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Research Article

Study of controlling the content of Pb, Cu, Cd, and Cr in soils using hyperaccumulator plants

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Abstract

This study aimed to determine the types of hyperaccumulator plants that can absorb the heavy metal content of Pb, Cu, Cd, and Cr based on the values of bioaccumulation factors (BAF) and translocation factors (TF). Results of the analysis showed that the BAF value of the *hanjuang* plant (*Cordyline fruicosa*), for heavy metals Pb, Cu, Cd, and Cr were 0.369, 0.442, 0.055, and 0.078, respectively. The TF values of the *hanjuang* plant for heavy metals Pb, Cu, Cd, and Cr were 1.572, 0.964, 0.108, and 1.358, respectively. The BAF values of the croton plant (*Codiaeum variegatum*) for Pb, Cu, Cd, and Cr were 0.021, 0.060, 0.000, and 0.003, respectively. The TF values of the croton plant for Pb, Cu, Cd, and Cr were 3.638, 0.000, 0.000, and 1.399, respectively. Sansevieria plant (*Sansevieria trifasciata*) had BAF values for Pb, Cu, Cd, and Cr of 0.090, 0.036, 0.015, and 0.002, respectively. The TF values of the sanseivera plant for Pb, Cu, Cd, and Cr were 0.410, 0.334, 0.222, and 0.726, respectively. Sunflower plant (*Helianthus annuus*) had BAF values for Pb, Cu, Cd, and Cr of 0.022, 0.094, 0.308, and 0.001, respectively. The TF values of the sanseivera plant for Pb, Cu, Cd, and Cr were 1.930, 0.399, 1.383, and 1.361, respectively. Based on a comparison of BAF values, the *hanjuang* plant is the best hyperaccumulator plant capable of accumulating Pb, Cu, Cr with a phytoextraction mechanism and accumulating Cd with a phytostabilization mechanism. At the same time, sunflower is a hyperaccumulator plant with the best translocation factor where the roots of sunflower plants absorb Pb, Cu, Cd, and Cr, which are then translocated to the stems and leaves optimally through a phytoextraction mechanism.

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Introduction

Environmental pollution, especially river pollution, continues to increase every year. Community activities originating from agricultural, industrial, and household activities produce waste and contribute to the decline in the quality of river waters. Heavy metals that enter the aquatic environment will dissolve and accumulate in sediments and can increase over time depending on the condition of the river. The heterogeneous lifestyle of the community makes the river switch function as a drain for domestic and industrial waste, thus reducing the quality of the river in terms of physical, chemical, and biological.

Badung River is one of the rivers that cross Denpasar City. Heavy metal pollution in the lower reaches of the Badung River is thought to be due to waste disposal from the dyeing/screen printing industry around the river. Water quality analysis at the mouth of the Badung River also detected heavy metal chromium (Cr) due to most of the dyeing/screen printing industry activities developing rapidly in the downstream area of the Badung River (Sari and Perwira, 2019). Badung River is used as a source of irrigation for agricultural land in Denpasar City. Subak Kerdung is an agricultural land whose irrigation comes from the Badung River.

Pollution of the Badung River will undoubtedly affect the condition of the land in Subak Kerdung. Plants will absorb the increased availability of heavy metals in the soil, which negatively affects human health (Hidayat, 2015). The utilization of the Badung River, which is indicated by heavy metals with high toxicity levels, namely lead (Pb), cadmium (Cd), copper (Cu), and chromium (Cr), if used as a means of irrigating land in Subak Kerdung, will affect food products so that it has a negative impact on public health if consumed intensively. The application of remediation technology on land was chosen as an alternative solution to heavy metal management on agricultural land in Subak Kerdung, irrigated by the Badung River. Phytoremediation is applied as a technology to clean soil and water from pollutants that can reduce pollutants in large quantities (Sabeen et al., 2013; Hamzah et al., 2017). The phytoremediation method can reduce heavy metal contamination in soil using plant species effectively, economically, and environmentally friendly (Abou-Shanab et al., 2011; Asiabadi et al., 2015; Sharma et al., 2015).

Phytoremediation is an environmentally effective and cost-efficient alternative, saving up to 75% of the cost compared to conventional methods, such as using chemicals to reduce pollutants. The mechanism of phytoremediation, according to Wong et al. (2002), consists of phytoextraction, phytovolatilization, phytodegradation, phytostabilization, and hemofiltration where this mechanism plays a role in reducing pollutants such as heavy metals in soil and water. Hyperaccumulator is the ability of plants to absorb heavy metals through the roots and then accumulate in plant organ tissues to be reprocessed or disposed of. Hyperaccumulator plants can absorb heavy metals as much as 1% of their dry weight. All plants can absorb metals but in varying amounts. Some plant species from several families have been shown to have tolerant properties, which can accumulate high concentrations of metals in roots and crown tissues, making them hyperaccumulators. Hyperaccumulator plants are plants used in the phytoremediation process. Plants used for phytoremediation can be cleaned by absorbing and storing pollutants in their organs (Gupta et al., 2013). Some types of hyperaccumulator plants can grow and adapt to heavy metal-contaminated soil. However, each plant has a different ability to accumulate heavy metals, and the selection of plant species depends on the tolerance capacity and biomass of the plant (Tangahu et al., 2011; Rezania et al., 2016).

