JPPIPA 11(11) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Exploration and Analysis of Ni Hyperaccumulator Plants in Ecosystem of Nickel Reach Forest in Southeast Sulawesi, Indonesia

Faisal[1*], Nina Ratna Djuita[2], Hamim[3]

[1] Plant Biology Study Program, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Bogor, Indonesia.
[2] Division of Ecology and Plant Resources, Department of Biology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Bogor, Indonesia.
[3] Division of Plant Physiology and Genetics, Department of Biology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Bogor, Indonesia.

Received: August 19, 2025
Revised: October 08, 2025
Accepted: November 25, 2025
Published: November 30, 2025

Corresponding Author:
Faisal
hamim@apps.ipb.ac.id

DOI: 10.29303/jppipa.v11i11.12585

Abstract: Indonesia, as the world's largest nickel producer, has vast ultramafic areas that have the potential to become habitats for nickel hyperaccumulator plants (Ni). This study aimed to explore and analyze nickel hyperaccumulator plants in the mining area of CV. Unaaha Bakti Persada, North Konawe Regency, Southeast Sulawesi, Indonesia. The research was conducted from June to November 2023 using the exploration method at three observation stations, each consisting of three plots. The research stages carried out include exploration, plant collection and identification, and analysis of Ni content in soil as well as plant tissue using Atomic Absorption Spectrophotometry (AAS). A total of 32 plant species were found, which was dominated by *Pteridium aquilinum* ferns at Stations I and III and *Scleria lithosperma* grasses at Station II. The Ni content of the soil was very high (5,458.32–5,938.41 mg/kg) and far above the normal threshold. Several species showed high Ni accumulation capacity, with the most of six were *Sarcotheca celebica*, *Knema metanensis*, *Pluchea carolinensis*, *Gymnostoma sumatrana*, and *Justicia gendarussa*. The post mining sites were categorized as marginal due to heavy metal toxicity (Ni, Co, Cr), and therefore, only tolerant plants can survive. *Sarcotheca celebica* had the highest BCF value (0.1421) and was classified as a moderate accumulator. All the six species has the potential to be used for phytoremediation, phytomining and reclamation of post mining areas in Southeast Sulawesi.

Keywords: Hyperaccumulator plant; Nickel (Ni); Phytomining; Phytoremediation; Revegetation; Ultramafic area

Introduction

Indonesia is one of the world's largest nickel producers; in 2022, for example, nickel production in Indonesia reached 1.6 million tons (Statista, 2023). Therefore, nickel has become an important economic resource for the country. On the other hand, the mining sector is recognized as one of the main sources of pollutants, especially heavy metals and other contaminants for the environment (Earth.org, 2023). The Southeast Sulawesi region, for example, is one of the areas rich in nickel, so there are many nickel mining industries. These mining activities can cause damage to the ecosystem due to heavy metal pollution such as nickel and other metals, which can reduce biodiversity. Humans, animals, and plants can also experience physiological stress when exposed to heavy metals (Hamim & Miftahudin, 2023). If this condition

How to Cite:
Faisal, Djuita, N. R., & Hamim. (2025). Exploration and Analysis of Ni Hyperaccumulator Plants in Ecosystem of Nickel Reach Forest in Southeast Sulawesi, Indonesia. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 707–716. https://doi.org/10.29303/jppipa.v11i11.12585

continues, the communities around the mining area will suffer even more.

Reducing heavy metal pollution requires high costs if is carried out using conventional methods such as leaching and electro-reclamation (Ullah et al., 2015). As a more environmentally friendly alternative, phytoremediation technology can be applied by utilizing accumulator plants that are capable of absorbing heavy metals from the environment (Gavrilescu, 2022). One of the important component in phytoremediation is hyperaccumulator plants, which capable of absorbing and accumulating very high amounts of heavy metals (Sarwar et al., 2017). Some species even show extreme tolerance to heavy metals (Hilmi et al., 2018). In general, ordinary plants can only accumulate nickel in the range of 10 mg/kg of tissue (Mesjasz-Przybyłowicz & Przybyłowicz, 2020), but hyperaccumulator species can accumulate more than 100 mg/kg, far exceeding the toxicity limits of ordinary plants (Baker & Brooks, 1989).

According to global data from 2017, there are 721 plant species classified as hyperaccumulators, with nickel (Ni) absorbing species being the most numerous, i.e.: 532 species (Hamim & Miftahudin, 2023). However, the records of nickel hyperaccumulator plants in Indonesia are still very limited. Only a few species have been reported, such as Sarcotheca celebica and Knema matanensis (Van der Ent et al., 2013). The previous research by a team of researchers from France, Australia, and Weda Bay Nickel Ltd. on Halmahera Island, North Maluku, discovered 13 species of nickel hyperaccumulators, 2 cobalt hyperaccumulators, 1 manganese hyperaccumulator, and 10 aluminum hyperaccumulators (Lopez et al., 2019). The most recent paper also reported that recently only 19 species categorized as Ni hyperaccumulator were found in Indonesia, and most of them from Halmahera, Soroako and Obi (Brearley, 2024). In fact, Indonesia has vast ultramafic lands with high potential as habitats for hyperaccumulator plants (Galey et al., 2017). However, exploration data on Ni hyperaccumulator plants in Indonesia is still minimal compared to other countries such as Cuba, New Caledonia, Turkey, and Brazil. Therefore, research on the potential of nickel hyperaccumulator plants in Indonesia is urgently needed to add to the data on species diversity and support post-mining land rehabilitation efforts. The strong effort involving inter-disciplinary should be done to find more hyperaccumulator (Brearley, 2024).

To date, there have been no scientific reports on the exploration of hyperaccumulator plants from nickel mining areas in Southeast Sulawesi. This indicates a gap in scientific information that needs to be filled. As notified by van der Ent et al. (2016) that Ni hyperaccumulator will be found in the Nickel-rich ultramafic soil, so Ni-mining area is an important site to find Ni hyperaccumulator. Therefore, this study was conducted to explore and analyze the nickel (Ni) content in plants and soil from the nickel mining area at CV. Unaaha Bakti Persada, North Konawe Regency, Southeast Sulawesi, Indonesia. The results of this study are expected to make an important contribution to the understanding of the biodiversity of hyperaccumulator plants in Indonesia and to serve as a basis for the application of phytoremediation and phytomining in post-nickel mining areas.

