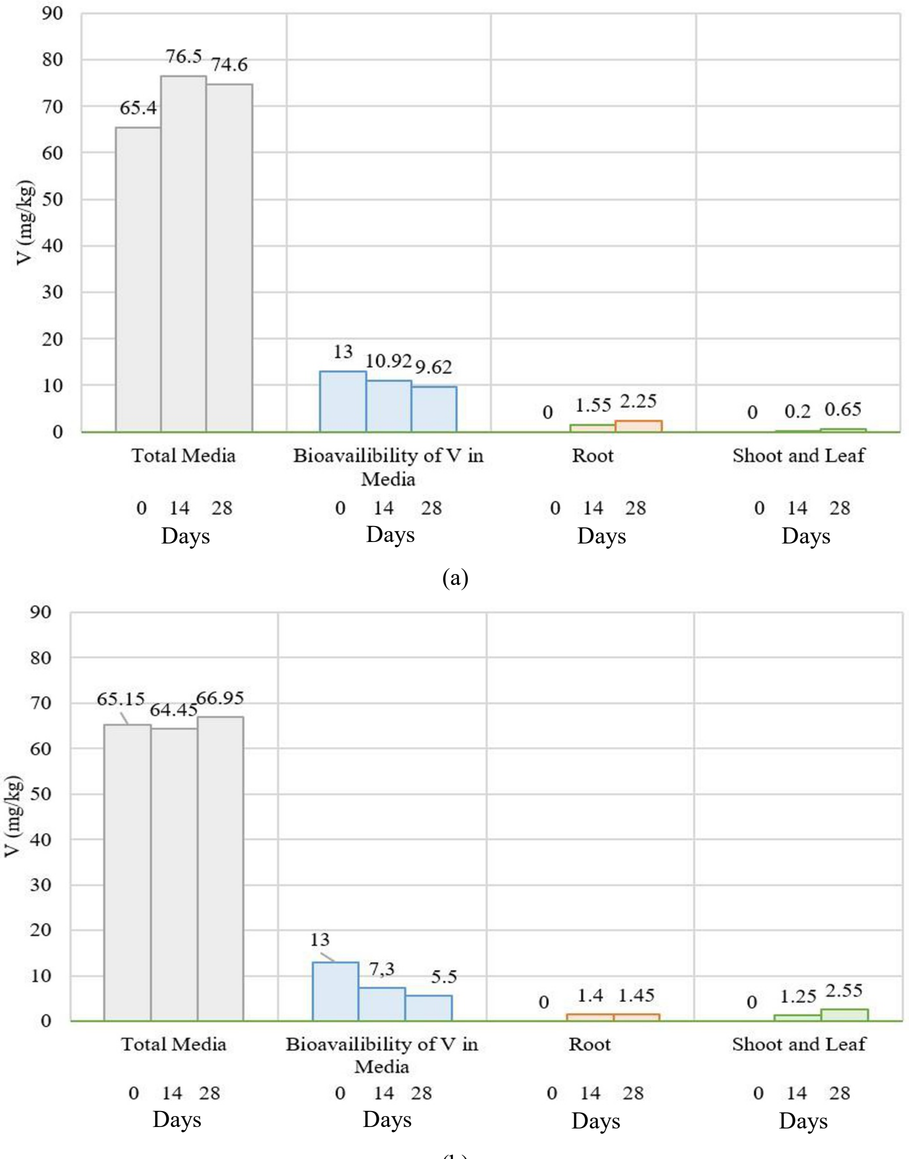


(a)

(b)

Figure 5. Cr concentration on (a) *J. curcas* and (b) *S. trifasciata*.

The initial bioavailability of V in the 5 % manure-sludge medium was 13 mg/kg, whereas V content was not detected in either plant at the initial conditio. In *J. curcas*, the accumulated V content in the roots was observed. The V content during the phytomining process is presented in Figure 6. Based on Figure 6, on days 14 and 28, there was a decrease in the bioavailability of V, indicating V uptake by the plants in the reactor. By day 28 , this reduction reached 9.62 mg/kg for *J. curcas* and 5.5 mg/kg for *S. trifasciata*. The Cr concentration in both the roots and aboveground parts of the plants also increased; in *J. curcas*, the Cr concentration in the roots reached 2.25 mg/kg, and in the aboveground parts, it reached 0.65 mg/kg by day 28. In *S. trifasciata*, the Cr concentration reached 1.45 mg/kg in the roots and 2.55 mg/kg in the aboveground parts. V generally tends to concentrate in the root area , where it is estimated to accumulate 2 to 1,000 times higher in the roots than in other parts of the plant [38]. This is demonstrated in *J. curcas*, where the concentration in the roots is higher than in the aboveground parts. However, this pattem does not hold in *S. trifasciata*, where V is more heavily accumulated in the aboveground parts compared to the roots.

