

Research Article

The use of citric acid and NPK fertilizer to enhance phytoextraction of nickel by Bajo starfruit plant (*Sarcotheca celebica* Veldk.)

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Abstract: Bajo starfruit is a wild plant that commonly grows in nickel mining areas, and it is known to have the ability to take up Ni metal from the soil, even though its Ni uptake ability is still relatively low. The objective of this study was to explore the effect of the application of citric acid and NPK fertilizer on the ability of Bajo starfruit plant in phytoextraction of Ni from post nickel mining land. Citric acid as a ligand is expected to enhance the availability of Ni in the soil so that Ni uptake by plants increases, while NPK fertilizer is expected to enhance crop biomass production. The treatments tested were combinations of four doses of citric acid (0, 1, 2 and 3 g of citric acid/kg of soil) with two doses of NPK fertilizer (0, and 1.33 g/kg of soil). Eight treatments were arranged in a factorial randomized block design with four replications. The results showed that the application of NPK fertilizer without citric acid increased the number of leaves and dry weight of plants. After the growth of Bajo starfruit for 25 weeks, the application of 3 g citric acid/kg of soil without application of NPK fertilizer reduced the total soil Ni from 8926 ppm to 2400 ppm i.e.73.11%. Application of 2 g citric acid/kg of soil and 1.33 g NPK fertilizer/kg of soil resulted in Ni uptake by of 118.18 mg/plant or increased by 38.59% compared to control. Application of 2 g citric acid/kg of soil without application of NPK fertilizer increased the BCF value of Bajo starfruit for nickel from 0.032 (control) to 0.035. However, treatments without the application of citric acid and fertilizer resulted in a higher TF value (13.9).

Keywords: *accumulators, fertilization, heavy metals, ligands, remediation*

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Introduction

Post-nickel mining in Sorowako, South Sulawesi Province still has a relatively high Ni content of around 8926 ppm (Haruna et al., 2018). It is difficult to clean, reclaim, and decontaminate areas contaminated with heavy metals because heavy metals cannot be degraded like organic compounds (Lasat, 2002). Most of the post-mining land has been rehabilitated by the Ni mining company by planting various types of pioneer and local plants to improve environmental conditions and ecosystems in the post-mining area. The use of post-nickel mining land for the development of

food crops is hazardous if it is not preceded by remediation measures because each plant can uptake heavy metals from the soil even though in different amounts. Nickel (Ni) is a component of Ni urease that is needed by several plant species in small amounts (about 1 µg/g dry weight). However, Ni is not essential for plant metabolism and can even be toxic at high concentrations (Seregin and Kozhevnikova, 2006). Remediation of metal-contaminated land can be carried out using accumulator plants, known as phytoremediation. One of the phytoremediation techniques is phytoextraction which the use of green plants to remove or treat soil pollutants,

surface water and groundwater (Muske et al., 2016). In an effort to enhance the ability of plants for phytoextraction of Ni on post-nickel mining land in Sorowako, it is necessary to select Ni accumulator plants that have phytoextraction capabilities. Plant species that can accumulate Ni at high concentrations in the aboveground part are called Ni-phytoextractor (Amari et al., 2016). The use of potential local plants as accumulator plants needs to be considered because local plants are easier to obtain, have high adaptability to their environment, and mobilization of plants to remediated land is easier and faster. Plants that are to be used in phytoextraction must be deep-rooted, have high adaptability to climate change and soil types, and have the ability to produce abundant biomass to accumulate large amounts of metal ions (Dağhan, 2016). One of the local plant species found growing around the Ni mining area of Sorowako, South Sulawesi Province, is Bajo starfruit (*Sarcotheca celebica* Veldk.) (Netty et al., 2012). The plant contains about 1,039.25 mg Ni/kg dry weight. However, the ability of Bajo starfruit plant to take up Ni from the soil is still low with a value of bioconcentration factor (BCF) for Ni is only 0.01 (Netty et al. (2013). Potential plants as hyperaccumulator plants are expected to have a BCF value of 1-10 (Malayeri et al., 2008) and TF value > 1 (Wei et al., 2008). The higher the BCF value, the ability of plants to absorb Ni metals from the soil is more exceptional, and if the TF value is higher, it means that the stored Ni concentration in the shoot is higher than in roots.