Method

Research Time and Location

The research was carried out in the mining area of CV. Unaaha Bakti Persada (UBP), North Konawe, Southeast Sulawesi (Figure 1). Data collection in the field was carried out from September to October 2023. The research location for exploration and data collection was in a nickel mining area CV. Unaaha Bakti Persada, Southeast Sulawesi. Plant observations and identification were conducted at the Ecology and Plant Resources Laboratory, Biology Department, Faculty of Mathematics and Natural Sciences (FMIPA), IPB University, Bogor, Indonesia. At the same time, plant tissue analysis was carried out at the Plant Physiology Laboratory, Biology Department, FMIPA, IPB University.

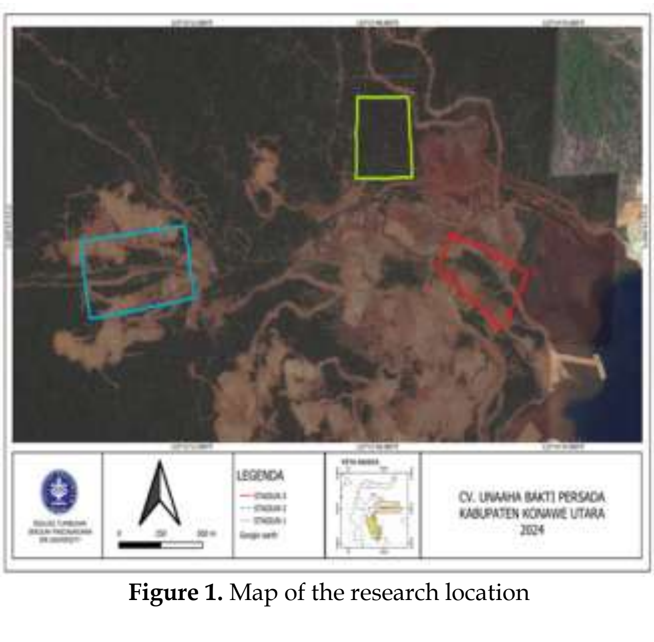

Figure 1. Map of the research location

This research comprised four main activities, i.e.: preliminary survey, sampling processes, vegetation analysis, plant identifications, and Ni analysis. All research activities are presented in a Flowchart as follow (Figure 2).

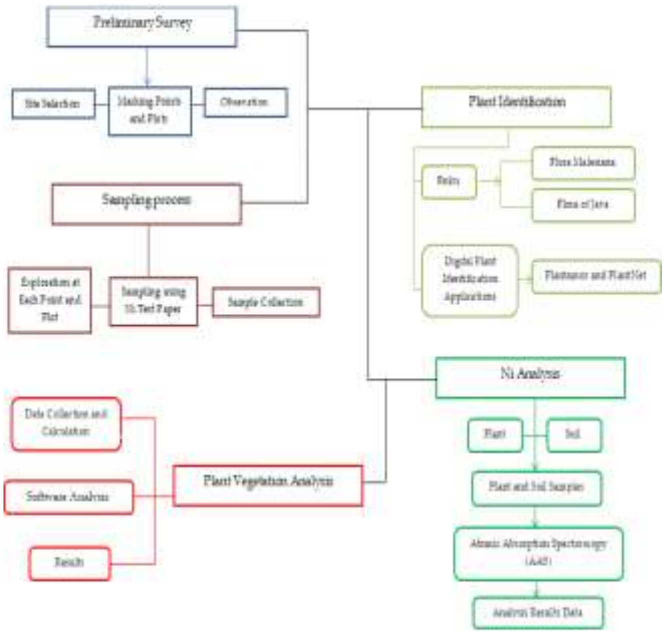

Figure 2. The flowchart of the research

Preliminary Survey

A preliminary survey was conducted to obtain basic information and determine the distribution of plants prior to observation. Sampling was carried out using the exploration and transect methods. The sampling location was divided into three points, and each point consisted of three sampling plots to represent one point (Kartika et al., 2019). Sampling points were determined using the purposive sampling method to place observation plots with rectangular plots measuring 20 m x 20 m for trees, 10 m x 10 m for poles, 5 m x 5 m for stakes, and 3 m x 3 m for seedlings.

Sampling Process

Sampling was done by collecting plants from the sampling area consisting of leaves and stems. Soil samples were also taken from the area around the plants at a depth of 20-40 cm (Neto et al., 2024) and taken as a composite of about 500 g per sample (Rotich et al., 2025). Rapid nickel analysis using the nickel paper test was also conducted in the field to predict whether or not the sampled plants contained high levels of Ni based on the color (pink or red) that appeared on the test paper after leaf or stem pieces were attached to the Ni test paper. The pink color formed indicates that the plant contains nickel and can be collected for further analysis (Disinger et al., 2024).

Plant Identification

Plant species identification is based on key references such as Flora Malesiana (Mabberley et al., 1995) and Flora of Java (van Steenis et al., 1972) and reinforced with the help of digital plant identification applications such as Plantamor and PlantNet.

Ni Analysis

Analysis of nickel (Ni) content in soil and plant tissue samples was conducted at the Integrated Chemistry Laboratory, Bogor Agricultural University (IPB) using Atomic Absorption Spectroscopy (AAS). A total of 32 plant samples and 9 soil samples were analyzed. The plant samples used came from leaves and stems that had been collected and dried from the field. The analyzed data were then used to determine the bioconcentration factor (BCF) of the hyperaccumulator plants obtained (Herlina et al., 2020).

Plant Vegetation Analysis

Vegetation analysis aims to determine the importance value index (IVI). The importance value index is obtained from the total relative frequency (KR), relative frequency (FR), and relative dominance (DR). The IVI value is calculated using Microsoft Excel 2019 software and estimated based on Odum (1971), while species diversity (H') can be calculated using the Shannon-Wiener index formula (Krebs, 1989).