The selection of hyperaccumulator plants that can be used for phytoremediation must be able to absorb metals through the roots and then translocate them to the stems and leaves. In addition, plants must also be able to convert metals into a form that is easily absorbed and produce high biomass because the higher the biomass production, the lower the amount of metal concentration in plant tissue and store metals in the leaves (not just in the roots), so that it is easier to reduce the metal by pruning the leaves more efficient. The selection of land plants is more effective in reducing pollutants compared to aquatic plants because the root system of land plants is more extensive and substantial. According to Hardiani (2009), the mechanism of absorption and accumulation of heavy metals by plants can be divided into three processes: absorption by the roots, translocation of metals from the roots to other plant parts, and localization of metals in cells and tissues.

Hanjuang plant (*Cordyline fruicosa*), croton plant (*Codiaeum variegatum*), sansevieria plant (*Sansevieria trifasciata*), and sunflower plant (*Helianthus annuus*) are plants that live in the tropics and can accumulate heavy metals with a high tolerance level. Sansevieria plant can absorb the heavy metal lead (Pb) of 112 mg/kg (Ratnawati and Fatmasari, 2018) and has an effective absorption capacity of the heavy metal copper (Cu) reaching 57.3% at a concentration of 400 ppm (Setyawan and Surya, 2017). Croton plant has the potential to absorb the maximum heavy metal lead (Pb) of 1.9991 µg/g (Suhaenah et al., 2020). The maximum accumulation of the heavy metal cadmium in the *hanjuang* plant is 36.2167 mg/kg (Sari et al., 2019). Sunflower plants can accumulate heavy metal Cd of 20 mg/kg with an average BAF (Bioaccumulation Factor) value of 1.67 (Alaboudi et al., 2018).

The aim of this study was to determine the best types of hyperaccumulator plants from *hanjuang* (*Cordyline fruicosa),* croton *(Codiaeum variegatum),* sansevieria *(Sansevieria trifasciata),* and sunflower *(Helianthus annuus)* plants absorbing Pb, Cu, Cd, and Cr with the experimental method.

Materials and Methods

This research used an experimental method with two treatment factors. The first factor was water pollution by heavy metals, consisting of 4 levels, i.e., water not polluted by heavy metals (P_c) as a control, water polluted by high levels of heavy metals (P_h), water polluted by medium levels (P_m), and water polluted by low levels (P_l) for each of the heavy metals lead (Pb), copper (Cu), cadmium (Cd), chromium (Cr). The second factor was the type of hyperaccumulator plant, which consists of four plants, i.e., *hanjuang* (H_1), croton (H_2), sansevieria (H_3), and sunflower (H_4). The combination was repeated three times, so the total experimental unit was 16 x 4 x 3 = 192 experimental units. The phytoremediation stage was carried out experimentally in the experimental garden of the Faculty of Agriculture, Udayana University.

The plants were placed in soil media from Subak Kerdung land with a clay texture and a water content of 10.31%-16.67% (Sumarniasih et al., 2021). Soil was placed in polybag size 10 x 15 cm, as much as 2 kg, then planted with *hanjuang*, croton, sansevieria, and sunflower plants. The four types of plants were planted in polybags filled with soil media and then watered daily during the acclimation process within two weeks to obtain stable plant conditions. After two weeks, the plant was irrigated with water mixed with heavy metal (as $PbNO_3$, $CuSo_4$, $CdSO_4$, $K_2Cr_2O_7$) solution. Heavy metal concentrations were determined in three levels, i.e., high (1,500 ppm), medium (1,300 ppm), and low (1,100 ppm). The aim of treatment injection of Pb, Cu, Cd, and Cr solution into the water used irrigation for *hanjuang*, croton, sansevieria, and sunflower plants was to determine the absorption capacity of heavy metals in the organ of plants.

