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Bioremediation potential of *Canna indica* plants through nickel and zinc accumulation in contaminated soils

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Abstract

This study aimed to determine whether banana male plantlets could remediate contaminated soils by absorbing and retaining zinc (Zn) and nickel (Ni), two elements that are often used in phytoremediation. Bioconcentration factor in roots (BCF1), shoots (BCF2), bioaccumulation coefficient (BAC), and translocation factor (TF) were calculated. Available Ni and Zn in soil increased proportionally with addition level but remained within FAO/WHO permissible limits in most treatments. BCF_2 sapace Ni accumulated predominantly in roots and stayed mostly below acceptable levels, Zn accumulated more in shoot tissues (particularly leaves), surpassing allowed limits at the highest addition level (T4). Root metal uptake was verified by BCF1 values for both metals. The results revealed that Zn was more efficiently translocated to the shoots than Ni, with greater BCF2, BAC exceeded 1 in several treatments, and TF values. Transfer from roots to shoots was weak in Ni. With its ability to efficiently absorb and store Ni and Zn, as well as its high effectiveness in transporting Zn to shoot tissues, the banana male plant is an attractive option for phytoremediation, especially in soils that are contaminated with Zn. However, since leaves accumulated high Zn concentrations proper post-harvest biomass management is important.

Keywords: Nickel (Ni); Zinc (Zn); *Canna indica* plant; Phytoremediation; Bioremediation; Heavy metal accumulation.

Introduction

Heavy metals significantly affect on soil fertility and plant growth. Zinc (Zn) and Nickel (Ni) are two essential trace metals for plant metabolism and overall health. Industrial and agricultural activities, such as the use of mineral fertilizers, chemical pesticides, and contaminated water for irrigation, may increase natural concentrations of these elements to potentially harmful levels. Plant health and crop yields may suffer when these elements accumulate. To comprehend the dynamics of soil-environment-plant interactions in agricultural systems, it is increasingly crucial to study the impacts of these factors on plants and how they accumulate [1].

Zinc, a structural and functional component of several enzymes and proteins, is essential for many plant functions, such as photosynthesis, chlorophyll formation, and glucose transport.

It improves plant tolerance to biotic and abiotic stressors, such as drought and salinity, and is crucial for root, stem, and leaf growth. According to [2], plants have stunted development, leaf chlorosis, reduced flowering, and reduced fruit yield when zinc levels are too low, whereas toxic effects on plant tissues are seen when zinc levels are too high.

Although nickel (Ni) is only needed in minimal levels, it has a major impact on plant development because it is involved in the urease enzyme's function, which turns urea into ammonium nitrogen that plants may use. This enhances nitrogen metabolism, which in turn promotes root and shoot development and better seed germination. A deficiency of nickel prevents the development of roots and slows down plant growth, whereas an excess of nickel damages cells and inhibits metabolism [3].

Soil pH, organic matter content, and exchangeable cation composition are three soil factors that affect zinc and nickel absorption. Acidic soils increase Zn solubility than those that are alkaline, and vice versa. Aside from nickel's ionic speciation and competition with elements like iron and cobalt, the following factors impact its consumption [1]

It becomes increasingly obvious that heavy metals have a negative effect on food safety and nutritional value when they accumulate in crops. Crops that are very rich in Zn or Ni can be endangering animals and people equally. From seed germination to flowering and fruit or seed production, researchers must study the impacts of each metal at every stage of plant development in order to develop environmentally friendly agricultural techniques that decrease pollution without losing crop quality or yield [3].

Keeping soil concentrations of trace metals steady is important because changes in Ni or Zn levels might disrupt plant biochemical responses. An example of a situation where an excess of Ni might cause secondary shortages is if it blocks the absorption of Zn and Fe. The converse is also true. Soil fertility, plant resistance to stress, and harvest quality and quantity may all be improved by keeping an eye on and adjusting these elements' concentrations [2].