Result and Discussion

Plant Biodiversity

Research at the study site identified 32 plant species, with varying growth forms ranging from grasses, shrubs, and vines to herbs and trees. Although the number of species (diversity) was dominated by herbs, the most abundant species were grasses and herbs. The total number of plants found at all observation points was 1,032 individuals. The highest number of plants was found at Point I, with 494 individuals, followed by Point III with 376 individuals, while only 162 plant individuals were found at Point II (Table 1). The species with the highest number of individuals were *Scleria lithosperma* (251 individuals), *Pteridium aquilinum* (242 individuals), and *Melastoma malabathricum* L. (137 individuals), while other species numbered less than 100 individuals (Table 1). Differences between points and species distribution may be related to variations in soil properties. Garnica-Díaz et al. (2023) stated that soil properties in tropical ultramafic regions are more variable than in temperate regions, which influences species variation.

The population is dominated by lower strata vegetation, which is known to be highly tolerant of degraded land conditions. Two pioneer species, *Scleria lithosperma* (251 individuals) and *Pteridium aquilinum* (242 individuals), dominate the forest at the study site. These two species are known to be able to quickly colonize nutrient-poor soils after disturbance, and *Pteridium aquilinum* often forms monospecific stands that can inhibit tree regeneration (Suazo-Ortuño et al., 2015). The presence of another heliophilous shrub, *Melastoma* *malabathricum* L. (137 individuals), further expands the initial vegetation cover, a pattern commonly observed in post-nickel mining areas in Sulawesi and Kalimantan (Soendjoto et al., 2023).

The presence of 27 individuals of *Knema matanensis*, an endemic species of Sulawesi known as a nickel hyperaccumulator with concentrations of up to more than 1,000 mg kg^{-1}, indicates that the substrate of the study site is classified as ultrabasic soil or nickel laterite (van der Ent et al., 2013). Meanwhile, at Points 3, the increase in the number of *Dicranopteris linearis* clonal ferns (22 individuals) indicates an ecosystem transition phase, as this taxon is known to stabilize eroded slopes and enrich the soil through litter accumulation (Yang et al., 2020).

The Rubiaceae family is the most dominant family with 5 individuals from the total sample. The dominance of Rubiaceae indicates that species from this family have good adaptations to the environmental conditions at the study site (Solfiyeni et al., 2023). Other families with smaller percentages include Apocynaceae, Cyperaceae, Dioscoreaceae, and Moraceae, each with two individuals, which may be less competitive or specific to certain ecological conditions. A total of 19 families had only one individual in the sample, including Acanthaceae, Anacardiaceae, Asteraceae, Fabaceae, and others. These families may have a rarer presence or more limited growth in the study environment. Factors such as soil type, nutrient availability, or environmental disturbances may influence their presence (Nurjaman et al., 2017).

Tabel 1. Plant Species Found at the Research Site

No	Family	Species Name	Common Name	Point			n	Habitus
				1	2	3		
1	Acanthaceae	*Justicia gendarussa*	Gandarusa	43	0	23	66	Bush
2	Anacardiaceae	*Gluta renghas*	Rengas	0	1	0	1	Tree
3	Apocynaceae	*Alstonia macrophylla*	Pulai	0	2	0	2	Tree
		Dyera polyphylla	Jelutung	0	1	0	1	Tree
4	Arecaceae	*Calamus manan*	Rotan	0	40	0	40	Herbs
5	Asparagaceae	*Dracaena* sp.	Pohon dracaena	0	0	3	3	Bush
6	Asteraceae	*Pluchea carolinensis*	Gabus hutan	3	5	4	12	Bush
7	Casuarinaceae	*Gymnostoma sumatrana*	Cemara gunung	0	1	0	1	Tree
8	Combretaceae	*Terminalia catappa*	Ketapang laut	0	2	0	2	Tree
9	Cunoniaceae	*Pterophylla fraxinea*	Pokok dedalu	5	0	0	5	Tree
10	Cyperaceae	*Machaerina mariscoides*	Pukul mati	11	19	24	54	Herbs
		Scleria lithosperma	Ijuk batu	112	11	128	251	Herbs
11	Dennstaedtiaceae	*Pteridium aquilinum*	Pakis lidah kucing	150	0	92	242	Herbs
12	Dioscoreaceae	*Dioscorea bulbifera*	Gembolo	3	0	8	11	Herbs
		Tacca palmata	Gadung tikus	0	0	1	1	Herbs
13	Fabaceae	*Erythrina Subumbrane*	Dadap serep	0	1	2	3	Tree
14	Gleicheniaceae	*Dicranopteris linearis*	Resam	0	0	22	22	Bush
15	Graminae	*Schizostachyum brachycladum*	Bambu lemang	32	13	15	60	Herbs
16	Melastomataceae	*Melastoma malabathricum* L.	Senduduk	106	7	24	137	Bush
17	Metaxyaceae	*Metaxya rostrata*	Paku	0	43	0	43	Herbs
18	Moraceae	*Brosimum sp.*	Buah murbei	1	0	0	1	Tree
		Ficus maclellandii	Alii fig	2	9	1	12	Tree
19	Myristicaceae	*Knema matanensis*	Dara-dara	8	0	19	27	Tree
20	Nepenthaceae	*Nephentes mirabilis*	Kantung semar	6	2	2	10	Herbs
21	Oxalidaceae	*Sarcotheca celebica*	Belimbing bajo	1	0	0	1	Tree
22	Rubiaceae	*Dibridsonia conferta*	Genting-genting	0	1	0	1	Bush
		Mitragyna speciosa	Kratom	0	1	0	1	Tree
		Neolamarckia cadamba	Jabon	7	0	0	7	Tree
		Nauclea latifolia	Persik liar	1	0	8	9	Tree
		Timonius flavescens	Kemuning liar	0	1	0	1	Bush
23	Rutaceae	*Melicope borbonica*	Kepel laut	3	0	0	3	Tree
24	Sapotaceae	*Pouteria sapota*	Mamey sapote	0	2	0	2	Tree
Number				494	162	376	1032	