Experiments with different concentrations of Pb, Cu, Cd, and Cr solutions were carried out as an alternative to the irrigation process. The treatment was given to *hanjuang* (H_1) without heavy metal contaminants as a control (H_{1c}), heavy metal lead (H_{1Pb}) injection 100 mL, injection of heavy metal cadmium (H_{1Cd}) 100 mL, injection of heavy metal copper (H_{1Cu}) 100 m, injection of heavy metal chromium (H_{1Cr}) 100 mL. The treatment was given to croton plants (H_2) without heavy metal contaminants as a control (H_{2c}), heavy metal lead (H_{2Pb}) injection 100 mL, cadmium (H_{2Cd}) injection100 mL, copper (H_{2Cu}) injection 100 mL, chromium (H_{2Cr}) injection 100 mL. The treatment was given to the sansevieria plant (H_3) without heavy metal contaminants as a control (H_{3c}), lead (H_{3Pb}) injection 100 mL, cadmium (H_{3Cd}) injection 100 mL, copper (H_{3Cu}) 100 mL, chromium (H_{3Cr}) injection 100 mL. The treatment was given to sunflower plant (H_4) without heavy metal contaminants as a control (H_{4c}), lead (H_{4Pb}) injection 100 mL, cadmium (H_{4Cd}) injection 100 mL, copper (H_{4Cu}) injection 100 mL, chromium (H_{4Cr}) injection 100 mL.

Two months later, all the plants were harvested. Samples of roots, stems, and leaves were dried for analysis of the content of Pb, Cu, Cd, and Cr. The dried solid samples were finely ground, and as much as 0.5 g (dry mass) of plant sample was weighed into the digestion vessels. Then 5.0 mL of concentrated HNO_3 and 1.0 mL of 30% H_2O_2 were added to each sample. Samples were pre-digested overnight for 16 hours in a fume hood at room temperature. Temperature control required a temperature sensor in one vessel during the entire decomposition. The plant samples were digested according to the internal temperature, which was limited to 240 °C during the last step and ventilation. After cooling, the entire digest was transferred into a 60 mL plastic bottle, diluted to 50 g with double deionized water, and ready for analysis. All samples were analyzed for Pb, Cu, Cd, and Cr contents using an Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) tool consisting of a combination of 2 methods, i.e., inductively coupled plasma and mass spectrometry (Retka et al., 2010). The ability of *hanjuang*, croton, sansevieria, and sunflower plants to absorb heavy metals was analyzed by the bioaccumulation factor (BAF) and translocation factor (TF). The BAF value ranges from 0 to >1, where the value indicates that the plant can accumulate heavy metals in its organs. TF is the ability of plants to absorb heavy metals through the roots and then be translocated from the roots to the upper organs of the plant. The TF value >1 indicates that the plant can translocate the heavy metals absorbed by the plant roots the plant shoots. The translocation factor is determined based on the ratio of the concentration of metal in the plant shoots to the concentration of metal in the roots (Branzini and Zubillaga, 2013).

$$\text{BAF} = \frac{\text{metal concentration in plants}}{\text{metal concentration in soil}}$$

$$\text{TF} = \frac{\text{metal concentration in stems and leaves}}{\text{metal concentration in roots}}$$

Results

The test results for heavy metals Pb, Cu, Cd, and Cr in hanjuang, croton, sansevieria and sunflower plants

The results of the analysis showed that the maximum absorption of heavy metal Pb in the *hanjuang* plant (*Cordyline fruicosa*) occurred at a treatment dose of 1,500 ppm, with the highest value in the roots at 228.458 ppm (Figure 1). According to Hernahadini et al. (2020), the organ of the *hanjuang* plant that accumulates the heaviest metal Pb occurs in the roots, and the higher the concentration of the heavy metal Pb in the soil, the lower the absorption capacity of the *hanjuang* plant. The maximum absorption of heavy metal Cu occurred at a treatment dose of 1500 ppm, with the highest accumulation value in the roots at 366.745 ppm. The maximum absorption of heavy metal Cd occurred at a treatment dose of 1,500 ppm, where heavy metal Cd was only detected in the roots at 94.973 ppm and stems at 30.779 ppm, while in the leaves, no heavy metal Cd was detected. Based on research by Sari et al. (2019) stated that the highest accumulation of heavy metal Cd was found in the roots of the *hanjuang* plant, but the absorption of heavy metal Cd was not found in the stems and leaves. The maximum absorption of heavy metal Cr occurred at a treatment dose of 1,500 ppm, as much as 72.871 ppm in the roots. Based on the analysis results, the roots of the *hanjuang* plant have a high absorption capacity of Pb, Cu, Cd, and Cr, which are then translocated to the stems and leaves. The roots of the *hanjuang* plant have a fine branch structure that spreads throughout the soil medium to absorb the heavy metal Pb from the underground (Haryanti et al., 2013). Based on the analysis results of croton plants (*Codiaeum variegatum)*, the maximum absorption of heavy metal Pb occurred at a treatment concentration of 1,500 ppm with the highest accumulation value in the leaves of

18.511 ppm (Figure 2). The maximum absorption of heavy metal Cu occurred at a treatment concentration of 1,300 ppm, which was only detected in the roots at 111.278 ppm, while the stems and leaves were not detected. This happened because the croton plant has a very thick and long root morphology to absorb the heavy metal Cu. Fajar et al. (2021) also showed where the cultivar of croton (*Codiaeum variegatum*) could absorb the heavy metal Cu, reaching 126.399 ppm in the roots.