According to Hidayati (2005), the effectiveness of phytoextraction of an accumulator plant can be enhanced by improving internal factors (genetic potential and physiology of plants) and external factors (management of soil management and crop cultivation). The application of ligands to planting media having high metal concentrations is one of the land management methods to induce phytoextraction. Synthetic chelates have been reported to be efficient for use in phytoextraction, but they are sensitive to leaching and can pollute groundwater (Melo et al., 2008). Organic acids which have a low molecular weight can increase the accumulation of metals in plants so as to eliminate the content of heavy metals in heavy metal polluted soils (Wu et al., 2003). A synthetic chelate that is often used in the activity of heavy metal phytoextraction is citric acid because the cost is cheap and environmentally friendly and without the risk of washing and contamination of groundwater (Wuana et al., 2010). Citric acid is a nontoxic extractant that forms a relatively strong and biodegradable complex but is less effective at removing metal ions (Salt et al., 1995). The increased concentration

of Ni that can be taken up by the roots due to application of ligands (citric acid) needs to be supported by the ability of plants to uptake and translocate metals into plant shoots. Application of fertilizer can improve plant growth and biomass, which in turn increases the amount of heavy metals that accumulate in plants. This then changes the shape and activity of heavy metals and affects the absorption and accumulation of heavy metals by plants (Wu et al., 2017). Nitrogen, phosphorus, potassium, and compound fertilizers are the most commonly used fertilizers to encourage plant growth in phytoremediation activities (Wu et al., 2017). Robinson (1997) states that the application of nitrogen fertilizer can increase the colony of *Alyssum* biomass, as a nickel hyperaccumulator, twice. Kidd and Monterroso (2005) report that increased Ni uptake by *A. serpyllifolium* can be achieved by increasing plant biomass through liming and fertilizing N, P, and K. However, excessive application of fertilizer can reduce phytoremediation efficiency (Xiong et al., 2012)

This study aimed to elucidate the effect of the application of citric acid and NPK fertilizer on the phytoextraction of Ni by Bajo starfruit plant in phytoremediation of post-nickel mining land in Sorowako.

Materials and Methods

The experiment was conducted in the nursery area of PT. Vale in Sorowako, South Sulawesi for eight months using a 40 x 50 cm polybag containing 15 kg of soil. The soil used as a planting medium was originated from post-mining sites in Inalahi VI site. The soil characteristics are as follows: total Ni of 8926 ppm, available Ni of 16 ppm, pH of 5.56, organic N of 0.1%, P₂O₅ of 67 ppm, K₂O of 77 ppm, available Fe of 612 ppm, and CEC of 13.57 cmol/kg soil. Seedlings of Bajo starfruit plant were extracted from the forest around the mining area with a plant height varied from 10 cm to 50 cm. The treatments tested were combinations of four doses of citric acid (0, 1, 2, and 3 g/kg of soil) with 2 doses of NPK fertilizer (0 and 1.33 g/kg of soil). Citric acid was supplied at 12, 16, 20 and 24 weeks after planting (WAP), while NPK fertilizer was applied at 8 WAP. Application of citric acid was done by dissolving 1 g citric acid in 1 L of water and the solution was then applied evenly on the planting media, while NPK fertilizer was incorporated in the planting media. Bajo starfruit plants were grown for 25 weeks. At the end of the experiment (age of 25 WAP), measurements were made for the number of plant leaves. Plants were harvested, washed and dried. Plant samples were dried in an oven at 60°C for 48 hours to determine

the plant dry weight. Plant samples were divided into shoot and root for Ni content analysis. Soil and plant sampling for the analysis of Ni concentration was carried out in a composite manner by collecting samples from each replication in each treatment. Analysis of Ni concentrations in soils and plants was carried out by the wet ashing method using HNO₃ and HClO₄ and measured by Atomic Absorption Spectrophotometer (Proklamasingsih and Hernayanti, 2010). Soil and plant analyses were carried out in the South Sulawesi Agricultural Technology Assessment Laboratory. The data obtained were analyzed to compare with control to find out their statistical variations. Ni concentrations in plants were expressed in units of mg/kg of biomass dry weight. Bioaccumulation Coefficient Factor (BCF) is the concentration of Ni in plants divided by the concentration of Ni in the soil. Nickel translocation from the root to the aerial portion was observed by the Translocation Factor (TF), which is the ratio of metal concentrations in the shoots to concentrations in the roots. Statistical significance was assessed using analysis of variance. The difference between the means was determined by the Tukey's Honest Significant Difference test at a level of 5%. All statistical analyses were performed with Microsoft Office Excel.

