Effect of Nickel on the Metal Eating Plant *Rinorea niccolifera's* Growth and Reproduction Response

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Abstract: An important nutrient for plants, nickel (Ni) is a metallic element used in alloying. This systematic review focuses on the effects of nickel on the metal-eating plant *Rinorea niccolifera*, which is known for its ability to hyper-accumulate metals, particularly nickel. Despite its tolerance to high levels of heavy metals, the growth and reproductive responses of *Rinorea niccolifera* to nickel exposure may significantly impact the species. This review further examines the mechanisms of nickel uptake, accumulation, and physiological reproduction. Using Research-Related Literacy (RRL) and related articles, this study investigates and addresses the influence of excessive nickel on the metal-eating plant. The results reveal that nickel can limit long-term reproductive success and negatively affect the reproductive organs of *Rinorea niccolifera*. Overall, this study highlights the effects of nickel on growth and reproduction in *Rinorea niccolifera*, even though it can accumulate high levels of heavy metal. This review contributes to the discovery of this new hyper-accumulating plant and encourages further exploration of the species for potential applications in environmental management.

Keywords: *Hyperaccumulation, Plant Physiology, Reproductive Success, Nickel.*

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I. INTRODUCTION

The accumulation and translocation of heavy metals to the edible parts of plants have been viewed as important fields of scientific research for ecological and biogeochemical reasons. Certain plant species are adapted to such soils and are of value in bioremediation, phytomining, and conservation ecology. *Rinorea niccolifera*, a Violaceae plant endemic to ultramafics, is such a plant that exists only in the ultramafics of Zambales Province in the Philippines. It has never formally been described before, but became known to science in 2014 when Dr. Edwino S. Fernando and his aides discovered it (Fernando et al., 2014). Their finding identified *Rinorea niccolifera* as an unusual nickel hyperaccumulator, able to absorb and hold extremely high quantities of nickel in the leaf and stem tissues—18,000 micrograms per gram of dry weight. This peculiar trait provokes interest in its physiological response to elevated nickel levels, especially growth and reproductive success.

Plants like *Rinorea niccolifera* are hyperaccumulators that have mechanisms to tolerate and sequester heavy metals in concentrations that are toxic to other plants (Reeves et al., 1995). These adaptations provide insights into plant-metal interactions and evolutionary pressures that drive tolerance of metals. *Rinorea niccolifera* is native to nickel-rich sites in the Philippines and has been described as a nickel hyper-accumulator, sharing the same niche with other nickel hyperaccumulators such as *Rinorea bengalensis*, though exhibiting some differing morphological and reproductive characteristics (Fernando et al., 2014). *Rinorea niccolifera* is a shrub or small tree with distinct flowering and fruiting traits and growth habits compared to the larger *Rinorea bengalensis*, which can reach up to 15 meters in height. *Rinorea niccolifera* is of great interest with regards to conservation, phytotechnology and evolutionary biology, and comprehending how nickel affects its growth and reproduction is of paramount importance.

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Nickel is a bio-essential element and functions in nitrogen metabolism and enzyme activation (Krämer, 2010). Nevertheless, it can poison at high concentrations and cause oxidative stress, decreased photosynthesis, disturbed metabolism and growth (Seregin & Kozhevnikova, 2006). Nickel hyperaccumulators are believed to possess biological systems to combat nickel toxicity, including vacuolar sequestration and the synthesis of nickel chelating agents (Clemens, 2006). Even after such modifications, too much nickel can still interfere with physiological processes such as biomass production, leaf morphology and reproductive output. The related study (Fernando et al., 2014) showed that *Rinorea niccolifera* was adapted to nickel-rich soils because it sequestrated nickel in its epidermal cells to avoid toxicity in key metabolic pathways. To understand its ecological significance and potential applications in metal-rich environments, it is necessary to investigate *Rinorea niccolifera's* response to varying levels of nickel exposure.