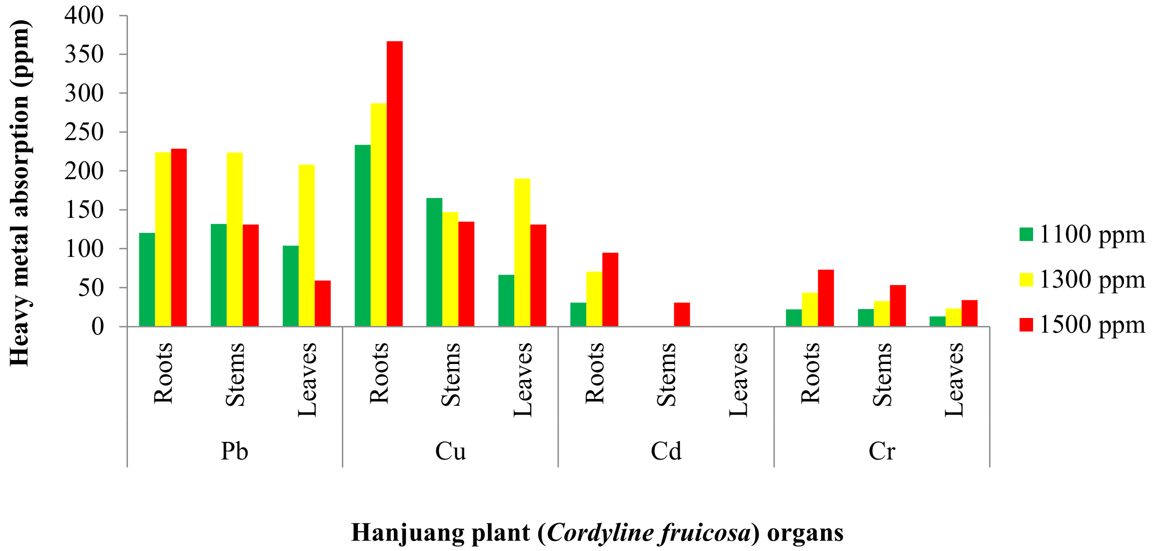


Figure 1. Comparison of concentrations of Pb, Cu, Cd, and Cr on the *hanjuang* plants (*Cordyline fruicosa*) organs.

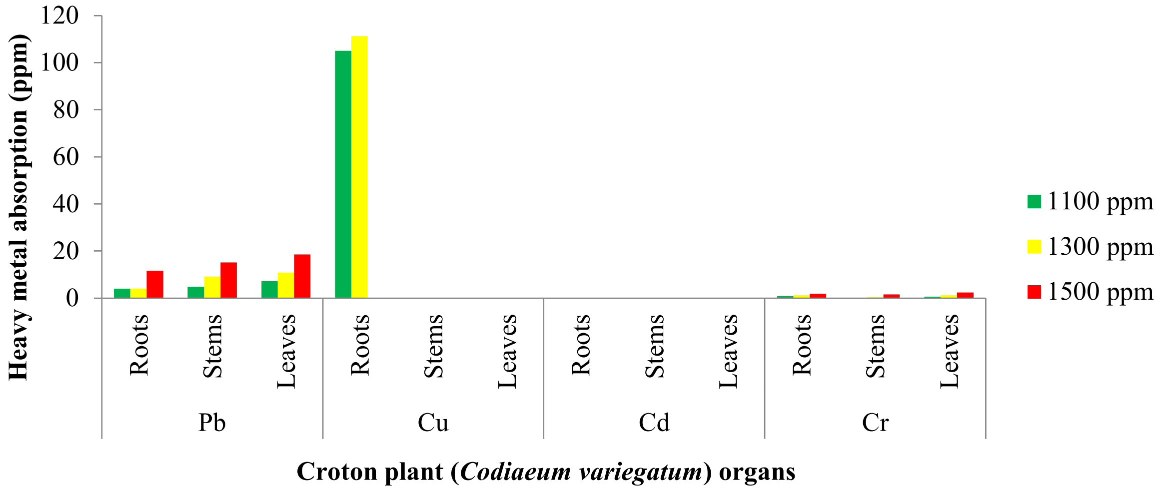


Figure 2. Comparison of concentration of Pb, Cu, Cd, and Cr on the croton plants (*Codiaeum variegatum*) organs.