When compared to other plant species, the banana male plantlets has an exceptional capacity to absorb heavy metals. It can retain a large quantity of trace and heavy elements in its tissues, and it grows so quickly. Researching the phytoremediation potential of this plant and understanding how it accumulates Ni and Zn might contribute to the remediation of metal-contaminated soils as well as agricultural and environmental sustainability.

Materials and Methods

The experiment, which was conducted as part of the Al-Mussaib Agricultural Project, started on 14 April 2025 and continued for three months in a lath house at the Al-Mussaib Technical College. In order to get the soil ready for planting, it was taken from the top 0-30 cm layer of the experimental site, dried in the air, pounded with a wooden hammer, and then passed through a 4-mm screen [4]. Each container was then filled with twenty kg of soil.

At quantities of 0, 10, 20, 40, and 60 mg kg^{-1}, Ni and Zn were added to the soil in separate sulfate solutions. The gravimetric method was used to regulate the moisture levels for one week while we mixed the soils with the solutions. After that, The soils were allowed to equilibrate. Two weeks after planting, the banana male plantlets were trimmed down to a single plant per pot. After the available water had been depleted by around 35%, the soil was maintained at field capacity by irrigation using river water, and chemical fertilizers (NPK) were added at the required rates.

In preparation for physical and chemical analysis, soil samples were taken prior to planting, let to air dry, then sieved through a 2-mm screen and stored in plastic containers.

At the end of the experiment, soil samples were obtained to determine the available concentrations of Ni and Zn. Plant samples (roots and shoots, with stems separated from leaves) were collected from each experimental unit.

Plant tissues were washed with tap water followed by distilled water, air-dried, and then oven-dried at 65 °C until constant weight. Dried samples were ground with a wooden hammer, homogenized, passed through a 0.5-mm sieve, and stored in plastic containers. Nickel and zinc concentrations were determined using Atomic Absorption Spectrophotometry (AAS). At the end of the experiment, plant height and dry biomass were recorded to assess the effects of metal accumulation on the growth of the banana male plant.

Table (1): Selected physico-chemical properties of the soil before planting

Property	Value	Unit
pH	7.65	–
Electrical conductivity (ECe)	3.08	$dS \cdot m^{-1}$
Organic matter	1.5	%
Cation exchange capacity (CEC)	18.7	$cmol(+) \cdot kg^{-1}$ soil
Bulk density	1.45	$g \cdot cm^{-3}$
Carbonate minerals	272.5	$g \cdot kg^{-1}$
Calcium sulfate	4.5	$g \cdot kg^{-1}$
Available Ni	0.05	mg kg^{-1}
Available Zn	0.18	mg kg^{-1}
Total Ni	6.9	mg kg^{-1}
Total Zn	4.73	mg kg^{-1}
Sand	**489.5**	**g kg^{-1}**

Silt	376.2	g kg^{-1}
Clay	134.3	g kg^{-1}
Texture	Loam	–

Plant Contamination Indices

To evaluate the ability of the *Canna indica* plant to absorb and accumulate nickel and zinc from the soil, a set of commonly adopted phytoremediation indices were used as follows:

1) Root Bio-concentration Factor (BCF_1) [5]

$$BCF_1 = \frac{(Metal)_{Root}}{(Metal)_{Soil}}$$

Where:

- BCF_1= Bio-concentration factor in roots
- (Metal)_Root = Metal concentration in root tissues (mg kg^{-1} dry weight)
- (Metal)_Soil = Total metal concentration in soil (mg kg^{-1})

A BCF value>1 indicates a high ability of the plant to absorb and accumulate the metal in its tissues, whereas values<1 reflect limited uptake capacity.