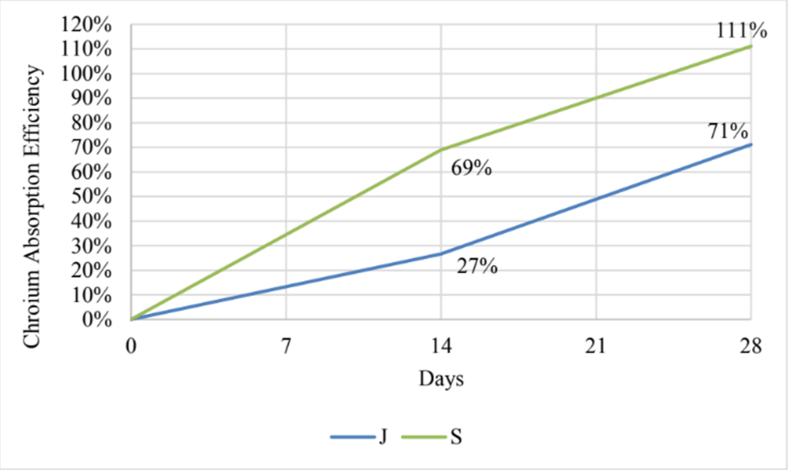


(a)

(b)

Figure 6. V concentration on (a) *J. curcas* and (b) *S. trifasciata*.

It can be observed in all reactors that the bioavailable metal content in the medium decreased. Heavy metals naturally transfer from areas of high concentration (the medium) to areas of low concentration (the plant) through diffusion and osmosis. This process occurs most rapidly at the beginning of phytomining due to the large concentration difference between soil and plant. From day 14 to day 28, the rate of decrease slowed. This reduction is attributed to the saturation of the plant's absorption capacity and factors related to medium conditions, including pH, moisture content, and microbial activity in the soil [38]. In this phytoprocess, there are several stages that reduce heavy metal levels in the soil. The first stage is phytoextraction, where heavy metals are absorbed from the medium and distributed throughout the plant. The second stage is phytodegradation, which involves the breakdown of heavy metals through soil metabolic systems into less harmful compounds. The final stage is phytovolatilization, a process by which heavy metals are converted into gaseous forms and released into the air through plant leaves [39].



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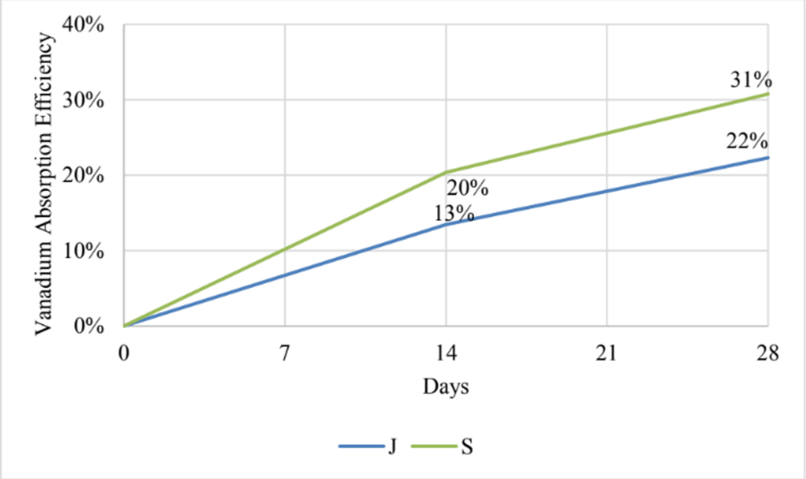

(b)

Figure 7. (a) Cr and (b) V Absorption efficiency in *J. curcas* and *S. trifasciata* J : *Jatrolpha curcas* + 95 % red mud + 5 % manure – sludge; S: *Sanselvielra trifasciata* + 95 % red mud + 5 % manure – sludge.

