



PHYTOEXTRACTION POTENTIALS AND EARLY GROWTH PERFORMANCE OF BLACK NIGHTSHADE (*Solanum nigrum*) SEEDLINGS ON CONTAMINATED SOILS FROM DIFFERENT MECHANIC SITES AROUND WUDIL KANO

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ABSTRACT

Heavy metal contamination from indiscriminate disposal of spent engine oil in mechanic workshops poses serious environmental and agricultural challenges in Wudil, Kano, Nigeria. This study evaluated the phytoextraction potential and early growth performance of *Solanum nigrum* seedlings grown on soils from four mechanic sites compared to uncontaminated farmland soil. A greenhouse pot experiment was conducted under a Completely Randomized Design (CRD) with five soil treatments and four replicates. Growth parameters (emergence, days to emergence, height, canopy width, leaf number, and biomass) were recorded for four weeks, while soil and plant tissues were analyzed for Pb, Cd, Zn, and Ni using atomic absorption spectrophotometry. Results showed significantly ($P < 0.05$) reduced germination (from 90% to 80%), seedling height (16 to 20 cm), and biomass in contaminated soils compared to control (95%, 22.5 cm, 1.80 g shoot DW), with mechanic site C performing worst. Post-harvest soil analysis revealed significant ($P < 0.05$) reductions in heavy metals from 17.9% to 11%, confirming active phytoextraction. Metal accumulation was higher in roots than shoots for Pb, Cd, and Ni, indicating phytostabilization, while Zn showed greater shoot translocation ($TF > 1$), highlighting phytoextraction potential. Bioconcentration factors (BCF) for most metals ranged from 0.28–0.41, with Zn showing relatively higher accumulation and mobility. These findings suggest that, *S. nigrum* tolerates contaminated soils, reduces metal concentrations, and may serve as both a phytostabilizer (Pb, Cd, and Ni) and a phytoextractor (Zn). The study concludes that *S. nigrum* is a promising, low-cost candidate for phytoremediation of mechanic site soils in northern Nigeria, though multiple cropping cycles may be required for effective decontamination.

1. Introduction

Anthropogenic activities, particularly those associated with urbanization and informal industries, are a primary source of heavy metal contamination in terrestrial ecosystems. Mechanic villages, common across many developing nations, are significant point sources of pollution, releasing metals like lead (Pb), cadmium (Cd), zinc (Zn), and nickel (Ni) from activities such as welding, battery disposal, and spillage of used engine oil and grease (Adesokan *et al.*, 2016; Ale, 2025). These metals are non-biodegradable, persist indefinitely in the soil, and pose severe risks to human and ecological health through their potential to enter the food chain (Ali *et al.*, 2013). Conventional remediation methods like soil washing or excavation are often prohibitively expensive and environmentally disruptive, especially for large, diffusely contaminated sites in low-income regions. This reality has catalyzed the search for sustainable, cost-effective alternatives, chief among them being phytoremediation, (Behera *et al.*, 2024).

The increasing number of mechanic workshops in Wudil, Kano has led to widespread and often unchecked disposal of spent engine oil into surrounding soils. This has resulted in degradation of soil quality, reduced agricultural productivity, and increased environmental health risks due to the accumulation of heavy metals and toxic hydrocarbons, (Nyateng, 2024). Conventional remediation approaches are expensive, technically intensive, and not readily accessible to local communities. However, there is insufficient data on the use of native plants such as *Solanum nigrum* in the phytoremediation of such contaminated soils in northern Nigeria.

The research addresses the need for cleaning up contaminated soils in Wudil, thereby helping to protect land and water resources from further pollution, also contributing to the growing body of knowledge on the phytoremediation potential of native plants, particularly under spent engine oil contamination. The rationale for selecting *Solanum nigrum* for phytoextraction is based on several favorable attributes; *Solanum nigrum* has been documented in several studies to accumulate heavy metals like cadmium (Cd), lead (Pb), and zinc (Zn) in its tissues without showing significant signs of phytotoxicity (Guo *et al.*, 2024). Its capacity to translocate metals from roots to shoots makes it a promising candidate for efficient phytoextraction. It grows in diverse environments, including disturbed soils and marginal lands, making it a practical choice for field-scale applications. Its adaptability to different climatic and edaphic conditions increases its utility in various geographic locations. It requires minimal agricultural inputs, making it suitable for low-cost and sustainable remediation projects. The study therefore aimed at evaluating the phytoextraction potentials and early growth performance of *Solanum nigrum* seedlings on contaminated soils from various mechanic sites in Wudil, Kano.