Results and Discussion

Number of leaves and plant dry weight

Application of NPK fertilizer and citric acid in the growing media showed an interaction and influenced the number of leaves and the dry weight

of the Bajo starfruit. Plants with media without citric acid and fertilizer (10p1 treatment) had a large number of leaves but were not different from the number of plant leaves in media without citric acid and with no fertilizer (10p0 treatment). The application of citric acid at a dose of 1 to 3 g/kg of soil caused the number of leaves to be less and significantly different compared to the treatment of citric acid application, both with or without fertilizer application (Figure 1). Bajo starfruit planted on media that were fertilized with no citric acid application (10p1 treatment) produced the highest dry weight and were significantly different from the dry weight of the plants which was given fertilizer, but not significantly different from the plant dry weight on media which was given 1 and 2 g citric acid/kg of soil (Figure 2).

The growth of Bajo starfruit plants in media that were given NPK fertilizer was better than that in the media without fertilization. This was indicated by the higher number of leaves formed and the higher dry weight of the plant. NPK fertilization in plants provides additional essential nutrients needed by plants for vegetative growth, cell division, plant metabolism, and plant development (Firgiyanto et al., 2018; Wulandari et al., 2018). Application of NPK fertilizer to the soil not only improves plant growth but can also reduce soil pH, thereby increasing the bioavailability of metals (Bani et al., 2008). Application of citric acid in the planting medium increased the amount of Ni available in the soil, thereby increasing the amount of Ni metal taken up by plant roots. Ni metal is not an essential nutrient for plants; so that when the amount of Ni exceeds the tolerable limit, it can be harmful to plants (Rahman et al., 2005).

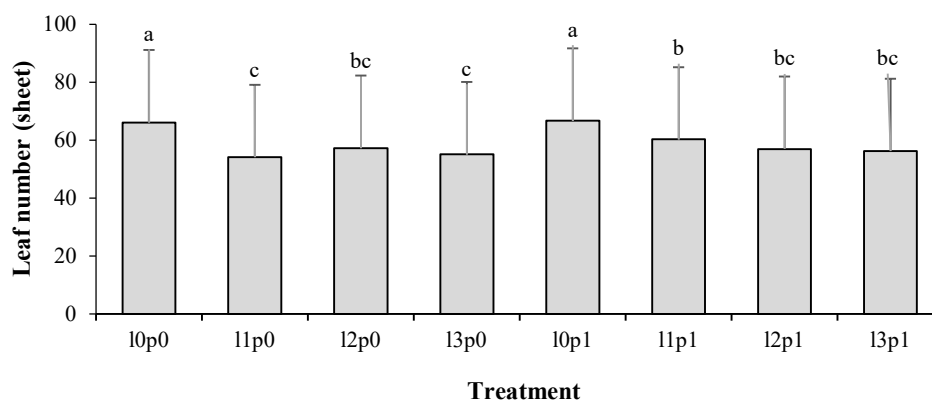


Figure 1. Number of leaves of Bajo starfruit plant at the age of 25 WAP. Different letters indicate significantly different treatments on the 5% Tukey's Honest Significant Difference test.

Note: 10p0 = without citric acid, without NPK fertilizer; 10p1 = without citric acid, with NPK fertilizer; 11p0 = 1 g citric acid/kg of soil, without NPK fertilizer; 11p1 = 1 g citric acid, with NPK fertilizer; 12p0 = 2 g citric acid/kg of soil, without NPK fertilizer; 12p1 = 2 g citric acid/kg of soil, with NPK fertilizer; 13p0 = 3 g citric acid/kg of soil, without NPK fertilizer; and 13p1 = 3 g citric acid, with NPK fertilizer.