The number of tree species dominated the mining areas at each point explored, although based on individual abundance, herbs were the most abundant habitat type (Nero 2021). Of the 24 plant families found, the family with the highest proportion of species in the observation area was Rubiaceae, with 5 species, followed by the families Moraceae, Apocynaceae, Cyperaceae, and Dioscoreaceae, each with 2 species. In comparison, the other families had only one species. The Rubiaceae family has high adaptability, is widely distributed, and can grow well in nickel mining areas. According to McCartha et al. (2019), Rubiaceae is one of the families tolerant to flood and drought stress, hence it is commonly found in this habitat with a high proportion. Based on this data, this family can also adapt well to ultramafic soils containing heavy metals, particularly nickel.

Vegetation Analysis Results

Based on the results of vegetation analysis in the nickel mining area of CV Unaaha Bhakti Persada, there are variations in species types shown in each growth phase with frequency (F), relative frequency (RF), density (D), relative density (RD), importance value index (INP), and species diversity (H') as written in Table 2. The importance value index (INP) is a quantitative parameter indicating the dominance level of a species within a plant community. Indriyanto (2006) A high importance value indicates that the species has the highest number of individuals, as well as high density and frequency of occurrence within the community. The results of the study show that there are species with the highest INP in each growth phase, namely for the tree level *Nauclea latifolia* 175.60%, pole phase *Knema matanensis* 114.40%, stake phase *Knema matanensis* 93.72%, seedling phase *Scleria lithosperma* 39.77% (Table 2). These species play important roles and influence their respective communities (Indriyanto 2010). Conversely, plants with the lowest INP values are not dominant and are not widely distributed in the location.

Table 2. Importance Value Index (IVI) of Five Plant Species at Each Growth Phase

Growth phase	Species name	Common Name	INP (%)	(H’)
Seedling	*Scleria lithosperma*	Ijuk batu	39.77	
	Pteridium aquilinum	Pakis lidah kucing	33.06	
	Melastoma malabathricum L.	Senduduk	29.75	2.05
	Schizostachyum brachycladum	Bambu lemang	19.75	
	Machaerina mariscoides	Pukul mati	15.28	
Sapling	*Knema matanensis*	Dara-dara	93.72	
	Ficus maclellandii	Alii fig	46.65	
	Neolamarckia cadamba	Jabon	35.99	1.95
	Pouteria sapota	Mamey sapote	19.93	
	Terminalia catappa	Ketapang laut	17.78	
Pole	*Knema matanensis*	Dara-dara	114.40	
	Ficus maclellandii	Alii fig	51.81	
	Nauclea latifolia	Persik liar	34.38	1.65
	Pterophylla fraxinea D.Don	Pokok dedalu	25.98	
	Neolamarckia cadamba	Jabon	23.80	
Tree	*Nauclea latifolia*	Persik liar	175.60	
	Erythrina Subumbrane	Dadap serep	53.12	1.08
	Brosimum sp.	Buah murbei	37.89	
	Gymnostoma sumatrana	Cemara gunung	33.40	

The diversity index (H') in the nickel mining area has a value range of 1≤H'≤3, indicating that the diversity index level falls into the moderate category based on Magurran's classification (Magurran, 2004). The seedling growth phase has the highest species diversity index with a value of 2.05, followed by the sapling growth phase with a value of 1.95, the pole phase with a value of 1.65, and the tree phase with a value of 1.08. These results illustrate that the ecosystem condition is moderate despite ecological pressure due to heavy metal pollution.

Previous research has shown that sediments or soil in mining areas contain high levels of metals, minimal organic matter, and low levels of macro nutrients (Setyaningsih et al., 2018). As a result, only certain plant species can survive in these conditions. Species diversity is an indicator of community level and community structure. A community is said to have high species diversity if it consists of various types. Conversely, if a community consists of only a few species, then its species diversity is low (Mou et al., 2023). Diversity reaches its maximum value when all individuals come from different genera or species, while the minimum value occurs when there is only one dominant genus or species (She et al., 2023).

Nutrient and Heavy Metal Content in Soil

The nutrient content in soil is very important for plants because soil is an important growth medium, so the adequacy of nutrients in the soil greatly determines the success of plants in growing and surviving. Based on the data presented in Table 3, the results of soil analysis indicate that the average macro nutrient content in the area is represented by nitrogen (N), phosphorus (P), and potassium (K). According to Musfal (2020), the nitrogen content is moderate (0.28%), phosphorus is very low (less than 1.07%), and high for K (305.43 mg/kg) (Table 3). Although the N and K content in the media taken from the nickel mining area is relatively sufficient, the phosphorus content is very low, so not all plants can grow and survive well in that area because P is an important macro element for plants to support energy development and produce various compounds needed for growth such as phospholipids, DNA, RNA, and others (Taiz et al., 2015). On the other hand, the soil also contains very high concentrations of micronutrients, such as Fe, Ni, and Co, as well as non-nutritive heavy metals like chromium (Cr) (Table 3). Micronutrients such as Fe, Ni, and Co are categorized as heavy metals, which can cause toxic effects on plants if absorbed in high amounts (Wang et al., 2017). Chromium (Cr) in high amounts, one type of heavy metal, can also cause poisoning in plants, even at low concentrations. In addition to Cr, the nickel content in seawater is also quite high, averaging 5728.27 ppm (Table 3). Although Ni is an essential element required by plants, its requirement is very low, approximately 0.1 ppm (Taiz et al., 2023). All these characteristics indicate that plants growing in this nickel mining area have a very high level of adaptation. In this area, interactions between plants and microbes such as mycorrhizae or endophytic fungi are crucial for supporting plant growth. Amir et al. (2023), for example, highlight that mycorrhizae are abundant in ultramafic soils with high heavy metal content, which helps plants grow under lower nutrient levels and high metal content. Aribal et al. (2017) also emphasize that heavy metal content does not affect the presence and distribution of mycorrhizae in ultramafic regions in the Philippines. These interactions are vital for plants growing in harsh conditions. Therefore, serious attention is needed to ensure these plants do not disappear and become extinct, as they are essential for post-mining environmental restoration.