2. Materials and Methods

2.1 Description of the study area

This research study was conducted in Wudil Local Government Area Kano State Nigeria, which is located in East Central Area of Kano State, and in the central area of Kano Region between longitude 8° 45'E, as well as between latitude 11° 37'N and latitude 11° 56'N. Wudil Local Government Area, was selected due to its growing number of automobile workshops and the prevalence of soil contamination from spent engine oil.

2.2 Collection of experimental plant and soil samples with spent engine oil

Soil samples were collected from four different mechanic workshop sites known for frequent disposal of used engine oil. Control soil (uncontaminated) was also collected from a farmland 2–3 km away from any industrial and mechanical activities.

2.3 Experimental design and layout

A pot experiment was conducted in a greenhouse using a Completely Randomized Design (CRD) factorial structure of 2x5x4. Each soil sample (four contaminated, one control) was used to grow *S. nigrum* seedlings with four (4) replicates per treatment.

2.4 Soil sampling and planting procedure

The top-soil from the farm yards and the contaminated soils from the four (4) mechanic sites, (M.Site A,B,C,D) that were collected for the experiment were air-dried for one week, crushed and sieved through a 2mm steel sieve. The soil sample was weighed 4kg each divided into 5 portions and replicated 4 times, giving a total of 20 experimental units, following the method of Oluwanisola and Abdulramann (2018). Those samples were thoroughly mixed with water to field capacity and allowed to stabilize before planting.

The seed viability was determined by simple floatation method before 10 viable seeds each were planted onto the contaminated and uncontaminated soil. After planting, the experimental setup was watered 2 times a day (morning and evening) to field capacity and monitored for 4 weeks after planting. The experiment was done under a shady environment to minimized evapo-transpiration parameters such as days of plant emergence, the rate of growth (in terms of number of leaves, height and width of the plant). The height (cm) and width of the plant was measured with the help of a thread and a meter rule, and also the numbers of leaves was counted visually for 3 weeks and recorded.

2.5 Phytoextraction and soil analysis

At the end of 8th week of experimentation, soil analysis was performed on the uncontaminated and contaminated after stabilization period of the soil samples, to evaluate the physicochemical properties phytoextraction potentials of the experimental plant by determining the level of some heavy metals of the soil. Both the shoots and roots sample of the plant on both contaminated and uncontaminated soil were digested separately after which the digested samples were determined for cadmium (Cd), lead (Pb), zinc(Zn) and nickel (Ni) on Atomic absorption spectrometer (Bello *et al.*, 2021).

2.6 Data Analysis

All collected data collected were used to calculate their respective means with Standard Deviation $(SD\pm)$ and subjected to Analysis of Variance (ANOVA) to determine significant differences among treatments. Fisher's Least Significant Difference (FLSD) test at $P \leq 0.05$ was used to separate (compare) means.

3. Results

3.1 Early growth and vigor of *S. nigrum* seedlings on soils from different mechanic sites

The result in Table 1 showed how the health of the *S. nigrum* seedlings were directly impacted by soil pollution (mechanic sites). The result revealed that, growth parameters significantly ($P < 0.05$) declined in soils from mechanic sites (MS), with the degree of reduction varying by site, the control (uncontaminated soil) had recorded the highest emergence (95%), fastest germination (4 days), tallest seedlings (22.5 cm), widest canopy (18 cm), highest number of leaves (10), and greatest biomass; shoot (1.80 g), root (0.42 g). Other mechanic sites showed progressive decline most especially M.Site C with 80% emergence, 16 cm height, 1.12 g shoot, performing worst, with increased in days of emergence from 4.0 (control) to 5.1 (MS C), suggests that metal contamination delayed germination and reduced vigor. This clearly showed that, uncontaminated soil provided a favorable environment for *S. nigrum* growth.

Table 1: Early growth and vigor of *Solanum nigrum* seedlings on soils from different mechanic sites around Wudil, Kano.