Croton cultivars can be used as a phytoremediation agent in environments contaminated with substantial, heavy metal Cu because they have long root morphology (Fajar et al., 2021). While the absorption value of heavy metal Cd was not detected in the roots, stems, and leaves. So, the croton plant was not a phytoremediation agent for the heavy metal Cd. The maximum absorption of heavy metal Cr occurred at a treatment dose of 1,500 ppm, with the highest accumulation of absorption in the leaves of 2.457 ppm. The absorption of heavy metals Pb and Cr mainly occurs in the leaves because croton leaves contain tannins, which make the adsorbent strap heavy metals to the maximum. Absorption of the heavy metal Pb into the croton plant organs can go through the xylem to stems and leaves and then enter the tissues through the stomata (Suhaenah et al., 2020). The analysis results on the sansevieria plant (*Sansevieria trifasciata)* showed that the maximum absorption of heavy metals Pb, Cu, and Cd occurred at a treatment dose of 1,300 ppm in the roots (Figure 3). The roots of the sansevieria can absorb the heavy metal Pb 94.010

ppm, Cu 43.595 ppm, and Cd 21.288 ppm. Meanwhile, the maximum absorption of heavy metals Cr occurred at a treatment dose of 1,500 ppm in the leaves at 2.497 ppm. With a compound root system, the sansevieria plant can absorb heavy metals Pb, Cu, and Cd effectively. The same results were also shown by the research of Ratnasari and Fatmawati (2018), where the sansevieria (*Sansevieria trifasciata*) had the highest ability to absorb the heavy metal Pb in the roots and the lowest in the leaves of the plant. This happened because the absorption process of heavy metal Pb in the root organ tissues interacts directly with the soil as a media contaminated with Pb pollutants. Hence, the concentration of Pb in the root tends to be higher than in the stems and leaves. Nutrients can contact the root surface in three ways, i.e., diffusion in the soil solution, passively carried by groundwater flow, and root interaction with the soil. In addition to the root organs, the highest accumulation of heavy metals also occurs in the leaves of the sansevieria. Accumulation of heavy metal Cr at 2.497 ppm was detected in the leaves of the sansevieria. This shows that the leaves of the sansevieria can be a good adsorbent for the heavy metal Cr because it contains a fairly high cellulose element of 50-60% (Hastutiningrum, 2022). Therefore, the sansevieria plant, as an ornamental plant, has the potential to absorb heavy metals in the roots and leaves. In the sunflower plant (*Helianthus annuus*), the analysis results showed that maximum absorption accumulation of Pb occurred at a treatment dose of 1,500 ppm in the leaves at 18.597 ppm (Figure 4). The roots of sunflower plants are not good enough to accumulate Pb compared with other heavy metals (Forte and Mutiti, 2017). The accumulation of Pb is more detected in the leaves of sunflower plants (Hamvumba et al., 2014; Aybar et al., 2023). Meanwhile, sunflower plants accumulated the highest Cu detected in the stems with a treatment dose of 1,300 ppm, reaching 94.667 ppm. Accumulation of absorption Cd by sunflower plants was detected as the highest in the stems occurred at a treatment dose of 1,300 ppm at 285.671 ppm.

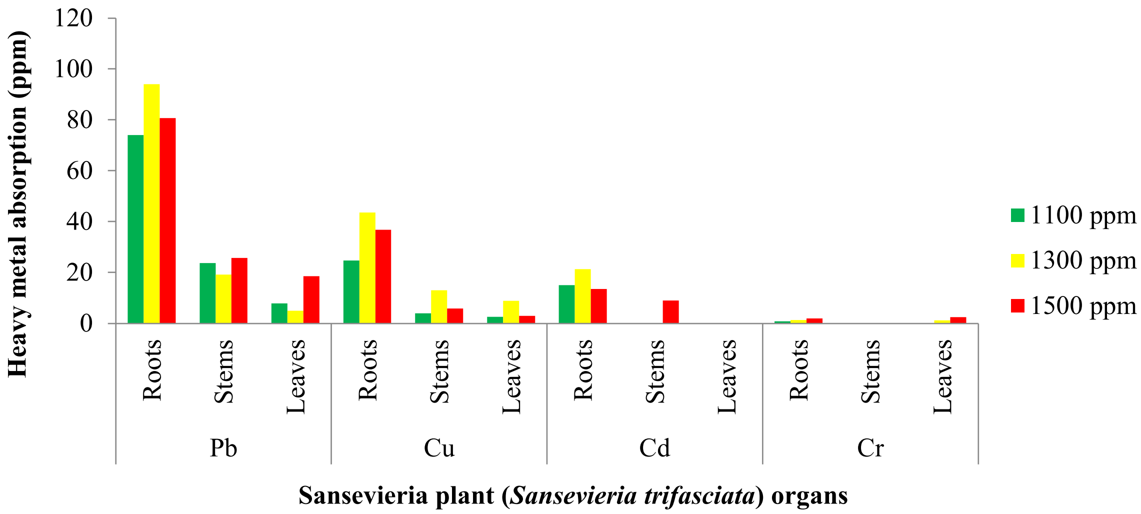


Figure 3. Comparison of concentration Pb, Cu, Cd, Cr on the sansevieria plant (*Sansevieria trifasciata*) organs.