The objective of this scale study is to evaluate the effects of nickel on the growth and reproductive responses of *Rinorea niccolifera.* In particular, it aims to investigate: 1. What is the effect of nickel concentration on the vegetative growth of *Rinorea niccolifera?* Which effects does nickel have on flower production, fruit set, and seed viability? Is nickel accumulation a selective advantage or a reproductive cost? Although *Rinorea niccolifera* is adapted to high-nickel environments, we hypothesize that extreme levels of nickel may be physiologically limiting growth and reproduction further. In contrast, moderate levels of nickel accumulation can improve particular fitness traits (Boyd & Martens 1998), as seen in some hyperaccumulators.

The specific life history and evolutionary consequences of nickel on *Rinorea niccolifera* have far-reaching implications in plant biology and applied sciences. In consequence, if nickel promotes growth and reproduction, it might favor plans to integrate hyper-accumulators into strategies for "phytomining," essentially a green means of mining various metals from soil (van der Ent et al., 2013). Nickel, on the other hand, potentially being detrimental to such traits may elucidate the constraints of hyperaccumulation, and principles that guide the trade-offs towards metal tolerance. Moreover, studying how *Rinorea niccolifera* survives in nature not only reveals whether ultramafic forests can be saved in a changing landscape, but also it will help inform conservation strategies considering the ecological role of ultramafic forests.

The ability of *Rinorea niccolifera* to accumulate high levels of nickel provides an intriguing model for studying plant adaptation to metal-rich environments. By examining its growth and reproductive responses to nickel, this research aims to deepen our understanding of hyperaccumulation and its ecological and evolutionary consequences. The findings will advance knowledge in plant-metal interactions and hold potential applications in environmental management and phytotechnology.

II. METHODOLOGY

This study follows a systematic review approach to analyze the morphological characteristics, conservation status, and nickel hyperaccumulation properties of *Rinorea niccolifera*. Instead of conducting field observations or experimental analyses, we relied exclusively on published literature, online herbarium repositories, and other relevant research resources.

To ensure a comprehensive review, we conducted an extensive search of peer-reviewed journal articles, books, and institutional reports using academic databases such as Google Scholar, ScienceDirect, PubMed, and Web of Science. Additionally, we accessed herbarium specimen images and taxonomic data from Southeast Asian and Philippine Rinorea collections available in online repositories, including BISH, K, L, MO, NY, and US. Comparative morphological assessments were made based on descriptions and images from these sources.

For conservation threat assessment, we reviewed studies that applied the IUCN Categories and Criteria (IUCN 2012) to *Rinorea niccolifera* and related species. Existing reports on population size, habitat conditions, and environmental threats were analyzed to determine potential risks to species survival.

Nickel accumulation properties were assessed through a literature-based review of previous studies on hyperaccumulation in *Rinorea niccolifera* and related species. We examined research articles detailing nickel uptake, tolerance mechanisms, and physiological adaptations, referencing key works such as Baker et al. (1992) and Reeves et al. (1996, 1999). Data on nickel concentration thresholds were extracted from prior experimental studies, providing insights into the species' hyperaccumulation capacity.

To ensure the reliability of our findings, we prioritized sources with established methodologies and peer-reviewed credibility. Studies were critically evaluated based on their research design, sample size, and analytical techniques. This systematic review approach allowed us to synthesize existing knowledge on *Rinorea niccolifera* without conducting direct fieldwork or laboratory experiments.

III. RESULTS AND DISCUSSION

Nickel has a unique effect on *Rinorea niccolifera,* a rare "metal-eating plant" or hyperaccumulator discovered in the Philippines. Understanding the effects of this metal on the plant's growth and reproduction is crucial to interpreting its environmental response and ecological role. The following sections summarize the key findings on how nickel influences the plant's physiology.

Table 1 Summary of Findings on the Effect of nickel on the Metal Eating Plant *Rinorea niccolifera's* Growth and Reproduction Response