2) Whole-plant Bio-concentration Factor (BCF2)

$$BCF_2 = \frac{(Metal)_{Plant}}{(Metal)_{Soil}}$$

Where:

- BCF2 = Bio-concentration factor for the whole plant (root + shoot)
- (Metal)_Plant = Metal concentration in the whole plant (mg kg^{-1} dry weight)
- (Metal)_Soil = Total metal concentration in soil (mg kg^{-1})

3) Bio-Accumulation Coefficient (BAC) [6]

$$BAC = \frac{(Metal)_{Shoot}}{(Metal)_{Soil}}$$

Where:

- BAC = Bio-accumulation coefficient
- (Metal)_Shoot = Metal concentration in shoot tissues (mg kg^{-1} dry weight)
- (Metal)_Soil = Total metal concentration in soil (mg kg^{-1})

4) Translocation Factor (TF) [6]

$$TF = \frac{(Metal)_{Shoot}}{(Metal)_{Soil}}$$

Where:

- TF = Translocation factor
- (Metal)_Shoot = Metal concentration in shoot tissues (mg kg^{-1}dry weight)

(Metal)_Root = Metal concentration in root tissues (mg kg^{-1} dry weight)

Results and Discussion

At the end of the experimental period, the available concentrations of Ni and Zn in the soil were measured for all treatments. A significant increase in the availability of Ni and Zn was seen as the application rate rose, and there were notable variances among the mean concentrations across the various addition levels. The direct correlation between the amount of metal applied and the residual buildup in soil is shown by these results.

Zn concentrations were always greater than Ni concentrations in all treatments, except for the control treatment (T_0), when both metals were at their lowest. The fact that the Zn concentration reached 2.62 mg kg⁻¹ at the highest addition level indicates that Zn is more soluble and mobile in soil compared to Ni. Zn is more bioavailable than nickel because of its mobility and accessibility, whereas nickel's bioavailability is reduced because of fixation or adsorption onto soil minerals. This variance is produced by the metals' interactions with the soil. Our findings corroborate those of previous studies showing that soils become more accessible to heavy metals at greater application amounts. Because of their effects on adsorption and precipitation, soil chemical characteristics such as pH and carbonate concentration govern the patterns of accumulation. The available Ni and Zn quantities were much lower than the global permissible limits, according to [7] regulations.

These results indicate that that the levels of addition used in this investigation were completely safe for the environment and did not lead to metal pollutionbeyond internationally accepted limits.

Table (2): Available concentrations of nickel and zinc (mg kg^{-1}) in the soil after the experiment.

Treatment	Ni (mg kg^{-1})	Zn (mg kg^{-1})
T0	0.05	0.19
T1	0.11	0.35
T2	0.29	0.7
T3	0.57	1.21
T4	1.11	2.62
Mean	0.426	1.014
$LSD_{0.05}$	0.41	0.11

Heavy Metals in Leaves

Table (3) shows that the contents of zinc and nickel in the tissues of the leaves varied significantly with application level. Treatment T_4 resulted in the greatest quantities of both metals, reaching 22.45 mg Ni per kg^{-1} dry weight and 18.32 mg Zn per kg^{-1} dry weight, while the control treatment T_0 showed very low concentrations, measuring just 0.00 mg kg^{-1}dry weight.

The linear relationship between addition level and Ni and Zn concentrations demonstrates that soil element availability positively corresponds with plant absorption capabilities. The results are consistent with [8], who discovered that soil availability primarily affects the accumulation of heavy metals in plants, and that higher concentrations in plant tissues are often linked to larger soil bioavailable fractions. [9] demonstrated that soils with a neutral to alkaline pH and a high carbonate content affect Zn absorption more strongly than Ni, which may explain why this investigation reported enhanced Ni accumulation at higher addition amounts. Accordingly, the transfer of metals from soil to plants is greatly influenced by the soil's chemical characteristics.

Ni and Zn concentrations in leaves were found to be below the internationally permitted limits defined by [7]. These limits state that the dry weight of Ni in leafy tissues should not exceed 30 $mg \cdot kg^{-1}$ and the dry weight of Zn should not exceed 40 $mg \cdot kg^{-1}$. The results show that the experimental addition rates were within the acceptable limit for environmental safety.

In addition, the current study's findings are in agreement with those of [10], who found that metal-accumulating plant species exhibit variable capacities for accumulating individual elements. Specifically, they found that in carbonate-rich soils, Ni accumulation in leaves is often greater than Zn accumulation.

Table (3): Nickel and zinc concentrations ($mg \cdot kg^{-1}$ dry weight) in leaves after the experiment.