The uptake of bioavailable Cr and V metals was effective in soil medium supplemented with a 5 % manure -sludge stimulant. Manure itself supplies nutrients and enriches the soil, aiding the phytoremediation process in contaminated soils [40]. As shown in Figure 7, the uptake efficiency of Cr and V in *S. trifasciata* was higher than in *J. curcas*. This is due *to S. trifasciata* producing secondary metabolites, such as pregnane glycosides, which enhance pollutant uptake [41]. The absorbed heavy metals accumulate in the roots, where they are detoxified with the aid of microbes. Pregnane glycosides support microbial activity in neutralizing toxins and transforming them into amino acids, sugars, and organic acids that are beneficial for plant growth. The uptake efficiency values exceeding 100 % in Figure 7b are attributed to an increase in metal bioavailability by day 28, driven by exudates. These exudates, which are organic acids, serve as an energy source for microorganisms in the Juzosphere surrounding the roots [42].

Another factor that makes *S. trifasciata* superior in metal uptake is its classification as a CAM (Crassulacean Acid Metabolism) plant [43]. This type of plant is capable of maintaining efficient photosynthetic processes even under highly stressful environmental conditions [44], ensuring a reliable energy source for the metal uptake process . In contrast *J. curcas* is a C3 plant, whose photosynthetic efficiency is highly influenced by environmental conditions [45], making it less effective than CAM plants in metal uptake from red mud.

3.5 Bioaccumulation factor (BCF) and translocation factor (TF)

Bioconcentration factor (BCF) and translocation factor (TF) are parameters used to assess the ability of plants in the metal translocation process. TF is the ratio of metal concentration in the shoots to the metal concentration in the roots. BCF is the ratio of metal concentration in the roots to the metal concentration in the soil. The TF and BCF values for Cr and V metals are presented in Table 3.

Table 3. TF and BCF values of Cr and V metal in plants

Parameter	**Metal**	**Reactor**	**Day of Observation**	
			14	28
TF	Cr	*J.curcas* + Red mud + 5% Manure – Slugde	0,83	0,70
		S. tridasciata + Red mud + 5% Manure – Sludge	0,27	0,47
	V	*J.curcas* + Red mud + 5% Manure – Slugde	0,13	0,29
		S. tridasciata + Red mud + 5% Manure – Sludge	0,89	1,76
BCF	Cr	*J.curcas* + Red mud + 5% Manure – Slugde	1,02	1,36
		S. tridasciata + Red mud + 5% Manure – Sludge	2,02	2,04
	V	*J.curcas* + Red mud + 5% Manure – Slugde	0,12	0,17
		S. tridasciata + Red mud + 5% Manure – Sludge	0,11	0,11

Plants suitable for the phytostabilization process generally have a TF value of less than 1 and a BCF value greater than 1. Conversely, plants suitable for the phytoextraction process exhibit a TF value greater than 1 and a BCF value less than 1. A high BCF value indicates a plant's ability to adsorb metals from the soil, while a low TF value indicates limited ability to translocate metals to the aboveground parts [46] . As shown in Table 3, *J. curcas* and *S. trifasciata* demonstrate phytostabilization capacity for accumulating Cr, consistent with previous findings. In phytostabilization, the roots limit pollutant mobility and reduce its bioavailability, thus decreasing toxicity. Some plants capable of phytostabilization can form complex compounds with pollutants, transforming them into less toxic and more stable forms once accumulated within plant tissues [47]. On the other hand, for V metals, both plants tend to be more suitable for phytoextraction. Ideal plants for phytoextraction can store metals in their cellular structures, with metals predominantly accumulating in the leaf vacuoles [47].

4 Conclusion

Based on the study findings, the use of *Jatropha curcas* and *Sansevieria trifasciata* planted in a 95% red mud and 5% manure-sludge mixture demonstrated differences in metal accumulation for chromium (Cr) and vanadium (V). *Sansevieria trifasciata* was more effective in absorbing both metals, accumulating up to 84% of Cr (1.85 mg/kg) and 37% of V (3.25 mg/kg) over 28 days, while *Jatropha curcas* absorbed 77% of Cr (1.6 mg/kg) and 23% of V (2.9 mg/kg) under the same conditions. Analysis of the translocation factor (TF) and bioaccumulation factor (BCF) revealed that both plants showed a higher tendency for metal accumulation in the roots than in the upper parts of the plants, indicating their capability as hyperaccumulators suitable for phytomining applications. Specifically, the TF values for Cr in *Jatropha curcas* reached 0.7 by day 28, while in *Sansevieria trifasciata*, TF for Cr was lower at 0.33, suggesting effective retention of metals in the roots.