Treatment	Emergence (%)	Days to emergence	Height (cm)	Canopy width (cm)	Leaves (no.)	Shoot DW (g)	Root DW (g)
Control	95 ± 3 ^a	4.0 ± 0.3 ^d	22.5 ± 1.8 ^a	18.0 ± 1.5 ^a	10 ± 10 ^a	1.80 ± 0.15 ^a	0.42 ± 0.04 ^a
M.Site A	90 ± 4 ^{ab}	4.2 ± 0.4 ^d	20.0 ± 1.6 ^{ab}	16.5 ± 1.4 ^{ab}	9 ± 11 ^{ab}	1.55 ± 0.13 ^{ab}	0.39 ± 0.04 ^a
M.Site B	86 ± 5 ^b	4.6 ± 0.5 ^c	18.3 ± 1.5 ^{bc}	15.2 ± 1.2 ^b	8 ± 14 ^{bc}	1.32 ± 0.12 ^{bc}	0.34 ± 0.03 ^b
M.Site C	80 ± 5 ^c	5.1 ± 0.6 ^a	16.0 ± 1.4 ^d	13.4 ± 1.1 ^c	7 ± 13 ^c	1.12 ± 0.10 ^c	0.30 ± 0.03 ^b
M.Site D	83 ± 5 ^{bc}	4.8 ± 0.5 ^b	17.2 ± 1.5 ^{cd}	14.1 ± 1.2 ^{bc}	7 ± 12 ^c	1.20 ± 0.11 ^{bc}	0.32 ± 0.03 ^b
P-value	0.004	0.001	0.001	0.001	0.001	0.001	0.031

Notes: M.Site = Mechanic Site; Control = uncontaminated farmland soil; Values are means of four replicates ± standard deviation (SD); Means with different superscript letters within a column differ significantly ($p < 0.05$, FLSD).

3.2 Soil metal concentrations pre- and post-experiment

The result of heavy metal concentrations recorded during pre- and post- experiment were significantly higher in mechanic site soils than the control soil, (Table 2). During pre-experiment, the concentration of lead (Pb) recorded ranged from 140–260 mg/kg in MS soils as compared to 18 mg/kg in the control soil, cadmium (Cd) was up to 3.1 mg/kg in MSC as compared to 0.20 in control, meanwhile, zinc (Zn) and nickel (Ni) were also much higher in contaminated soils. The result of Post-harvest reductions showed that, *S. nigrum* actively extracted metals, after just one harvest of *S. nigrum*, the concentration of every single metal (Pb, Cd, Zn, and Ni) dropped significantly in all the contaminated soils. The % reduction (Δ %) was substantial, ranging from 11% to 17.9%, notably, M. Site C (the most contaminated site) had the highest % reduction rates (16.7% Zn, 16.4% Ni) amongst other sites, which was a huddled decrease for a single growing season. Whereas, the control soil showed only minor natural decreases (~3–5%), indicating that the reductions in MS soils were due to phytoextraction by *S. nigrum*.

Table 2: Soil metal concentrations ($\text{mg}\cdot\text{kg}^{-1}$ Dry Weight) pre-planting and post-harvest and % reduction

Soil	Time	Pb	Cd	Zn	Ni
Control	Pre	18.0 ± 2.1	0.20 ± 0.05	65 ± 6	22 ± 3
	Post	17.2 ± 2.0	0.19 ± 0.04	63 ± 5	21 ± 3
	$\Delta\%$	4.4	5.0	3.1	4.5
MS1	Pre	220 ± 18	2.8 ± 0.3	320 ± 25	95 ± 8
	Post	192 ± 16	2.3 ± 0.3	276 ± 22	82 ± 7
	$\Delta\%$	12.7	17.9	13.8	13.7
MS2	Pre	180 ± 15	2.2 ± 0.2	280 ± 24	80 ± 7
	Post	159 ± 14	1.9 ± 0.2	240 ± 21	70 ± 6
	$\Delta\%$	11.7	13.6	14.3	12.5
MS3	Pre	260 ± 20	3.1 ± 0.4	360 ± 30	110 ± 9
	Post	220 ± 18	2.6 ± 0.3	300 ± 26	92 ± 8
	$\Delta\%$	15.4	16.1	16.7	16.4
MS4	Pre	140 ± 12	1.6 ± 0.2	240 ± 20	70 ± 6
	Post	122 ± 11	1.4 ± 0.2	208 ± 18	60 ± 5
	$\Delta\%$	12.9	12.5	13.3	14.3
ANOVA Pre (P)		<0.001	<0.001	<0.001	<0.001
ANOVA $\Delta\%$ (P)		0.012	0.021	0.009	0.015

$\Delta\% = 100 \times (\text{Pre} - \text{Post})/\text{Pre}$; Cd = Cadmium, Pb = Lead, Zn = Zinc, Ni = Nickel