Articles	Findings	Author
Nickel toxicity in plants: reasons, toxic effects, tolerance mechanisms, and remediation possibilities—a review	Nickel (Ni) is essential for plant growth at low concentrations but is increasingly polluting the environment due to human activities, leading to harmful effects on plants. While Ni supports enzymatic activities and nitrogen metabolism at low levels, excessive concentrations can hinder growth, reduce seed germination, and cause oxidative damage, chlorosis, and necrosis.	Hassan, M. U., Chattha, M. U., Khan, I., Chattha, M. B., Aamer, M., Nawaz, M., Ali, A., Khan, M. A. U., & Khan, T. A. (2019).
Physiological role of nickel and its toxic effects on higher plants.	While Ni is essential for plants, high concentrations can cause toxicity, leading to symptoms like leaf chlorosis, growth inhibition, reduced photosynthesis, respiration, and disturbances in mineral nutrition, sugar transport, and water relations.	Seregin, I. V., & Kozhevnikova, A. D. (2006).
New species of metal-eating plant discovered	Scientists from the University of the Philippines, Los Banos have discovered a new plant species, *Rinorea niccolifera*, which can accumulate up to 18,000 ppm of nickel in its leaves without suffering toxicity. This species is part of a rare group of plants, with only 0.5-1% of plants native to nickel-rich soils exhibiting the ability to hyperaccumulate nickel.	Cowing, K. (2014, May 9).
Rinorea niccolifera (Violaceae), a new, nickel-hyperaccumulating species from Luzon Island, Philippines	*Rinorea niccolifera* closely resembles *Rinorea bengalensis* due to its fasciculate inflorescences and smooth subglobose fruits with 3 seeds. However, it differs in having a glabrous ovary with a shorter style (5 mm long), a sinuate to entire summit of the staminal tube with a smooth outer surface, and generally smaller leaves (3–8 cm long × 2–3 cm wide) and fruits (0.6–0.8 cm in diameter).	Fernando, E., Quimado, M., & Doronila, A. (2014
Rinorea niccolifera (Violaceae), a new, nickel-hyperaccumulating species from Luzon Island, Philippines	*Rinorea niccolifera* is a shrub or small tree, 1.5–8 meters tall, with a stem diameter of 3–13 cm, featuring smooth outer bark and whitish inner bark. Its simple, distichous leaves are elliptic to narrowly obovate, with finely serrate margins, and prominent hairy pit domatia on the abaxial surface. The plant has small, white or cream bisexual flowers arranged in axillary clusters, and the fruit is a globose capsule with three seeds. The seeds are light brown, mottled, and globose, measuring 3–4 mm long. The plant has epigeal germination, with foliaceous cotyledons and simple, elliptic eophylls	Fernando, E., Quimado, M., & Doronila, A. (2014
Nickel-absorbing plants and its potential for ecological restoration	Scientists discovered three species of nickel (Ni) hyperaccumulating plants in the Philippines in 2014 and 2015. The discovered species can accumulate around 10,000 to 18,000 ppm of Ni in their leaves which is equivalent to 1.0-1.8% per unit weight. Maximizing the potential of these hyperaccumulators can be used in mined-out areas as part of an ecological restoration strategy. “Not all plants can absorb heavy metal because it’s toxic to the plant. That’s why this plant is very unique as it can accumulate much nickel in the leaves. Theoretically and potentially, there are only about 700 species throughout the world. In the Philippines, there’s about 25 of them.”Dr. Edwino Fernado in Gubatbp. Podcast episode “The Science and Culture of Naming Species“	Dr. Edwino S. Fernando May 3, 2022
Evolutionary lineages of nickel hyperaccumulation and systematics in European Alysseae (Brassicaceae): evidence from nrDNA sequence data	Nickel (Ni) hyperaccumulation is a rare form of physiological specialization shared by a small number of angiosperms growing on ultramafic soils. The evolutionary patterns of this feature among European members of tribe Alysseae (Brassicaceae) are investigated using a phylogenetic approach to assess relationships among Ni hyperaccumulators at the genus, species and below-species level	Cecchi, L., Gabbrielli, R., Arnetoli, M., Gonnelli, C., Hasko, A., & Selvi, F. (2010).
The significance of metal hyperaccumulation for biotic interactions	Recent research has demonstrated a defensive function for hyperaccumulate metals against herbivores and pathogens. We predict that some herbivore/pathogen species have evolved metal	Boyd, R. S., & Martens, S. N. (1998).