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References

[1] Liu, Y., Lin, C., & Wu, Y. (2007). Characterization of red mud derived from a combined Bayer Process and bauxite calcination method. Journal of Hazardous materials, 146(1-2), 255 261.

[2] Anugrah, R. I., & Mamby, H. E. (2020). Pelindian Alumina dan Besi Oksida Bijih Bauksit Kalimantan Barat dengan Metode Pelindian Asam Klorida. Jurnal Teknologi Mineral dan Batubara, 16(1), 1-13.

[3] Wang, M., & Liu, X. (2021). Applications of red mud as an environmental remediation material: A review. Journal of Hazardous Materials, 408, 124420.

[4] Rossalina, W., Zaharah, T. A.,& Silalahi, I. H. (2021). Komposisi Unsur dan Karakterisasi Mineral Magnetik dalam Red Mud, Residu Bauksit di PT. Indonesia Chemical Alumina (ICA) Kalimantan Barat (Elemental Composition and Mineral Characteristics of Magnetic Red Mud, Bauxite Residue at PT. Indonesia Chemical Alumina (ICA), (West Kalimantan). Indonesian Journal of Pure and Applied Chemistry, 4(3), 139-144.

[5] Imron, I., Dermiyati, D., Sriyani, N., Yuwono, S. B., dan Suroso, E. (2019). Perbaikan Kualitas Air Limbah Domestik Dengan Fitoremediasi Menggunakan Kombinasi Beberapa Gulma Air: Studi Kasus Kolam Retensi Talang Aman Kota Palembang. Jurnal Ilmu Lingkungan, 17(1).

[6] Handayanto, E., Nuraini, Y., Muddarisna, N., Syam, N., & Fiqri, A. (2017). Fitoremediasi dan phytomining logam berat pencemar tanah. Universitas Brawijaya Press.

[7] Kumari, P., Kumar, P., & Kumar, T. (2019). An overview of phytomining: A metal extraction process from plant species. J. Emerg. Technol. Innov. Res.(JETIR), 6, 1367-1376.

[8] Febrianti, N., Ilham, M., Hazzah, N. A., Andriana, A., Erwing, E., Irfandi, R., ... & Ruslang, R. (2023). Fitoremediasi Tanaman Jarak Pagar (*Jatropha curcas*) pada Tanah Tercemar Logam Berat Timbal (Pb) dari Limbah Batubara. BIOEDUSAINS: Jurnal Pendidikan Biologi dan Sains, 6(1), 300-305.

[9] Ratnawati, R., & Fatmasari, R. D. (2018). Fitoremediasi tanah tercemar logam timbal (Pb) menggunakan tanaman lidah mertua (*Sansevieria trifasciata*) dan jengger ayam (Celosia plumosa). Al-Ard, 3(2), 62-69.

[10] Christopher, I. (2015). Uji Efektivitas Fitoremediasi Logam Berat Tembaga (Cu) dengan Penggunaan Tumbuhan Lidah Mertua (*Sanseviera trifasciata*) pada Tanah Tercemar Limbah Industri Tembaga dan Kuningan.

[11] Dahono. 2012. Pembuatan Kompos dan Pupuk Cair Organik dari Kotoran dan Urin Sapi. Loka Pengkaji Teknologi Pertanian (LPTP) Kepulauan Riau.

[12] Ummah, Marita F. 2018. Pengeringan Lumpur IPAL Biologis pada Unit Sludge Drying Bed (SDB). Jurnal Purifikasi 18(1) : 39-48

[13] Aden, D.R., Endang, S., Octaviana, K.G.C., Okto, F., Siti, H., Tasqia, T., Tiwi, P. (2016) ,Analisis Kandungan Logam dalam Sampel Air Mineral (ADES) Menggunakan ICP OES, Semarang: Universitas Negeri Semarang.

[14] Manggara, A. B., & Shofi, M. (2018). Analisis kandungan mineral daun kelor (Moringa oleifera Lamk.) menggunakan spektrometer XRF (X-Ray Fluorescence). Akta Kimia Indonesia, 3(1), 104-111.

[15] Jamaluddin, K. (2010). X-RD (X-Ray Diffractions). Program Studi Pendidikan Fisika Fakultas Keguruan dan Ilmu Pendidikan. Universitas Haluoleo. Kendari.