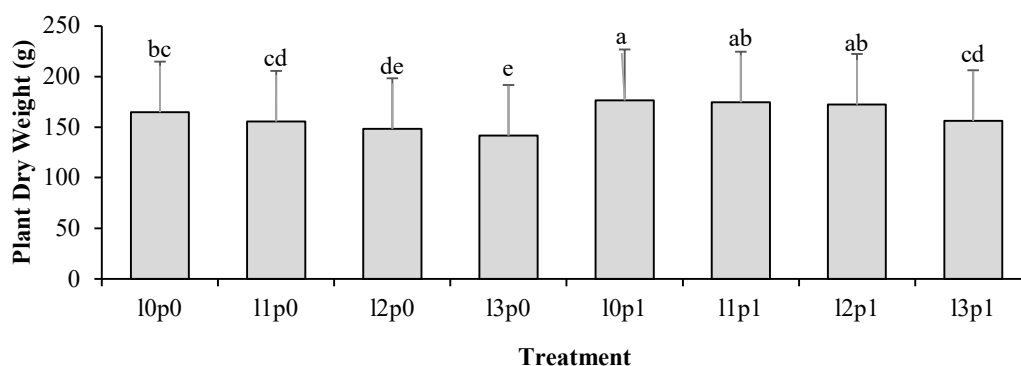


Figure 2. Dry weight of Bajo starfruit plant at the age of 25 WAP. Different letters indicate significantly different treatments on the 5% Tukey's Honest Significant Difference test.

Note: 10p0 = without citric acid, without NPK fertilizer; 10p1 = without citric acid, with NPK fertilizer; 11p0 = 1 g citric acid/kg of soil, without NPK fertilizer; 11p1 = 1 g citric acid, with NPK fertilizer; 12p0 = 2 g citric acid/kg of soil, without NPK fertilizer; 12p1 = 2 g citric acid/kg of soil, with NPK fertilizer; 13p0 = 3 g citric acid/kg of soil, without NPK fertilizer; and 13p1 = 3 g citric acid, with NPK fertilizer.

Reduced number of leaves and dry weight of the Bajo starfruit plants (Figures 1 and 2) could be a symptom that arose due to excess Ni metal in plants. Heavy metals can change plant growth, physiology, and metabolism which ultimately results in a reduction in growth and yield (Ashfaq et al., 2016). The results of a study conducted by Sheoran et al. (1990) showed that the application of Ni with a concentration of 1 mM caused the net photosynthesis of beans decreased by 32%, while the addition of Ni with a higher concentration of 10 mM reduced the photosynthesis by 65%.

Soil total Ni

Total Ni concentration of soil after Bajo starfruit planting for 25 weeks was on average of 2523,375 ppm with sd \pm 134,702. The results of the analysis showed that the application of citric acid 2 g/kg of soil and without the application of NPK fertilizer significantly reduced the total Ni concentration of the soil at lowest, while the application of acid citrate 3 g/kg of soil and without application of NPK fertilizer tended to reduce the total Ni concentration of soil at higher. The application of 3 g citric acid/kg of Bajo starfruit growing media without fertilization caused the total soil Ni concentration to decrease to 2400 ppm after 25 WAP with the total amount of Ni loss being 6526 ppm or 73.11% (Figure 3). However, the difference in the decrease in total Ni concentration between controls (10p0 treatment) and those given 3 g citric acid (13p0 treatment) was only 3.81%.

Ni metal which is in the form of absorbed on soil particles cannot be absorbed by plants so the presence of Ni metal in the soil tends to be high.

According to Kabata-Pendias and Pendias (2001), heavy metals in soil consist of various forms, including bound and soluble forms in the soil. Bonded metals are difficult to wash and are relatively unavailable to plants. Citric acid functions to chelate Ni metal which is bound to soil particles so that ligand-metal bonds are formed which can cause metal mobility to increase and Ni becomes in the available form. Citric acid is known to increase metal solubility and plant uptake through the formation of soluble metal-citrate complexes (Qu et al., 2011). Jean et al. (2008) reported that the application of citric acid in soil contaminated with Ni increased Ni content in plants, but reduced plant biomass. According to Priyadi et al. (2013), citric acid has a functional group -COOH, -OH which has the opportunity to form complexes with Ni metal ions.

Citric acid has three carboxylic-COOH groups which can release protons of H⁺ in soil solution. The more amount of citric acid that is applied to media that contains many Ni metal, the amount of Ni that can be chelated is also higher. Ni metals in soil solutions in the form available, can not only be absorbed by plants but also easily washed by water. Application of 3 g citric acid/kg of soil caused Ni to be released from soil particles to become more and could be lost from the soil either by being absorbed by plant roots or lost by rainwater or splashing water. The ability of each plant to take up Ni metal is different. Some plants are able to take up metals in very high amounts without experiencing toxic known as hyperaccumulator plants, but some plants are susceptible to excessive amounts of metals (non-accumulators).