Treatment	Ni ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)
T0	0	0
T1	5.015	3.98
T2	8.95	6.541
T3	14.987	11.198
T4	21.785	17.925
Mean	10.147	7.928
$LSD_{0.05}$	10.375	8.361

Heavy Metals in Stems

Table (4) shows that the amounts of zinc and nickel in the stem varied significantly among the treatments. When compared to the other treatments, the metal accumulation was greatest in treatments T2, T3, and T4. Zinc concentrations were 9.021, 12.056, and 17.213 mg Zn per kg^{-1} dry weight for the same treatments as nickel concentrations of 9.143, 15.675, and 21.568 mg Ni per kg^{-1}dry weight for T2, T3, and T4, respectively. The values that were observed as lowest in the control treatment (T0) were 0.00 $mg\ kg^{-1}$ dry weight.

There are a number of reasons why Ni and Zn contents in stems rise with increasing addition levels: (1) Soil supplementation increases metal availability, which roots can absorb more readily; (2) In metal-accumulating plant species, there is a positive correlation between soil concentration and tissue accumulation; (3) Element specificity, for example, Zn is more rapidly translocated to leaves than Ni, which means that nickel stays in a more absorbable form in plant tissues for longer.

Table (4): Nickel and zinc concentrations (mg kg^{-1} dry weight) in stems after the experiment.

Treatment	Ni (mg kg^{-1})	Zn (mg kg^{-1})
T0	0	0
T1	7.067	4.689
T2	9.143	9.021
T3	15.675	12.056
T4	21.568	17.213
$LSD_{0.05}$	2.583	2.626
Mean	10.69	8.595

It is clear from comparing the metal concentrations in stems and leaves (Table 3) that: Nickel accumulated more in stems than in leaves, suggesting that its movement throughout plant tissues was significantly slower.

The rapid redistribution of zinc throughout the plant was shown by its increased mobility towards the leaves, where concentrations were higher than in the stems. These findings are consistent with previous studies. The amount of heavy metals in the soil correlates directly with the rate at which these metals accumulate in plant tissues, according to [11]. The pattern of translocation is determined by the element's chemical properties and the characteristics of the soil. Similarly, [12] demonstrated that heavy metals move through plants in distinct ways; for example, zinc is more readily translocated to the aerial parts, whereas nickel accumulates in the stem prior to reaching the leaves. From these studies, it is evident that soil metal availability and plant chemical physiology play significant roles in determining the distribution of heavy metals throughout plant organs. This study's results also show that soil availability follows the same pattern as accumulationin stems, with nickel being higher than zinc. For the purpose of assessing the effectiveness of phytoremediation techniques and the consequences of contaminated soils on plant growth and human health, this direct relationship highlights the association between soil metal concentrations and plant absorption efficiency.

Heavy Metals in Roots

Table (5) shows that the quantities of zinc and nickel in the roots varied significantly between the treatments.

The accumulation quantities were highest for treatments 2, 3, and 4, in compared with the other treatments. The concentration of nickelwas 11.920 mg Ni per kg^{-1}dry weight for T2, 19.265 mg Ni·kg^{-1}dry weight for T3, and 27.013 mg Ni per kg^{-1}dry weight for T4, in that order. A zinc content of 4.024, 5.986, and 9.543 mg Zn per kg^{-1}dry weight was observed in the corresponding treatments. In the control treatment (T0), the lowest values were observed, which were 2.001 mg Ni and 0.500 mg Zn per

kg^{-1}dry weight. An increase in the amounts of soil addition causes an increase in the concentrations of Ni and Zn in the roots, indicating preferential accumulation in roots to absorb and store metals before they are transferred to other portions of the plant, such the stems and leaves. This pattern shows that Zn is more mobile toward the aerial portions of plants, whereas Ni is more likely to concentrate in the roots. All of the metals' known chemical behaviors and transport capabilities inside plant tissues are consistent with our results.

Table (5): Nickel and zinc concentrations (mg kg^{-1} dry weight) in roots after the experiment.