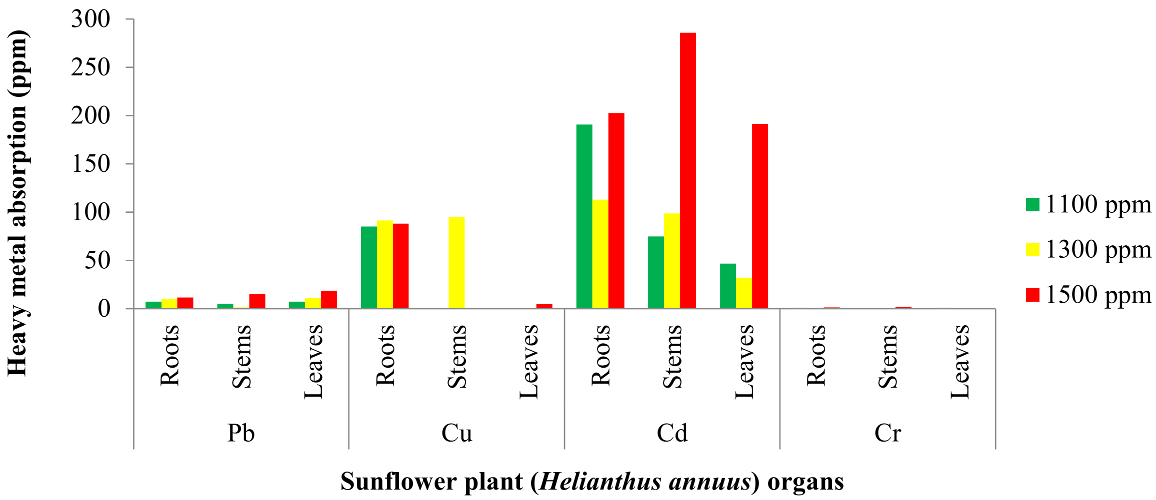


Figure 4. Comparison of heavy metal content Pb, Cu, Cd, Cr on the sunflower plant (*Helianthus annuus*) organs.

Sunflower plants can accumulate heavy metal Cd in the stems more than Pb with a BAF value >1 (Alaboudi et al., 2018). The translocation of heavy metal Cd by the stems to the leaves does not occur optimally, so Cd is only localized in the stems, and accumulation in the leaves is very low. Sunflower has a high tolerance value for heavy metals (Pilon-Smits, 2005; Rahman et al., 2013; Chirakkara and Reddy, 2015; Alaboudi et al., 2018; Govarthanana et al., 2018). In addition, sunflower plant organs can absorb relatively large amounts of heavy metal concentration, translocate them from the roots to the shoots, and produce large amounts of biomass (Farid et al., 2020).

Bioaccumulation factor (BAF) of Pb, Cu, Cd, Cr by hanjuang, croton, sansevieria, and sunflower plants

The ability of plants to absorb heavy metals can be determined by bioaccumulation factors (BAF) and translocation factors (TF). The BAF values of the *hanjuang* plant for Pb, Cu, Cd, and Cr were 0.369, 0.442, 0.055, and 0.078, respectively (Figure 5).

These results indicate that the *hanjuang* plant can absorb the heavy metals Pb, Cu, Cd, and Cr in the soil quite well. The concentration of heavy metals that accumulated in the roots, stems, and leaves of the *hanjuang* plant were lower than that of heavy metals in the soil, so the BAF value was <1. The average BAF values of the croton plant for heavy metals Pb, C u, Cd, and Cr were 0.030, 0.096, 0, and 0.004, respectively (Figure 6). The accumulation of heavy metal Cd in croton plants is shallow compared to heavy metals Pb, Cu, and Cr. The BAF values of sansevieria plants against heavy metals Pb, Cu, Cd, and Cr were 0.090, 0.036, 0.015, and 0.002, respectively (Figure 7). Sansevieria can accumulate heavy metals Pb and Cu more than Cd and Cr. The average BAF values of sunflower plants for heavy metals Pb, Cu, Cd, and Cr were 0.022, 0.094, 0.308, and 0.001, respectively (Figure 8). The BAF value <1 indicates that sunflower plants cannot accumulate heavy metal Pb quite well compared to other types of heavy metals (Forte and Mutiti, 2017).