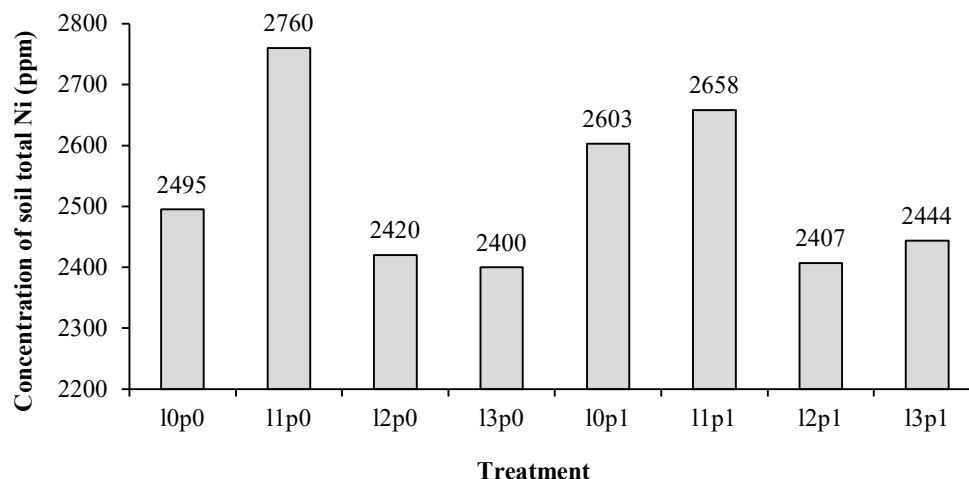


Figure 3. Total soil Ni concentration after *Bajo starfruit* plant at the age of 25 WAP on different planting media and dosage of citric acid.

Note: 10p0 = without citric acid, without NPK fertilizer; 10p1 = without citric acid, with NPK fertilizer; 11p0 = 1 g citric acid/kg of soil, without NPK fertilizer; 11p1 = 1 g citric acid, with NPK fertilizer; 12p0 = 2 g citric acid/kg of soil, without NPK fertilizer; 12p1 = 2 g citric acid/kg of soil, with NPK fertilizer; 13p0 = 3 g citric acid/kg of soil, without NPK fertilizer; and 13p1 = 3 g citric acid, with NPK fertilizer.

Bajo starfruit plant is one of the accumulator plants which has the potential as hyperaccumulator plants because it can live on growing media containing high concentrations of Ni and can take up 1,039 mg Ni/kg (Netty et al., 2012). The amount of available Ni in the soil was quite high due to the application of 3 g citric acid/kg of soil making the *Bajo starfruit* plant took up large amounts of Ni metal so that the total Ni concentration of the soil became down. The limitation of other nutrients in the soil compared to the amount of Ni caused the Ni metal which was absorbed by the roots to become more than the soil in which there were many other nutrients due to fertilizer application.

Ni in plant

The amount of Ni uptake by *Bajo starfruit* plants for 25 weeks was on average of 91.25 mg/plant with sd \pm 14.30 (Figure 4). The results of the analysis showed that the application of 2 g citric acid/kg of soil without and with the application of NPK fertilizer significantly yielded the highest Ni uptake (118.18 mg/plant), while the application of 1 g citric acid/kg of soil and without application of NPK fertilizer significantly yielded the lowest Ni uptake. The application of 2 g citric acid/kg of soil increased the Ni uptake by *Bajo starfruit* plant. On the soil with NPK fertilizer, Ni uptake was 27.84% while that on the soil without NPK fertilizer was 23.35% higher compared to control. The application of 1 g citric acid/kg of soil decreased