Treatment	Ni (mg kg^{-1})	Zn (mg kg^{-1})
T0	2.001	0.5
T1	4.989	2.011
T2	11.92	4.024
T3	19.265	5.986
T4	27.013	9.543
$LSD_{0.05}$	12.639	4.287
Mean	13.036	4.412

The following trends are discernible when examining the metal concentrations in roots, stems, and leaves (Tables 3 and 4), respectively: Due to its low mobility, Ni primarily accumulates in roots rather than in stems or leaves. Zn is more mobile and occurs in higher concentrations in stems and leaves, suggesting rapid translocation to aerial parts, while its root concentration is lower. These findings are supported by prior research. Higher concentrations of soil-available metals cause roots to store more of the element, and plants move Ni more slowly than Zn, according to [9] and [13]. The possibility of heavy metal accumulation in roots is determined by the soil's characteristics and the chemical makeup of the metal, say (Seid and Azita, 2008). Ni, not Zn, is the element that roots are most likely to retain. In a similar vein, [10] demonstrated that roots serve as a plant's primary metal storage mechanism, with increasing root accumulation being associated with increased soil metal availability. According to these results, the sequence of metal accumulation in roots is as follows: Ni>Zn.

Since this pattern reveals that zinc is more mobile than Ni, it is useful for evaluating the effects of contaminated soils on plant physiology and food safety.

Heavy Metals in the Whole Plant (Ni and Zn)

According to the data shown in Table 6, the concentrations of Zn and Ni in plants differed significantly among treatments. For the same treatments, whereas Ni concentrations were 18.055 and 25.680 mg Ni per kg^{-1} dry weight, respectively, at the higher addition levels (T3 and T4), Zn concentrations were 6.110 and 8.988 mg Zn per kg^{-1} dry weight. The Zn level in the control treatment (T0) was 0.700 mg Zn per kg^{-1} dry weight, in contrast. Since Ni and Zn are more easily soluble in soil at high addition levels, plants may take up more of these metals via root absorption, translocation, and aggregation in stems and leaves. The pattern seen here represents the relationship between the amount of heavy metals present in the soil and the amount that plants accumulate.

These results are consistent with [14], these results show that the amount of bioavailable metals in the soil determines the rate of heavy metal accumulation in plants.

Table (6): Ni and Zn concentrations (mg kg^{-1} dry weight) in the whole plant after the experiment.

Treatment	Ni (mg kg^{-1})	Zn (mg kg^{-1})
T0	1.901	0.7
T1	3.599	1.623
T2	12.22	2.457
T3	18.557	6.11
T4	25.68	8.988
$LSD_{0.05}$	12.639	4.287
Mean	12.669	4.297

All Zn concentrations stayed under the acceptable threshold (≤ 40 mg Zn per kg^{-1} dry weight), suggesting safe levels with regard to Zn accumulation, when the Ni and Zn concentrations in plant tissues were compared with the globally authorized limits [7]. It seems that the plant could store Ni without experiencing any negative physiological effects, as the amounts in the higher treatments were considerably raised but still below the critical limits.

Order of Metal Accumulation in the Plant

Generally, the accumulation order was Ni>Zn, based on the analysis of elemental distribution in plant tissues.

This trend lines up with the soil availability order (Table 2), proving that the bioavailable fraction of a metal is the primary determinant of the amount of metal that accumulates in plant tissues.

Plant Contamination Metrics

It is common practice to use the following signs to gauge the plant's ability to absorb and store heavy metals:

When comparing plant tissues to soil or particular organs, the bioaccumulation coefficient (BAC) may be used as a measure of the metal presence in plants.

The Bio-concentration Factor (BCF) is a metric for gauging the efficiency with which plants take up certain metals from soil.

When comparing metal concentrations in aerial and root sections, the translocation factor (TF) may be used.

plants are classified as heavy metal accumulators if they have several indices larger than one [15].

Root Bio-concentration Factor (BCF_1)

One way to compare the concentration of metals in soil and roots is by looking at the bio-concentration factor (BCF_1), which is shown in Table 7. Different treatments with Ni and Zn showed statistically significant differences.