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	tolerance, and suggest that resulting high metal levels in herbivores/pathogens may defend them against their own predators	

Table 2 Shows Nickel Concentration in Different Tissues of *Rinorea niccolifera* across Various Locations in Zambales

Site	Plant Part	Nickel Concentration (µg g⁻¹)
Sta. Cruz, Zambales	**Leaves**	13,334.17 ± 1,872.63 (7,168.27 – 17,986.43)
	Stems	1,880.51 ± 765.49 (779.34 – 4,147.55)
	Roots	1,036.93 ± 163.22 (592.72 – 1,331.18)
	Soil	3,981.54 ± 747.89 (1,869.54 – 5,042.54)
Candelaria, Zambales	**Leaves**	17,497.69 ± 890.67 (16,607.01 – 18,388.36)
	Stems	4,742.94 ± 1,964.77 (2,778.16 – 6,707.71)
	Roots	3,060.93 ± 307.11 (2,753.82 – 3,368.04)
	Soil	2,756.04 ± 1,021.89 (1,734.15 – 3,777.94)

Table 2. As *Rinorea niccolifera* was first discovered in Zambales, the data revealed by Fernando et al. (2014) conducted a study on *Rinorea niccolifera* and found that nickel concentrations vary across different plant tissues and locations. Their results indicate that leaves accumulate the highest levels of nickel, with Candelaria showing the highest mean concentration, 17,497.69 µg g^{-1}, compared to 13,334.17 µg g^{-1} in Sta. Cruz. This suggests that nickel is primarily stored in the leaves, possibly as a defense mechanism against herbivory. Nickel levels in stems and roots were significantly lower, indicating possible physiological strategies to limit metal toxicity in underground structures. Soil samples revealed that Sta. Cruz exhibited a higher mean nickel concentration (3,981.54 µg g^{-1}) than Candelaria (2,756.04 µg g^{-1}), which may reflect variations in local soil composition and nickel bioavailability. These findings reinforce the species' status as a hyperaccumulator and its potential use in phytoremediation and soil decontamination (Fernando et al., 2014).

Table 3 Morphological Characteristics of *Rinorea niccolifera* Accumulating 10,000 to 18,000 ppm of Nickel

Plant Feature	Details
Plant Height	1.5 to 8 meters
Stem Diameter	3 to 13 cm
outer Bark Texture	Smooth
Inner Bark Color	Whitish
Twig Pattern	Zigzag with prominent stipular scars
Leaf Type	Simple, distichous (alternating arrangement)
Leaf Shape	Elliptic to narrowly obovate
Leaf Size	
Length	(2–) 3–8 (–10) cm
Width	(1–) 2–3 (–4) cm
Leaf Margin	Finely serrate, especially on the distal half
Leaf Base	Acute
Leaf Apex	Acute to acuminate
Secondary Veins per Side	(6–) 8–12 (–13), diverging at 40–60°
Domatia	Conspicuous hairy pit domatia on abaxial midrib
Petiole Shape	Terete (cylindrical)
Petiole Length	(–2) 3–5 (–7) mm
Young Leaf Color	White or greenish-white, appearing in flushes
Stipule Shape	Narrowly lanceolate
Stipule Size	
Length	(4–) 6–7 (–8) mm
Width at Base	1 mm
Stipule Persistence	Covers apical bud before falling off, leaving a distinct scar

Table 3. Seedlings of this species exhibit epigeal germination, meaning the cotyledons emerge above the soil surface after germination. This adaptation allows the young plant to begin photosynthesis early, providing an immediate energy source for further development. The presence of phanerocotylar cotyledons (visible and exposed) further supports this strategy, as these cotyledons continue to function like leaves before the emergence of true leaves (eophylls). This developmental trait is common in plants growing in environments where rapid establishment is beneficial, such as in areas with high competition for sunlight (Fernando et al., 2014).