Ni uptake by 12.14% in the untreated soil, and 8.29% in the fertilized soil compared to the control. This can be caused by the presence of citric acid which functions as a ligand capable of blowing Ni metals bound to colloidal soils. According to Setiawan (2008), chelation using organic acids increases with increasing chelating concentration. High concentrations of water-soluble organic acids can pull metal ions back into the soil solution and form complexes. The removal of metals from colloidal soils into the soil solution can make it easier for roots to absorb metals from the soil so that the amount of Ni in plants increases. The role of organic acids in heavy metal hyperaccumulation is related to free amino acids, such as histidine and nicotinamine, which form stable complexes with bivalent cations (Callahan et al., 2006; Rascio and Navari-Izzo, 2011). Application of fertilizer resulted in a better plant growth with a higher number of leaves so that the shoot accumulated more Ni. Application of 2 g citric acid/kg of soil increased the amount of available Ni in the soil but it has not caused toxic for plants so that plants continued to grow well with the high number of leaves and dry weight. Nascimento et al. (2006) and Hsiao et al. (2007) reported an increase in Ni concentration in the green parts of *Brassica juncea* plant due to the application of citric acid compared to control treatment. The addition of organic acids to the soil increases the bioavailability of metals in the soil (Eren, 2019).

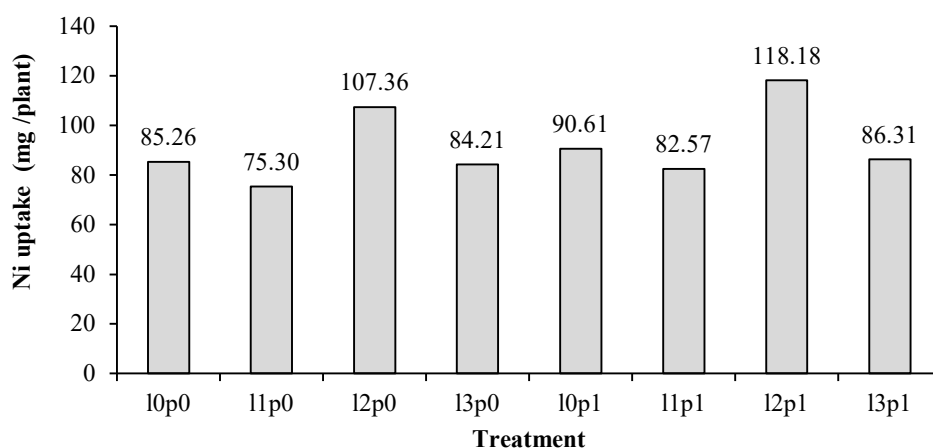


Figure 4. Ni uptake by Bajo starfruit plant at the age of 25 WAP in different growing media and dosages of citric acid.

Note: 10p0 = without citric acid, without NPK fertilizer; 10p1 = without citric acid, with NPK fertilizer; 11p0 = 1 g citric acid/kg of soil, without NPK fertilizer; 11p1 = 1 g citric acid, with NPK fertilizer; 12p0 = 2 g citric acid/kg of soil, without NPK fertilizer; 12p1 = 2 g citric acid/kg of soil, with NPK fertilizer; 13p0 = 3 g citric acid/kg of soil, without NPK fertilizer; and 13p1 = 3 g citric acid, with NPK fertilizer.

NPK fertilization in Bajo starfruit plant caused a better plant growth which was characterized by an increase in plant dry weight due to the growth and development of various plant organs such as leaves, branches and roots. Long and many roots have the potential to absorb more metal compared to plants with short and little roots. Plants with a higher number of leaves increase the ability of plants to accumulate Ni metal in the leaves. The more leaves owned by Bajo starfruit plants the place for more metal storage so that the translocation of metal from root to leaf can also increase. According to Hidayati (2013), Ni and several other metals are mostly concentrated in epidermal cell vacuoles and subepidermal leaf. Uptake of Ni metal in excess of plant requirements can be toxic to plants, but accumulator plants can detoxify metals by binding Ni metal by ligands produced by plants. According to Yang et al. (2005), the type of ligand that plays a role depends on location in plant parts and plant age, such as Zn in the cytoplasm associated with histidine and nicotinamine ligands, while in the shoot is associated with organic acids. Cd in the shoot is generally bound to organic acids, mainly malic acid, while Ni in the leaves is bound by ligands, especially histidine.

Bioconcentration factor and translocation factor

Bajo starfruit planted on media with high Ni metal content had a high BCF value if applied with 2 g citric acid/kg of soil alone without NPK fertilizer.