T_3 and T_4 treatments resulted in much higher BCF_1 values for Ni compared to T_0 and T_1, with values of 1.077 and 1.192, respectively. A moderate outcome of 0.994 was attained by the T_2 treatment.

The roots acquired a large quantity of Zn under these circumstances, as shown by the greatest BCF_1 values for Zn in treatments T_0 and T_2, which were 1.543 and 1.278, respectively.

In contrast, treatments T_1, T_3, and T_4 had values below 1 at 0.531, 0.465, and 0.612, respectively, showing that the roots were unable to accumulate as much Zn under these conditions.

Table (7): Root bio-concentration factor (BCF_1) for Ni and Zn under different addition treatments.

Treatment	BCF_1 — Ni	BCF_1 — Zn
T0	0.382	1.543
T1	0.765	0.612
T2	0.994	1.278
T3	1.077	0.465
T4	1.192	0.531
$LSD_{0.05}$	0.241	0.193
Mean	0.743	0.906

The capacity of the banana male plant to absorb and store Ni in its root system makes it an effective accumulator for the metal, which explains why the bio-concentration factor values for Ni tend to rise under certain treatments. Ni may be absorbed by many plant species from polluted soils, stored in root tissues, and then translocated to other sections of the plant, increasing concentrations in various organs [16].

Zn accumulation in roots is confirmed by higher BCF values under certain treatments. Because Zn is a mobile micronutrient, its relative accumulation in roots is lower than in other tissues; this may explain why other treatments showed lower levels. Its quick translocation from roots to aerial portions may also play a role.

This confirms what[17] found: plants with a high concentration of heavy metals in their roots have a high capacity for absorption and have developed tolerance mechanisms that enable them to store and transport these metals to their organs in the air.

Bio-Accumulation Coefficient in Shoots (BAC)

The BAC values for Zn and Ni in the banana male plant's shoot system are shown in Table (8). All of the Ni BAC levels were less than one; specifically, T_0, T_1, T_2, T_3, and T_4 recorded values of 0.316, 0.161, 0.573, and 0.386, respectively. This proves that Ni moves slowly from root to aerial tissues and suggests that it is mostly kept in the root system instead of being translocated to shoots. These results corroborate those of [18], who found that roots absorb slower-moving mineral elements like Ni than shoots.

In contrast, Zn BAC levels were more than one in the majority of treatments, with T0 having a value of 8.042, T1 through T4 having values of 2.022, 6.540, 2.513, and 5.581, respectively. This is because the plant is an efficient Zn accumulator due to its strong transport and accumulation capabilities in shoot tissues. [19] state that plants with BAC values greater than one are considered to be good options for phytoremediation of heavy metal-contaminated soils.

Table (8): Bio-accumulation coefficient (BAC) for Ni and Zn in shoots of the banana male plant under different addition treatments.

Treatment	BAC — Ni	BAC — Zn
T0	0.316	8.042
T1	0.161	2.022
T2	0.573	6.54
T3	0.386	2.513
T4	0.266	5.581
$LSD_{0.05}$	0.083	1.672
Mean	0.243	4.86

The findings showed that the shoot system could not go very far from the roots to the aerial regions since all of the Ni BAC values were less than one. Zn consistently showed BAC values over one in all treatments, supporting the plant's exceptional ability to store Zn in its shoot tissues. Plants growing in polluted soils may have BAC values more than one in their shoots, according to [9,20]. This is a sign of metal uptake and transfer from the ground to the air. Their findings are in line with ours.

Whole-plant Bio-concentration Factor (BCF2)

This indicator shows how much metal is present in the soil as a percentage of the total plant (roots and shoots) concentration. The results in Table (9) show significant differences among treatments in BCF2 values for both Ni and Zn in banana male plants.

For Ni, the highest BCF_2 values were recorded under T3 and T4 treatments (1.337 and 1.424 respectively), with no significant difference between them. Lower values of 1.056 and 1.245 were recorded under T1 and T2 respectively, whereas the control treatment (T0) showed the lowest value (0.376).