[16] Julinawati, J., Marlina, M., Nasution, R., & Sheilatina, S. (2015). Applying Sem-edx Techniques to Identifying the Types of Mineral of Jades (Giok) Takengon, Aceh. Jurnal Natural Unsyiah, 15(2), 116128.

[17] Kurniawan, R., Hendriarianti, E., & Wulandari, C. D. R. (2022). Fitoremediasi dalam Menurunkan kadar BOD, COD, Amoniak, dan Fosfat di Outlet IPAL MCK Terpadu Tlogomas Kota Malang dengan Menggunakan Tanaman Penahan Erosi. Jurnal Mahasiswa" ENVIRO", 1(1).

[18] Rossiana, N., & Malini, D. M. (2020). Toksisitas Oil Sludge Hasil Fitoremediasi Long Term Pada Hitologis Hati Mencit (Mus Musculus). Quagga: Jurnal Pendidikan dan Biologi, 12(2), 130-136.

[19] Gautam, M. & Agrawal, M., 2019. Identification of Metal Tolerant Plant Species for Sustainable Phytomanagement of Abandoned Red Mud Dumps. Applied Geochemistry, **104**(1), pp. 83-92.

[20] Vijayaraghavana, K., Arockiarajb, J. & Kamala-Kannan, S., 2017. *Portulaca grandiflora* as Green Roof Vegetation: Plant Growth and Phytomining Experiments. International Journal of Phytomining, **19**(6), pp. 537-544.

[21] Erken, K. 2023. Generative production and evaluation of ornamental plant potential of an endemic flax species for ecological landscape applications. *Ecological Research*, **38**(3), 420-433.

[22] Longchar, T. B., & Deb, C. R. 2022. Optimization of in vitro propagation protocol of Dendrobium heterocarpum Wall. ex. Lindl. and clonal genetic fidelity assessment of the regenerates: An orchid of horticultural and medicinal importance. *South African Journal of Botany*, **149**, pp. 67-78.

[23] Huang, P., Yang, J., Ke, J., Cai, L., Hu, Y., Ni, J., ... & Tang, M. 2024. Inhibition of flowering by gibberellins in the woody plant *Jatropha curcas* is restored by

overexpression of JcFT. *Plant Science*, **344**, 112100.

[24] Dewatisari, S. W. F. 2015. Pertumbuhan enam kultivar *Sansevieria trifasciata* dengan stek pangkal daun. *Jurnal Matematika Sains dan Teknologi*, **16**(1), 36-43.

[25] Li, Y., Mi, X., Zhao, S., Zhu, J., Guo, R., Xia, X., ... & Wei, C. 2020. Comprehensive profiling of alternative splicing landscape during cold acclimation in tea plant. *Bmc Genomics*, **21**, 1-16.

[26] Hidayati, N. 2005. Fitoremediasi dan potensi tumbuhan hiperakumulator. *Hayati Journal of Biosciences*, **12**(1), 35-40

[27] Javed, M. T., Tanwir, K., Abbas, S., Saleem, M. H., Iqbal, R., & Chaudhary, H. J. 2021. Chromium retention potential of two contrasting Solanum lycopersicum Mill. cultivars as deciphered by altered pH dynamics, growth, and organic acid exudation under Cr stress. *Environmental Science and Pollution Research*, **28**, 27542-27554.

[28] Moore, E. K., Hao, J., Spielman, S. J., & Yee, N. 2020. The evolving redox chemistry and bioavailability of vanadium in deep time. *Geobiology*, **18**(2), 127-138.

[29] Nurcholis, & Sumarsih. (2007). Jarak pagar dan pembuatan biodiesel. *Kanisius*. Yogyakarta.

[30] Putri, A. D. (2021). Fitoremediasi tanah tercemar logam timbal dan kadmium dengan tumbuhan lidah mertua pada media tanah berkompos (Doctoral dissertation, Universitas Hasanuddin).

[31] Fang, Q., Zhao, Y., Wei, J., Wang, Z., & Yao, J. (2023). Investigation of the Working Mechanism of CO2–H2O Flow Corrosion of Mild Carbon Steel. *Industrial & Engineering Chemistry Research*, **63**(1), 636-647.

[32] Corwin, D. L., & Yemoto, K. 2020. Salinity: Electrical conductivity and total dissolved solids. *Soil science society of America journal*, **84**(5), 1442-1461.