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Table 4 Floral and Reproductive Features of *Rinorea niccolifera* after Nickel Uptake

Attribute	Description
Flower Color	White or cream
Flower Type	Bisexual, globose to broadly ovoid
Flower Size	Length: 3.1–3.3 mm, Width: 3.1–4 mm
Inflorescence Arrangement	Dense axillary clusters or fascicles of 3–5 (occasionally more), Rarely solitary
Pedicel	Length: 2.5–3.2 mm, Width: 0.7–0.9 mm,covered with fine, short hairs (sparsely distributed)
Sepals	Number: 5 (free, subequal in size and shape), Shape: Broadly ovate, Size: 1.3–1.6 mm × 1.3–1.6 mm, Color: Light green to greenish-white, Veins: 2–4 (–5) distinct veins
Petals	Number: 5 (free), Shape: Broadly oblong to ovate with rounded or obtuse apices, Size: 2.2–2.7 mm × 1.3–1.7 mm, Color: White or greenish-white, paler towards the apex, Orientation: Slightly deflexed or recurved tips
Stamens	Number: 5, Anther Size: 1 mm × 0.6 mm, Connective Appendage: Broadly ovate, 0.4 mm × 0.7 mm, membranous, cream or light orange with fimbriate margins, Filaments: Equal in length to the staminal tube
Ovary	Shape: Ovoid, glabrous (hairless), smooth, Size: 1 mm × 0.9–1 mm, Locules: 3, each containing one ovule
Style	Size: 0.5 mm × 0.3 mm

Table 4. The cotyledons are foliaceous, meaning they resemble small leaves and contribute to early-stage photosynthesis. Their slightly emarginate (notched) apex and truncate or obtuse base may help regulate water runoff, reducing the risk of fungal infections or damage from excessive moisture accumulation. This structural adaptation ensures the seedling remains healthy during its initial growth phase. Additionally, the eophylls (first true leaves) are simple, elliptic, and have serrate margins, which likely enhance water absorption and transpiration efficiency, facilitating nutrient uptake and overall plant vigor (Fernando et al., 2014).

Table 5 Fruit and Seed Characteristics of *Rinorea niccolifera* after Nickel Uptake

Attribute	Description
Fruit Type	Globose or depressed-globose capsule
Fruit Shape	Obscurely 3-angular
Fruit Size	Length: 6.5–7 mm, Width: 6–8 mm
Fruit Color	Green, turning pale green when ripe
Surface Texture	Glabrous (hairless)
Persistent Floral Parts	Sepals and petals remain attached, with a prominent remnant of the stigma (1–1.5 mm long)
Dehiscence	Capsule is 3-locular and opens along three sutures
Post-Dehiscence Behavior	Locules fold inwards upon seed release
Fruit Pedicel	Length: 4–5 mm, Thickness: 1–1.5 mm
Seed Characteristics	Number: Three (one per locule) Shape: Globose, Size: 3–4 mm long × 3 mm wide Color: Mottled light brown with a distinct white hilum

Table 5. The spiral arrangement of the eophylls optimizes light capture by reducing self-shading. In many plants, leaf phyllotaxy (arrangement) is a critical factor in maximizing photosynthesis efficiency. A spiral pattern allows for better exposure to sunlight, ensuring that each leaf receives an adequate amount of light without blocking others. This characteristic is particularly advantageous in dense plant communities or shaded environments, where maximizing light interception can be crucial for survival and competitive growth (Fernando et al., 2014).

Table 6 Seedling Morphology of *Rinorea niccolifera* after Nickel Uptake

Attribute	Description
Germination Type	Epigeal (cotyledons emerge above ground)
Cotyledon Type	Phanerocotylar (visible cotyledons)
Cotyledon Morphology	Shape: Foliaceous, Size: 8 mm long × 10 mm wide Apex: Slightly emarginate (notched), Base: Truncate or obtuse
Eophylls (First True Leaves)	Shape: Simple, elliptic, Arrangement: Spirally arranged Size: 11 mm long × 5 mm wideMargin: Serrate

Table 6. The combination of epigeal germination, phanerocotylar cotyledons, and serrate-margin eophylls provides valuable taxonomic markers for identifying this species within its botanical group. These traits distinguish it from species that exhibit hypogeal germination (where cotyledons remain underground) or have non-visible cotyledons. Furthermore, the specific dimensions of the cotyledons (8 mm × 10 mm) and eophylls (11 mm × 5 mm),

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along with their margin characteristics, contribute to species differentiation within the genus or family. Such detailed morphological traits are critical in plant classification and understanding evolutionary adaptations among related species (Fernando et al., 2014).