Table 3. Concentration of Macro Nutrients (N, P, K) and Micro Nutrients (Fe, Ni, and Co), as Well as Cr Content in Soil Samples

Soil Sample	N (%)	P (%)	K (mg Kg^{-1})	Fe (%)	Ni (mg Kg^{-1})	Co (mg Kg^{-1})	Cr (mg Kg^{-1})
Point 1	0.33	< 1.07	399.50	33.77	5938.41	510.67	3994.03
Point 2	0.29	< 1.07	228.35	32.57	5788.07	379.18	2776.04
Point 3	0.23	< 1.07	288.43	31.28	5458.32	422.15	4098.48
Average	0.28	< 1.07	305.43	32.54	5728.27	437.33	3622.85

Nickel (Ni) Content and BCF Value of Plants

Data on nickel (Ni) content in plants collected from nickel mines show varying results, with some species containing high levels of Ni, such as *Sarcotheca celebica,* which has the highest content at nearly 1000 mg Kg-1 Ni, while the lowest is *Pouteria sapote*, which contains only 6.2 mg Kg-1 Ni. Measurements of Ni content in plants and tailing sediments are used to determine the plants' ability to absorb/extract metals from the surrounding soil, and 1000 mg/kg is a common criterion for plants to be categorized as Ni accumulators (Reeves et al., 2018).

Belimbing bajo (*Sarcotheca celebica*) is a type of wild fruit plant that is always found growing around nickel mining sites in Sulawesi. It is classified as a fruit with acidic properties and is often found growing in areas with ultrabasic soil rich in iron and nickel (Pitopang 2011). Observations of the leaf tissue structure of belimbing bajo reveal high nickel accumulation, illustrating how belimbing bajo adapts to nickel-contaminated environments through specific strategies (Haruna et al., 2018). Bajo starfruit can support the utilization of native wild plants that grow and are available in nickel-contaminated environments (Haruna et al., 2018).

Table 4 shows that only *Sarcotheca celebica* has a BCF value between 0.1 and 1, therefore this plant is the only plant categorized as a moderate accumulator. Thirteen other species (*Knema matanensis, Pluchea carolinensis, Gymnostoma sumatrana, Justicia gendarusa, Dioscorea bulbifera, Brosimum* sp, *Calamus manan*, and *Pterophylla fraxinea* D. Don) have BCF values ranging from 0.0111 to 0.0755, meaning they belong to the low accumulator group, while the last 18 plant species (*Dracaena* sp, *Ficus maclellandii, Dicranopteris linearis, Erythrina subumbrane, Neolamarckia cadamba, Alstonia macrophylla, Dyera polyphylla, Pteridium aquilinum, Timonius flavescens, Terminalia catappa, Metaxya rostrata, Machaerina mariscoides, Melicope borbonica, Scleria lithosperma, Mitragyna speciosa, Schizostachyum brachycladum, Gluta renghas, Pouteria sapote*) are categorized as non-accumulators because their BCF values are less than 0.01. The plant species with the lowest BCF value is *Pouteria sapote* (Table 4).

Conversely, the 18 species at the bottom of the indicator table show nickel concentrations below 50 mg kg^{-1} and BCF values less than 0.01, a range commonly found in non-metallophytic plants in environments with high nickel content (Vischetti et al., 2022). Nevertheless, the presence of species such as *Ficus maclellandii* and

Dicranopteris linearis remains important, as their root systems contribute to the stability of mine land surfaces and erosion mitigation, which are vital components of sustainable revegetation approaches (Zhou et al., 2024).

Overall, the observed pattern supports findings in the literature stating that nickel hyperaccumulators are very rare and generally originate from endemic taxa growing in ultrabasic soils (Kikis et al., 2024). The data in this table underscore the potential of *Sarcotheca celebica, Knema matanensis, Pluchea carolinensis, Gymnostoma sumatrana*, and *Justicia gendarusa* as key species in Indonesia's phytomining initiatives, while emphasizing the importance of a mixed approach involving both moderate accumulators and non-accumulators to balance the objectives of metal extraction, land rehabilitation, and post-mining ecosystem stability.

Table 4. Average Nickel Content and Bioconcentration Factor (BCF) Values of Plants

Species Name	Ni (mg/kg)	BCF	Indicators (g/g)
Sarcotheca celebica	944.93	0.1421	Medium accumulator
Knema metanensis	501.95	0.0755	Low accumulator
Pluchea carolinensis	363.26	0.0546	Low accumulator
Gymnostoma sumatrana	306.5	0.0459	Low accumulator
Justicia gendarusa	230.91	0.0418	Low accumulator
Dioscorea bulbifera	195.55	0.0354	Low accumulator
Brosimum sp.	177.19	0.0314	Low accumulator
Tacca palmata	173.9	0.0424	Low accumulator
Nephentes mirabilis	168.09	0.0253	Low accumulator
Canthium confertum	81.95	0.0200	Low accumulator
Nauclea latifolia	79.33	0.0141	Low accumulator
Melastoma affine	73.66	0.0111	Low accumulator
Calamus manan	72.48	0.0128	Low accumulator
Weinmannia fraxinea	62.76	0.0111	Low accumulator
Dracaena sp.	49.23	0.0076	Non accumulator
Ficus maclellandii	46.65	0.0070	Non accumulator
Dicranopteris linearis	41.35	0.0099	Non accumulator
Erythrina subumbrane	38.32	0.0093	Non accumulator
Neolamarckia cadamba	33.84	0.0051	Non accumulator
Alstonia macrophylla	33.52	0.0059	Non accumulator
Dyera polyphylla	27.09	0.0048	Non accumulator
Pteridium aquilinum	26.39	0.0040	Non accumulator
Timonius flavescens	25.22	0.0038	Non accumulator
Terminalia catappa	23.48	0.0035	Non accumulator
Metaxya rostrata	23.41	0.0041	Non accumulator
Machaerina mariscoides	20.59	0.0037	Non accumulator
Melicope borbonica	18.53	0.0028	Non accumulator
Scleria lithosperma	11.35	0.0020	Non accumulator
Mitragyna speciosa	8.77	0.0021	Non accumulator
Schizostachyum brachycladum	8.07	0.0012	Non accumulator
Gluta renghas	7.58	0.0013	Non accumulator
Pouteria sapota	6.17	0.0011	Non accumulator