Bajo starfruit BCF values appeared to be low if the dose of citric acid of 0 and 1 g/kg of soil (Figure 5). The application of 3 g citric acid/kg of soil and without NPK fertilizer increased the value of Bajo starfruit BCF by 9.38% compared to the control (10p0 treatment). The higher value of BCF for Ni in Bajo starfruit plant that grew in the growing media without fertilizer compared to those grown on fertilized media was probably because the amount of Ni ions in solution was more due to the limited other ions from nutrients in the soil. In fertilized media, the presence of other ions such as N, P and K derived from fertilizers was dissolved in the soil solution so that it could reduce the amount of Ni ions in the soil solution. Soil fertility conditions can also affect the movement of metals from soil to plants (Alloway, 1995). In infertile soils, heavy metals will be separated from the bonds of the earth in the form of ions that move freely and then absorbed by plants through ion exchange. This causes the soil to be dominated by Ni ions so that the availability of Ni ions in the root absorption complex increases. The reduced amount of Ni metal uptake due to the addition of fertilizers also occurred in *Arundo donax* L. plant supplied with NPK fertilizer (Atma et al., 2017).

The value of BCF for Ni of Bajo starfruit achieved in this study was higher compared to previous studies conducted by Netty et al. (2013) of 0.01. Although the BCF value obtained in this study has increased, it has not been able to make the starfruit crop into the category of the medium

accumulator. According to Malayeri et al. (2008), if a plant has a BCF value > 1.0 then it can be classified as a high accumulator, 0.1-1.0 is classified as a medium accumulator, 0.01-0.1 is classified as a low accumulator, and <0.01 is classified as a non-accumulator plant. Bajo starfruit BCF values in the range of 0.01-0.1 indicating that the ability of plants to take up Ni metals is still low.

The ability of Bajo starfruit plant in translocating Ni from the root to the shoot can be seen from the TF value of the plant. TF value > 1 indicates that the accumulation of Ni metal in the shoot is more than in the root. The highest Bajo starfruit TF value in this experiment was 13.9 in the plant without citric acid and without fertilizer (10p0 treatment) (Figure 6).

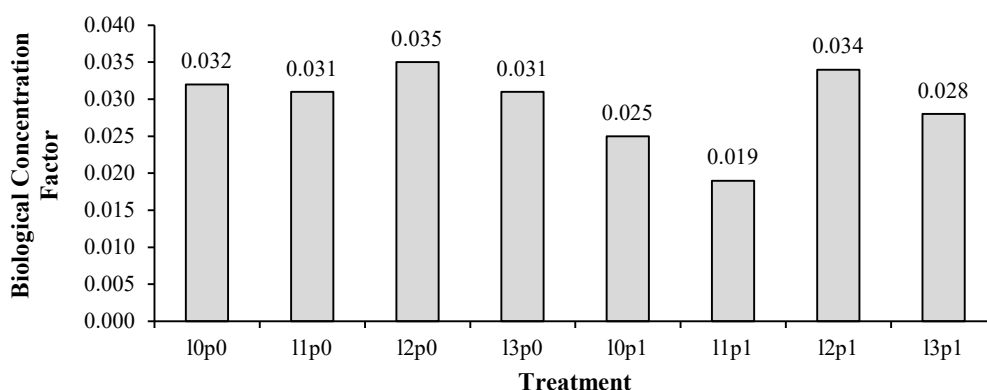


Figure 5. Biological Concentration Factor (BCF) for Ni of Bajo starfruit plant at the age of 25 WAP on various growing media and the dose of citric acid.

Note: 10p0 = without citric acid, without NPK fertilizer; 10p1 = without citric acid, with NPK fertilizer; 11p0 = 1 g citric acid/kg of soil, without NPK fertilizer; 11p1 = 1 g citric acid, with NPK fertilizer; 12p0 = 2 g citric acid/kg of soil, without NPK fertilizer; 12p1 = 2 g citric acid/kg of soil, with NPK fertilizer; 13p0 = 3 g citric acid/kg of soil, without NPK fertilizer; and 13p1 = 3 g citric acid, with NPK fertilizer.