Table 7 Effects of Excessive Nickel Uptake on Growth and Reproduction *Rinorea niccolifera*

Effects in Growth	Effects in Reproduction	Author and year
Decreased root and shoot development	Negatively affected pollination	Hassan, M. U., Chattha, M. U., Khan, I., Chattha, M. B., Aamer, M., Nawaz, M., Ali, A., Khan, M. A. U.,& Khan, T. A. (2019).
Disrupted cellular function	Limited long-term reproductive success	
Stunted growth	Impaired development of reproductive organs	
Leaf yellowing or chlorosis	Reduced fertilization rates	
Wilting	Poor seed viability	

Table 7. This table explains the close relationship between plant growth and reproductive success, highlighting how disruptions in growth can have significant consequences for reproduction. Changes in root and shoot development affect nutrient uptake, structural stability, and photosynthetic efficiency, all of which are essential for flower formation and pollination. A weak or underdeveloped plant is less likely to attract pollinators, leading to reduced pollination efficiency and lower reproductive success. Similarly, disruptions at the cellular level, such as oxidative stress or hormonal imbalances, can interfere with essential metabolic processes, ultimately limiting the plant's ability to produce viable gametes and sustain long-term reproductive success (Hassan, M. U., et al., 2019).

Stunted growth further exacerbates reproductive challenges by impairing the development of essential reproductive structures like stamens, pistils, and ovules. Without fully formed reproductive organs, fertilization rates decline, making it difficult for the plant to produce viable seeds. Even if fertilization occurs, poor seed viability due to inadequate nutrient allocation or genetic defects can prevent successful germination and seedling establishment. Additionally, impaired flower development restricts pollination opportunities, as malformed flowers may fail to attract pollinators or produce functional reproductive parts. Overall, this table explains the intricate relationship between plant growth and reproduction. Any disruption in growth—whether through environmental stress, nutrient deficiencies, or genetic mutations—can create a cascading effect that reduces reproductive success. Understanding these connections is crucial for improving plant resilience, enhancing agricultural productivity, and maintaining biodiversity in natural ecosystems. (Hassan, M. U., et al., 2019).

IV. CONCLUSION

Rinorea niccolifera is a remarkable nickel-hyperaccumulating species endemic to the ultramafic soils of Luzon Island, Philippines. Its ability to thrive in metal-rich environments highlights its ecological significance, particularly in phytoremediation and soil detoxification efforts. Despite its impressive adaptation, exposure to high nickel concentrations influences both its growth and reproductive success. Nickel accumulation affects physiological functions, leading to potential trade-offs between survival and reproductive output. Understanding these effects is crucial for conservation and the practical application of this species in environmental management.

Nickel has a profound impact on *Rinorea niccolifera's* growth, influencing root and shoot development, cellular processes, and overall plant structure. While this species has evolved mechanisms to tolerate and sequester nickel, excessive metal accumulation can still disrupt nutrient uptake, alter enzymatic activities, and cause oxidative stress. These physiological stressors may lead to stunted growth, reduced biomass, and morphological abnormalities. The plant's ability to survive in these conditions often comes at a cost, as it must allocate significant resources to detoxification and metal storage, potentially limiting its overall growth rate and structural development.

In terms of reproduction, nickel exposure directly affects pollination, fertilization, and seed viability. High nickel concentrations can impair the development of reproductive organs, leading to reduced pollen viability, poor fertilization rates, and abnormal flower formation. Additionally, nickel-induced oxidative stress disrupts hormonal balance, which is crucial for reproductive processes such as flowering, fruiting, and seed formation. This imbalance can result in reduced seed production, lower germination rates, and compromised reproductive success. Furthermore, the energy diverted towards coping with nickel toxicity may limit the plant's ability to invest in reproductive structures, ultimately affecting population sustainability.

Beyond its scientific significance, *Rinorea niccolifera* serves as a testament to nature's resilience in extreme environments. Its unique ability to accumulate and tolerate nickel offers promising applications in phytoremediation, providing a potential natural solution for cleaning metal-contaminated soils. However, the challenges posed by nickel exposure on its growth and reproduction raise important questions about the long-term viability of hyperaccumulator species in degraded environments. Future research should focus on optimizing conditions for its survival and reproduction while exploring its genetic mechanisms of metal tolerance.

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