In this exploration, at least five species were found to have Ni content of more than 200 ppm (Table 4). Two species, *Sarcotheca celebica, Knema matanensis, Pluchea carolinensis, Gymnostoma sumatrana*, and *Justicia gendarusa*, are known as endemic Ni hyperaccumulators due to their ability to accumulate nickel at high concentrations (van der Ent et al., 2016). However, in this exploration, the Ni content in *Knema matanensis* was less than 1000 ppm, whereas according to the records presented by van der Ent et al. (2013), this species has a Ni content of 2,500–5,000 mg Kg-1. This difference may be due to variations in Ni content in the soil where the plants grow, as the Ni content at this exploration site is only 5,728 ppm, while at other exploration sites it is more than 10,000 ppm (van der Ent et al., 2013). Other species with high Ni accumulation include *Pluchea carolinensis, Gymnostoma sumatrana*, and *Justicia gendarusa*. Among the five species, *Sarcotheca celebica* and *Gymnostoma sumatrana* were only found in one individual at all three sites in Table 1, indicating that the distribution of these species is rare in this area. Several studies have noted that there is no data showing the distribution of *Sarcotheca celebica* in Southeast Sulawesi except on the islands of Kabaena, Tinoleri, and Lamedai Kolaka (Astuti et al., 2018). With the discovery of *Sarcotheca celebica* in North Konawe, even though only one species was found in the sample area, it can be used as a reference for the existence of this species in North Konawe, Southeast Sulawesi.

Conclusion

The exploration conducted in a nickel mining area of CV. Unaaha Bakti Persada in North Konawe, Southeast Sulawesi, successfully identified a total of 32 plant species from 24 families that were adapted to ultramafic soil conditions with very high nickel (Ni) content (average 5,728.27 mg/kg). Based on Ni content in plant tissues in this study, no species was found to reach the minimum threshold of hyperaccumulator plant i.e.: 1,000 mg/kg of Ni in the tissue. The species with the highest Ni accumulation was *Sarcotheca celebica* (944.93 mg/kg), which was classified as a moderate accumulator (BCF 0.1421). Other species with high Ni accumulator were *Knema matanensis, Pluchea carolinensis, Gymnostoma sumatrana, and Justicia gendarusa* which are potential for phytomining activities and post-mining land reclamation in the Southeast Sulawesi region.

Acknowledgments
This research was funded by the Ministry of Education, Research, and Technology, Republic of Indonesia, through the Master's Thesis Research Program scheme. We would like to thank CV. Unaaha Bakti Persada, North Konawe, Southeast Sulawesi, Indonesia, for its support as the exploration area in this research.

Author Contributions
Conceptualization, M. H.; methodology, M. H., G. G; validation, M. H., G. G.; formal analysis, R. A.; investigation, H. H., M. A.; resources, M.H; data curation, S.S.W: writing—original draft preparation, M. M. H. and S.S.W.; writing—review and editing, H.M., G.G., S.S.W.; visualization, H.H, R.A. All authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by the Ministry of Education, Research and Technology, Republic of Indonesia, through the Master's Thesis Research Program scheme.

Conflicts of Interest
The authors declare no conflict of interest.

References

Amir, H., Cavaloc, Y., Crossay, T., Bourles, A., Gensous, S., Lagrange, A., Burtet-Sarramegna, V., & Guentas, L. (2023). Importance and roles of arbuscular mycorrhizal fungi in New Caledonian ultramafic soils. *Botany Letters*, *170*(3), 449–458. https://doi.org/10.1080/23818107.2022.2160808

Aribal, L. G., Marin, R. A., Paquit, J. C., & Zanoria, J. A. (2017). Abundance and Distribution of Arbuscular Mycorrhiza in the Ultramafic Soils of Mt. Kiamo in Bukidnon, Philippines. *International Journal of Scientific Research in Environmental Sciences*, *5*, 36–41. https://doi.org/10.12983/ijres-2017-p0036-0041

Astuti, I. P., Sari, R., Susandarini, R., & Zuhro, F. (2018). *Sarcotheca celebica* Veldkamp: Persebarannya di Sulawesi, Status Konservasi dan Kelangkaan. *Jurnal Biologi Indonesia*, *14*(1), 143–146. https://doi.org/10.47349/jbi/14012018/143

Baker, A. J. M., & Brooks, R. (1989). Terrestrial higher plants which hyperaccumulate metallic elements. A review of their distribution, ecology and phytochemistry. *Biorecovery, 1*(2), 81-126. https://doi.org/10.1080/01904168109362867.