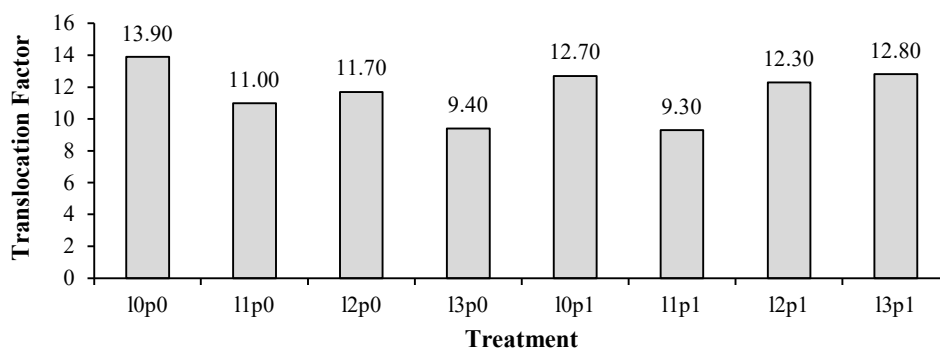


Figure 6. Translocation Factor (TF) for Ni of Bajo starfruit plant at the age of 25 WAP on various planting media and citric acid dose.

Note: 10p0 = without citric acid, without NPK fertilizer; 10p1 = without citric acid, with NPK fertilizer; 11p0 = 1 g citric acid/kg of soil, without NPK fertilizer; 11p1 = 1 g citric acid, with NPK fertilizer; 12p0 = 2 g citric acid/kg of soil, without NPK fertilizer; 12p1 = 2 g citric acid/kg of soil, with NPK fertilizer; 13p0 = 3 g citric acid/kg of soil, without NPK fertilizer; and 13p1 = 3 g citric acid, with NPK fertilizer.

The TF value in plants can be caused by plant growth factors, the amount of available Ni in the soil, and the presence of citric acid as a ligand in the soil. Bajo starfruit plant that grew on media without citric acid and fertilizer showed a better

growth that can be seen from a large number of plant leaves. The addition of citric acid to the media caused the amount of available Ni in the soil to increase and could cause growth pressures for plants. The use of growing media which had a high

total Ni concentration was possible for the availability of Ni ions in the soil even without the addition of citric acid. A large number of leaves, available Ni in soil with optimal amounts, and Ni uptake due to the absence of other elements such as N, P, K derived from fertilizers, caused the Bajo starfruit plant that grew on media without citric acid and fertilizer had higher TF value than other treatments. The ability of Bajo starfruit plant to grow on media with high Ni concentration without visible symptoms of chlorosis and necrosis indicated the high adaptation of the plant to its environmental conditions. Heavy metals Zn, Cu, Mo, Mn, Co, and Ni, are essential in biological processes (Salla et al., 2011; Shahid et al., 2015). However, the metals can reduce plant productivity if the concentration exceeds the optimal value (Xiong et al., 2012). These toxic elements cause morphological abnormalities, and metabolic disorders in plants which in turn reduce plant yields (Amari et al., 2017).

The high adaptability of Bajo starfruit plant to live on land with high concentrations of Ni can be one reason to consider the use of Bajo starfruit as an accumulator plant in remediation activities of land contaminated with Ni metal. Some criteria for a type of plant potential as a heavy metal accumulator are resistance to metal elements in high concentrations in root and canal tissues, high rate of absorption of elements from the soil compared to other plants, has a high rate of translocation and an accumulation of metal elements from root to crown at a rate that is high (Brown et al. 1995) and has a high potential for biotechnical production (Reeves, 2003). Based on the results of the study, Bajo starfruit plant growing on fertilized or unfertilized soils has high Ni uptake with TF values of more than 1 (Figure 5). According to Mellem et al. (2009), if the TF value is more than 1, translocation occurs more in the shoot. The high TF value indicates that the amount of metal translocated to shoot is also high. Two characters possessed by Bajo starfruit plant are (a) the plant can survive on media with high concentrations of Ni metal, and (b) the plant can translocate Ni metal to the shoot in large quantities. Therefore, Bajo starfruit plant fulfils the requirements as an accumulator plant and has the potential to be utilized in remediation of post-nickel mining land in Sorowako, which still has a high concentration of Ni.

Conclusion

Application of 2 g citric acid/kg of soil and 1.33 g NPK fertilizer/kg of soil resulted in Ni uptake by Bajo starfruit plant of 118.18 mg/plant for 25

weeks or increased by 38.59% compared to control, and thus decreased the total Ni concentration in the soil from 8926 ppm to 2407 ppm or 73.03%.

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