[33] Munawaroh, I., Prasetyo, H. D., & Latuconsina, H. 2023. Potency of indian shot (*Canna indica*) as phytoremediator physical parameters of water quality in supit urang fecal waste treatment plant malang city. *Agrikan Jurnal Agribisnis Perikanan*, **16**(2), 1-8.

[34] Afasedanya, M. M. T., & Cresli, E. (2023). Kualitas AirTanah Untuk Kebutuhan Konsumsi Warga Sekitar Kampus 1 dan Kampus 2 Politeknik Amamapare Timika-Papua Tengah. *Jurnal Teknik AMATA*, **4**(1), 69-73.

[35] Liu, H. L., Zhou, J., Li, M., Hu, Y. M., Liu, X., & Zhou, J. 2019. Study of the bioavailability of heavy metals from atmospheric deposition on the soil-pakchoi (Brassica chinensis L.) system. *Journal of hazardous materials*, **362**, 9-16.

[36] Sudaryono, S. 2008. Pengaruh pemupukan pada tanaman jarak pagar (jathropa curcas l.) terhadap daya serap logam berat kromium. *Jurnal Teknologi Lingkungan BPPT*, **9**(2), 146465

[37] Yang, J., Wang, Y., Gao, X., Zuo, R., Song, L., Jin, C., ... & Teng, Y. 2022. Vanadium: A review of different extraction methods to evaluate bioavailability and speciation. *Minerals*, **12**(5), 642.

[38] Setiawan, A., Rahmadania, A. N., & Mayangsari, N. E. 2021. Adsorpsi Cu (II) menggunakan zeolit sintesis kombinasi abu terbang dan abu dasar dengan variasi waktu aging. *Jurnal Riset Teknologi Industri*, **15**(1). 113-124.

[39] Mangkoedihardjo, S. 2010. *Fitoteknologi terapan*.

[40] Tanmenu, C. F., Sawitri, B., & Wahyudie, T. 2024. Kajian Pembuatan Pupuk Kompos dari Kotoran Sapi dengan Bioaktivator Mikroorganisme Lokal (MOL) Bonggol Pisang di Desa Lemahbang Kecamatan Sukorejo. *Biofarm: Jurnal Ilmiah Pertanian*, **20**(1), 104-116.

[41] Kaur, J., Dhar, S. K., Chauhan, A., Yadav, S., Mudgal, G., Lyudmila, A., ... & Abdi,

G. (2023). GC-MS validated phytochemical up-leveling with in vitro-raised *Sansevieria trifasciata* [Prain]: The Mother in Law's tongue gets more antibacterial. *Current Plant Biology*, **35**, 100308.

[42] Meng, H., Yan, Z., & Li, X. (2022). Effects of exogenous organic acids and flooding on root exudates, rhizosphere bacterial community structure, and iron plaque formation in Kandelia obovata seedlings. *Science of The Total Environment*, **830**, 154695.

[43] Permana, B. H., Krobthong, S., Yingchutrakul, Y., Saithong, T., Thiravetyan, P., & Treesubsuntorn, C. (2023). Evidence of brassinosteroid signalling and alternate carbon metabolism pathway in the particulate matter and volatile organic compound stress response of Sansevieria trifasciata. *Environmental and Experimental Botany*, **205**, 105116.

[44] Kumar, V., Sharma, A., Soni, J. K., & Pawar, N. (2017). Physiologival response of C3, C4 and CAM plants in changeable climate. *The Pharma Innovation*, **6** (9), 70.

[45] Yong, J. W. H., Ng, Y. F., Tan, S. N., & Chew , A. Y. L. (2010). Effect of fertilizer application on photosynthesis and oil yield of Jatropha curcas L. *Photosynthetica*, **48**, 208-218.

[46] Usman, K., Al-Ghouti, M. A., & Abu-Dieyeh, M. H. 2019. The assessment of cadmium, chromium, copper, and nickel tolerance and bioaccumulation by shrub plant Tetraena qataranse. *Scientific reports*, **9**(1), 5658.

[47] Putri, R. W. P., Hariani, P. L., & Arifin, Z. (2023). Biokonsentrasi faktor (BCF) dan faktor translokasi (TF) purun tikus (*Eleocharis dulcis*) dalam fitoremediasi air asam tambang. *Jurnal Pengendalian Pencemaran Lingkungan (JPPL),* **5**(1), 76-82.