Brearley, F. Q. (2024). Metal hyperaccumulation in the Indonesian flora. *Ecological Research, 39*(6), 957-965. https://doi.org/10.1111/1440-1703.12497

Disinger, H. P., Navarrete Gutiérrez, D. M., Díaz Reyes, A. M., Rodas Duarte, R., Quezada, M. L., van der Ent, A., Baker, A. J. M., Echevarria, G., & Pollard, A. J. (2024). Herbarium and field studies of nickel hyperaccumulator plants from ultramafic soils in Guatemala. *Ecological Research*, *39*(6), 838–851. https://doi.org/10.1111/1440-1703.12495

Earth.org. (2023). *The Environmental Problems Caused by Mining*. Retrieved from https://earth.org/environmental-problems-caused-by-mining/ Accessed on 20th December 2023

Galey, M. L., van der Ent, A., Iqbal, M. C. M., & Rajakaruna, N. (2017). Ultramafic geoecology of South and Southeast Asia. *Botanical Studies*, *58*(1). https://doi.org/10.1186/s40529-017-0167-9

Garnica-Díaz, C., Berazaín Iturralde, R., Cabrera, B., Calderón-Morales, E., Felipe, F. L., García, R., Hechavarría, J. L. G., Guimarães, A. F., Medina, E., Paul, A. L. D., Rajakaruna, N., Restrepo, C., Siebert, S. J., van den Berg, E., van der Ent, A., Velasquez, G., & M. Hulshof, C. M. (2023). Global plant ecology of tropical ultramafic ecosystems. *Botanical Review*, *89*(2), 115–157. https://doi.org/10.1007/s12229-022-09278-2

Gavrilescu, M. (2022). Enhancing phytoremediation of soils polluted with heavy metals. *Current Opinion in Biotechnology*, *74*, 21–31. https://doi.org/10.1016/j.copbio.2021.10.024

Hamim, & Miftahudin. (2023). *Tumbuhan Toleran Logam Berat: Potensinya Untuk Fitoremediasi dan Fitomining*. Bogor: IPB Press.

Haruna, N., Wardiyati, T., Maghfoer, M. D., & Handayanto, E. (2018). Fitoremediasi lahan yang mengalami cekaman logam berat nikel dengan menggunakan tumbuhan endemik belimbing bajo

(*Sarcotheca celebica* Veldk). *Journal TABARO*, *2*(2), 239–246. https://doi.org/10.35914/tabaro.v2i2.133

Herlina, L., Widianarko, B., Purnaweni, H., Sudarno, S., & Sunoko, H. R. (2020). Phytoremediation of lead contaminated soil using croton (*Codiaeum variegatum*) plants. *Journal of Ecological Engineering*, *21*(5), 107–113. https://doi.org/10.12911/22998993/122238

Hilmi, M., Hamim, H., Sulistyaningsih, Y. C., & Taufikurahman. (2018). Growth, histochemical and physiological responses of non-edible oil producing plant (*Reutealis trisperma*) to gold mine tailings. *Biodiversitas*, *19*(4), 1294–1302. https://doi.org/10.13057/biodiv/d190416

Indriyanto. (2006). *Ekologi hutan*. Bumi Aksara.

Indriyanto. (2010). *Ekologi Hutan*. Bumi Aksara.

Kartika, A. D., Pringgenies, D., & Ridlo, A. (2019). Kajian kandungan besi (Fe) dan seng (Zn) pada kerang hijau (*Perna viridis*) di perairan Bandengan, Jepara dan Tanjung Mas, Semarang. *Jurnal Moluska Indonesia*, *3*(April), 5–12. https://doi.org/10.20874/jmi.moluska.2019.3.1.5-12

Kikis, C., Thalassinos, G., & Antoniadis, V. (2024). Soil Phytomining: Recent Developments—A Review. *Soil Systems*, *8*(1). https://doi.org/10.3390/soilsystems8010008

Krebs, C. J. (1989). *Ecological Methodology*. New York: Harper & Row

Lopez, S., Benizri, E., Erskine, P. D., Cazes, Y., Morel, J. L., Lee, G., Permana, E., Echevarria, G., & van der Ent, A. (2019). Biogeochemistry of the flora of Weda Bay, Halmahera Island (Indonesia) focusing on nickel hyperaccumulation. *Journal of Geochemical Exploration*, *202*, 113–127. https://doi.org/10.1016/j.gexplo.2019.03.011

Mabberley, D. J., Pannel, C. M. (1995). *Meliaceae: Flora Malesiana 1* (1st ed.). Leiden: Hortus Botanicus.

Magurran, A. E. (2004). *Measuring Biological Diversity*. Oxford, UK: Blackwell Publishing.

McCartha, G. L., Taylor, C. M., van der Ent, A., Echevarria, G., Navarrete Gutiérrez, D. M., & Pollard, A. J. (2019). Phylogenetic and geographic distribution of nickel hyperaccumulation in neotropical Psychotria. *American Journal of Botany*, *106*(10), 1377–1385. https://doi.org/10.1002/ajb2.1362

Mesjasz-Przybyłowicz, J., & Przybyłowicz, W. J. (2020). Ecophysiology of nickel hyperaccumulating plants from South Africa – from ultramafic soil and mycorrhiza to plants and insects. *Metallomics*, *12*(7), 1018–1035. https://doi.org/10.1039/C9MT00282K

Mou, J., Liu, K., Huang, Y., Lin, J., He, X., Zhang, S., Li, D., Zu, Y., Chen, Z., Fu, S., Lin, H., & Liu, W. (2023). Species Diversity and Community Structure of Macrobenthos in the Cosmonaut Sea, East Antarctica. *Diversity*, *15*(12), 1–13. https://doi.org/10.3390/d15121197

Musfal. (2020). *Kesuburan Tanah dan Teknik Pengujian Status Hara*. Medan: Enam Media.

Nero, B. F. (2021). Structure, composition and diversity of restored forest ecosystems on mine-spoils in South-Western Ghana. *PLoS ONE*, *16*(6), 1–22. https://doi.org/10.1371/journal.pone.0252371

Neto, C., Catarino, A., Sobreiro, J., das Dores, J., Patanita, M., Tomaz, A., & Palma, P. (2024). Effect of Different Irrigated Crop Successions on Soil Carbon and Nitrogen–Phosphorus–Potassium Budget Under Mediterranean Conditions. *Agriculture (Switzerland)*, *14*(11), 1–21. https://doi.org/10.3390/agriculture14111908

Nurjaman, D., Kusmoro, J., & Santoso, P. (2017). Perbandingan Struktur dan Komposisi Vegetasi Kawasan Rajamantri dan Batumeja Cagar Alam Pananjung Pangandaran, Jawa Barat. *Jurnal Biodjati*, *2*(2), 167–179. https://doi.org/10.15575/biodjati.v2i2.1304

Odum, E. P. (1971). *Fundamental of Ecology*. Philadelphia: WB Sounders Company.