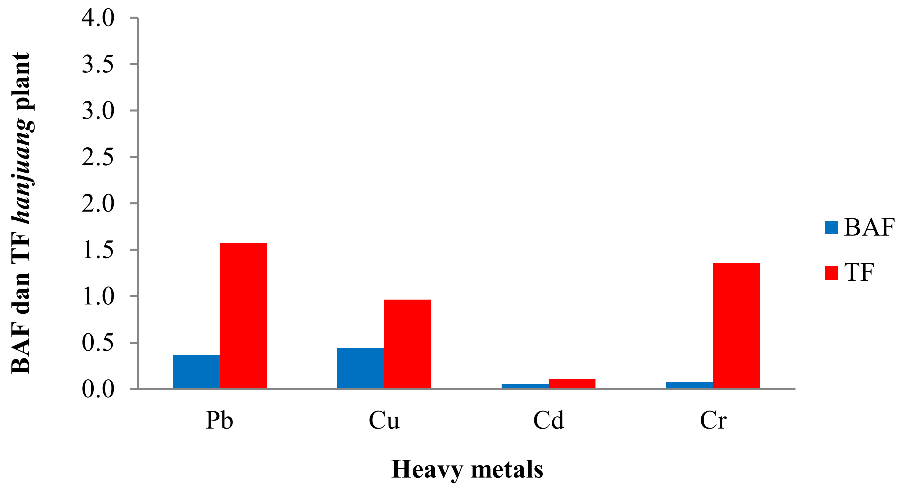


Figure 5. Comparison of bioaccumulation factor (BAF) and translocation factor (TF) *hanjuang* plant to Pb, Cu, Cd, and Cr.

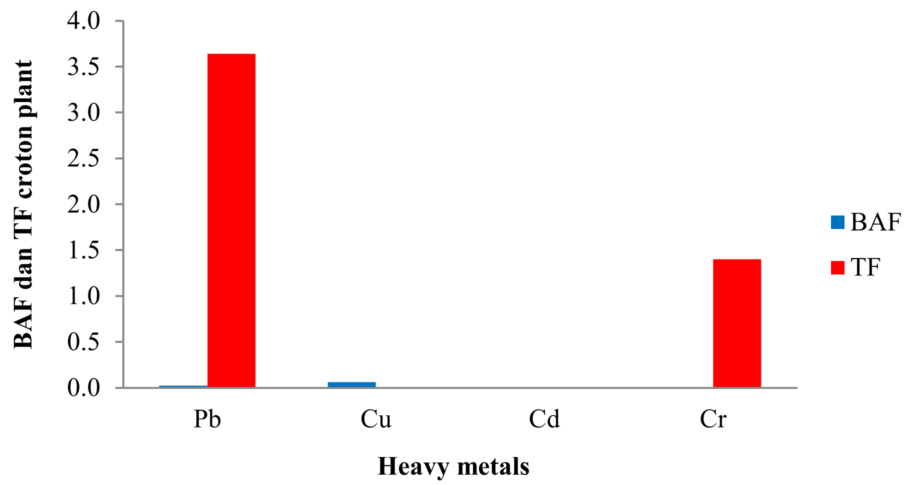


Figure 6. Comparison of bioaccumulation factor (BAF) and translocation factor (TF) croton plant to Pb, Cu, Cd, and Cr.