For Zn, all BCF_2 values exceeded unity across treatments, indicating active transfer of Zn from soil into plant tissues. The highest value was recorded under T_2 (7.317), followed by T_4 (4.360) and T_3 (4.059), while T_1 recorded a value of 2.270. Interestingly, the control treatment (T_0) recorded the highest BCF_2 value overall (11.030), surpassing all amended treatments.

Table (9): Whole-plant bio-concentration factor (BCF_2) for Ni and Zn in banana male plant under different addition treatments

Treatment	BCF_2 — Ni	BCF_2 — Zn
T0	0.465	11.03
T1	1.056	2.27
T2	1.245	7.317
T3	1.337	4.059
T4	1.424	4.36
$LSD_{0.05}$	0.921	2.367
Mean	1.38	6.52

Table (9) shows that, with the exception of the control (T_0), all of the Ni treatments (T_1, T_2, T_3, and T_4) had BCF_2 values greater than one. This proves that banana male plants can take Ni up from polluted soil and move it to their roots and shoots, while the latter still accumulate more than the former. These results are in agreement with those of [9], who found that heavy metals mostly concentrate in roots and seldom make it to shoots.

In terms of Zn, every single BCF_2 value including the control treatment—was higher than one. This proves that Zn is a micronutrient that can be easily transported from soil to various plant tissues and then accumulates significantly in the organs responsible for vegetative growth. Zn is among the most mobile trace nutrients in plants, and this is in line with the findings of [21], who observed that heavy metal mobility and translocation differ by element and species.

Because of its tolerance mechanisms that allow it to store and translocate metals, as well as its great ability to grow in soils polluted with metals, the banana male plant may be considered an accumulator of metals like Ni and Zn.

Translocation Factor (TF)

A metal's transit from a plant's roots to its aerial portions may be captured by the TF index. There are notable variations in Ni TF levels between treatments, as seen in Table (10). In terms of Ni TF levels, the T_4 treatment came out on top with 0.468, followed by T_1, T_3, and T_2 with 0.402, 0.389, and 0.244 correspondingly. In contrast, the control group (T_0) had the lowest value at 0.057. Ni has a limited mobility and a propensity to combine with intracellular organic molecules, therefore its restricted migration from roots to shoots is shown by the fact that all TF values for Ni stayed below one.

Table (10): Translocation factor (TF) for Ni and Zn under different addition treatments

Treatment	TF — Ni	TF — Zn
T0	0.057	7.567
T1	0.402	4.489
T2	0.244	5.424
T3	0.389	4.84
T4	0.468	7.224

$LSD_{0.05}$	0.14	2.099
Mean	0.267	5.497

Consistent with the findings of (Abdel-Baqi, 2000), who found that heavy metals' slow mobility from roots to shoots may account for only a small fraction of their concentration in roots, leading to low TF values, the results shown above show that Ni accumulated more extensively in the root system than in the shoot system. [9] categorized Ni as an element that tends to collect mostly in roots and is generally stationary within plant tissues; our results are consistent with that classification.

There were no statistically significant variations in Zn levels among treatments; however, there were substantial disparities between all treatments and the control. The TF values that were reported for T_0, T_4, T_3, T_2, and T_1 were 7.224, 4.840, 5.424, and 4.399, respectively. It is evident that Zn is transported and mobilized from the root system to the aerial regions of the plant, since all values are greater than one. These results are consistent with those of [21], who noted that Zn is an involved component in many plant physiological and enzymatic activities, making it a mobile micronutrient that, as a result, tends to concentrate in shoot tissues.

This study's results show that banana male plantlets may absorb and store a lot of Zn and Ni from polluted soil. The banana plant prefers to store Zn in its aerial tissues and Ni in its root system. Plants are efficient Zn accumulators, according to bio-concentration and translocation indices, but they store Ni mostly in their roots since it is less mobile. It is feasible to use the banana male plantlets for phytoremediation without causing immediate dangers to the environment or food safety, since the metal concentrations found in plant tissues were below internationally allowed levels. In sum, the findings lend credence to the idea that this species might be a good fit for long-term soil reclamation plans aimed at removing heavy metals from soils.

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