Pitopang, R., Lapandjang, I. F. B. (2011). *Profil herbarium celebense dan deskripsi 100 jenis pohon khas Sulawesi*. Palu: UNTAD Press.

Reeves, R. D., van der Ent, A., & Baker, A. J. M. (2018). *Global distribution and ecology of hyperaccumulator plants*. Springer International Publishing. https://doi.org/10.1007/978-3-319-61899-9_5

Rotich, B., Szegi, T., Gelsleichter, Y. A., Fuchs, M., Ocansey, C. M., Phenson, J. N., Abdulkadir, M., Kipkulei, H., Wawire, A., Mutuma, E., Mesele, S. A., Michéli, E., & Csorba, Á. (2025). Variation in soil organic carbon and total nitrogen stocks across elevation gradients and soil depths in the Mount Kenya East Forest. *Land*, *14*(6), 1–17. https://doi.org/10.3390/land14061217

Sarwar, N., Imran, M., Shaheen, M. R., Ishaque, W., Kamran, M. A., Matloob, A., Rehim, A., & Hussain, S. (2017). Phytoremediation strategies for soils contaminated with heavy metals: Modifications and future perspectives. *Chemosphere*, *171*, 710–721. https://doi.org/10.1016/j.chemosphere.2016.12.116

Setyaningsih, L., Wulandari, A. S., & Hamim, H. (2018). Growth of typha grass (*Typha angustifolia*) on gold-mine tailings with application of arbuscular mycorrhiza fungi. *Biodiversitas*, *19*(2), 454–459. https://doi.org/10.13057/biodiv/d190218

She, Y., Li, X., Li, C., Yang, P., Song, Z., & Zhang, J.

(2023). Relationship between species diversity and community stability in degraded Alpine Meadows during bare patch succession. *Plants*, *12*(20), 1–16. https://doi.org/10.3390/plants12203582

Soendjoto, M., Riefani, M., Triwibowo, D., Wahyudi, F., Choirun, D., & Perdana, Y. (2023). Spontaneously growing plants on revegetation sites of former coal mine in South Kalimantan Province, Indonesia. *Biodiversitas Journal of Biological Diversity*, *24*, 1610–1620. https://doi.org/10.13057/biodiv/d240333

Solfiyeni, Rahmayani, H., & Gusmawarni, W. (2023). Vegetation Analysis of sapling and understorey invaded by invasive alien species (IAS) *Bellucia pentamera naudin* in Lembah Harau Sanctuary. *Jurnal Sains Natural*, *13*(3), 115–125. https://doi.org/10.31938/jsn.v13i3.455

Statista. (2023). *Major Countries in Worldwide Nickel Mine Production in 2022*. Retrieved from https://www.statista.com/statistics/272379/major-countries-in-worldwide-nickel-mine-production/

Steenis, C. G. G. V. (1972). *The Mountain Flora of Java*. Leiden: Brill Publishers.

Suazo-Ortuño, I., Lopez-Toledo, L., Alvarado-Díaz, J., & Martínez-Ramos, M. (2015). Land-use change dynamics, soil type and species forming mono-dominant patches: the case of *Pteridium aquilinum* in a Neotropical Rain Forest Region. *Biotropica*, *47*(1), 18–26. Retrieved from https://www.jstor.org/stable/48575161

Taiz, L., Møller, I. M., Murphy, A., & Zeiger, E. (2023). *Plant physiology and development*. https://doi.org/10.1093/hesc/9780197614204.001.0001

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. S. (2015). *Plant Physiology and Development*. Sunderland: Sinauer Associates.

Ullah, A., Heng, S., Munis, M. F. H., Fahad, S., & Yang, X. (2015). Phytoremediation of heavy metals assisted by plant growth promoting (PGP) bacteria: A review. *Environmental and Experimental Botany*, *117*, 28–40. https://doi.org/10.1016/j.envexpbot.2015.05.001

Van der Ent, A., Baker, A. J. M., van Balgooy, M. M. J., & Tjoa, A. (2013). Ultramafic nickel laterites in Indonesia (Sulawesi, Halmahera): mining, nickel hyperaccumulators and opportunities for phytomining. *Journal of Geochemical Exploration*, *128*, 72–79. https://doi.org/10.1016/j.gexplo.2013.01.009

Van der Ent, A., Echevarria, G., & Tibbett, M. (2016). Delimiting soil chemistry thresholds for nickel hyperaccumulator plants in Sabah (Malaysia). *Chemoecology*, *26*(2), 67–82. https://doi.org/10.1007/s00049-016-0209-x

Vischetti, C., Marini, E., Casucci, C., & De Bernardi, A. (2022). Nickel in the environment: bioremediation techniques for soils with low or moderate contamination in European Union. *Environments - MDPI*, *9*(10). https://doi.org/10.3390/environments9100133

Wang, S., Yuan, S., Su, L., Lv, A., Zhou, P., & An, Y. (2017). Aluminum toxicity in alfalfa (*Medicago sativa*) is alleviated by exogenous foliar IAA inducing reduction of Al accumulation in cell wall. *Environmental and Experimental Botany*, *139*, 1–13. https://doi.org/10.1016/j.envexpbot.2017.03.018.

Yang, L., Huang, Y., Lima, L. V., Sun, Z., Liu, M., Wang, J., Liu, N., & Ren, H. (2020). Rethinking the ecosystem functions of *Dicranopteris*, a Widespread Genus of Ferns. *Frontiers in Plant Science*, *11*, 581513. https://doi.org/10.3389/fpls.2020.581513

Zhou, M., Zhu, Q., Wang, H., Wang, X., Zhan, Y., Lin, J., Zhang, Y., Huang, Y., & Jiang, F. (2024). Effect of soil moisture content on the shear strength of *Dicranopteris linearis*-rooted soil in different soil layers of collapsing wall. *Forests*, *15*(3), 1–19. https://doi.org/10.3390/f15030460