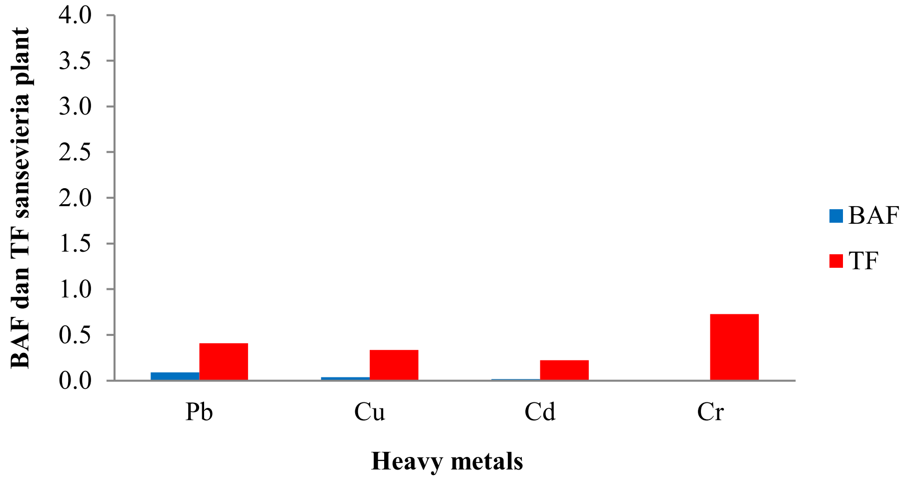
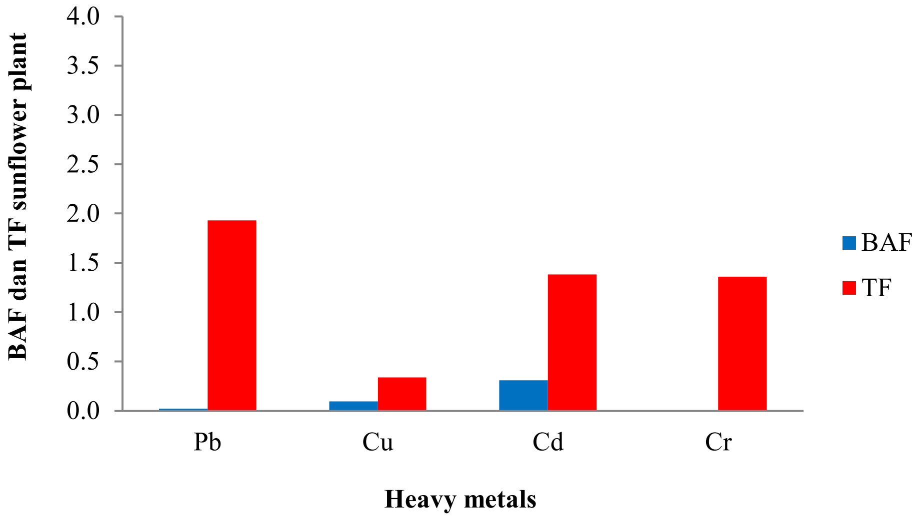


Figure 7. Comparison of bioaccumulation factor (BAF) and translocation factor (TF) sansevieria plant to Pb, Cu, Cd, and Cr.



Gambar 8. Comparison of bioaccumulation factor (BAF) and translocation factor (TF) sunflower plant to Pb, Cu, Cd, and Cr.

Translocation factor (TF) of Pb, Cu, Cd, Cr by hanjuang, croton, sansevieria, and sunflower plants

The average TF value of the *hanjuang* plants for heavy metals Pb, Cu, Cd, and Cr were 1.572, 0.964, 0.108, and 1.358, respectively (Figure 5). Based on the results of the analysis, the *hanjuang* plant has a TF value of > 1 for the heavy metals Pb and Cr, which indicates that the *hanjuang* plant can absorb the heavy metals Pb and Cr through the roots and then translocate from the roots to the organs of the stems and leaves through the mechanism that occurs is phytoextraction. Meanwhile, the TF value of the *hanjuang* plant for heavy metal Cd is lower than Pb, Cu, Cr because the heavy metal Cd is localized more in the roots, so the translocation of the metal to other organs is very low. In croton plants, the average TF values for heavy metals Pb, Cu, Cd, and Cr were 3.638, 0.000, 0.000, and 1.399, respectively (Figure 6). TF value >1 indicates that croton plants can properly translocate heavy metals Pb and Cr from roots to other organs such as stems and leaves. Meanwhile, croton plants cannot maximally translocate Cu and Cd heavy metals from roots to other organs. Results analysis of the average TF values of sansevieria plants for Pb, Cu, Cd, and Cr were 0.410, 0.334, 0.222, and 0.726, respectively (Figure 7). TF value of sansevieria plant < 1 indicates that plants are unable to translocate heavy metals Pb, Cu, and Cr from roots to stems and leaves organ maximally. In sunflower plants, the average TF values for Pb, Cu, Cd, and Cr were 1.930, 0.339, 1.383, and 1.361, respectively (Figure 8). Sunflower plant had a TF value > 1, indicating that the plant can translocate Pb, Cd, and Cr from the roots to the organs of the stems and leaves organ maximally.

Conclusion

Hanjuang plant (*Cordyline fruicosa*) had the highest BAF compared to croton, sansevieria, and sunflower plants. The BAF values of the *hanjuang* plant for the heavy metals Pb, Cu, Cd, and Cr were 0.369, 0.442, 0.055, and 0.078, respectively. The BAF values in the range of 0-1 indicate that *hanjuang* plants can accumulate heavy metals Pb, Cu, Cd, and Cr in the root organs through the phytoextraction mechanism. The sunflower plant (*Helianthus annuus)* had the highest TF value compared to *hanjuang*, croton, and sansevieria plants. The TF values of the sunflower plant for the heavy metals Pb, Cu, Cd, and Cr were 1.930, 0.339, 1.383, and 1.361, respectively. Translocation factor value >1 indicates that the sunflower plant can translocate the heavy metals Pb, Cd, and Cr from the roots and absorb them to the stem and leaf organs maximally through the phytoextraction mechanism.

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