3.3 Heavy metal accumulation in plant tissues (roots and shoot) at harvest

The result presented in Table 3 showed the accumulation was significantly higher ($P \leq 0.05$) in seedlings grown on contaminated soils compared to control. This result tracked the toxic journey of the metals inside the plant tissues, showing that, it's not just about removing metals from soil, but also storing them safely. The metal levels in tissues of the plant growing in the control soil were relatively very low, like a normal, edible plant (though *S. nigrum* can be toxic naturally). The roots being the primary storage vaults for every metal, recorded the highest concentration most especially in M.Site C, with lead (Pb) in the roots (78 mg/kg) was double that in the shoots (40 mg/kg). Cd in the roots ranged from 0.60 to 1.02 mg/kg, as compared to the shoots from 0.41 to 0.62 mg/kg. Zn uptake with shoots often exceeding roots in, MS C; 196 in shoot as compared to 140 in the root. More so, Ni showed similar trend with higher accumulation in the root, but the shoots still retained significant amounts. The most polluted site (MS C) created the most contaminated plants. This directly links the soil pollution to the metal accumulation inside the plant. The plant growing in the worst soil (MS C) became the most toxic itself.

Table 3: Heavy metal accumulation in *S. nigrum* tissues at harvest ($\text{mg}\cdot\text{kg}^{-1}$ DW)

Soil	Pb(Root)	Pb (Shoot)	Cd (Root)	Cd (Shoot)	Zn (Root)	Zn(Shoot)	Ni (Root)	Ni (Shoot)
Control	4.2 ± 0.5 ^d	2.1 ± 0.3 ^d	0.08 ± 0.02 ^d	0.05 ± 0.01 ^d	48 ± 0.6 ^d	53 ± 0.6 ^d	6.8 ± 0.9 ^d	4.1 ± 0.6 ^d
MS1	62 ± 0.7 ^b	36 ± 0.5 ^b	0.82 ± 0.10 ^b	0.54 ± 0.07 ^b	122 ± 1.2 ^b	168 ± 15 ^b	28 ± 0.3 ^b	18 ± 0.2 ^b
MS2	54 ± 0.6 ^b	32 ± 0.4 ^b	0.71 ± 0.09 ^b	0.48 ± 0.06 ^b	110 ± 1.0 ^b	152 ± 14 ^b	24 ± 0.3 ^b	16 ± 0.2 ^b
MS3	78 ± 0.8 ^a	40 ± 0.5 ^b	1.02 ± 0.12 ^a	0.62 ± 0.08 ^a	140 ± 1.3 ^a	196 ± 18 ^a	34 ± 0.4 ^a	21 ± 0.3 ^a
MS4	46 ± 0.5 ^c	28 ± 0.4 ^c	0.60 ± 0.08 ^c	0.41 ± 0.06 ^c	98 ± 0.9 ^c	136 ± 13 ^c	21 ± 0.2 ^c	14 ± 0.2 ^c
ANOVA (P)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Values are means of four replicates ± standard deviation (SD); Means with different superscript letters within a column differ significantly ($p < 0.05$, FLSD).

3.4 Phytoextraction indices (dimensionless): Bioconcentration Factor (BCF) and Translocation Factor (TF).

Bioconcentration Factor (BCF) in the Root values for Pb, Cd, Zn, and Ni were generally ranged from 0.28 to 0.41, showing moderate ability to accumulate metals relative to soil concentration. This means the plant was selective and didn't hyper-accumulate to extreme levels in its roots, but it did concentrate them there. And the BCF in the shoot was lower (0.30 for Pb and Cd), indicating preferential retention in roots, except Zn which had the BCF in the shoot from 0.53 to 0.57, showing relatively higher translocation. The Pb and Cd Translocation Factors (TFs) were relatively lower, ranged from 0.5 to 0.68 (i.e. <1), meaning most Pb and Cd were sequestered in roots (useful for phytostabilization). Zn had TF values ranged from 1.11 to 1.40, which is >1, showing efficient translocation to shoots, indicating suitability for phytoextraction. Meanwhile, Ni TF values were consistently <1 (0.60 to 0.67), showing restricted movement to shoots. Thus, *S. nigrum* behaves as a Zn phytoextractor (shoot accumulator) but acts as a phytostabilizer for Pb, Cd, and Ni, locking them mainly in roots.

Table 4: Phytoextraction indices (dimensionless): Bioconcentration Factor (BCF) and Translocation Factor (TF).

Soil	Pb			Cd			Zn			Ni		
	BCF Rt	BCF Sht	PbTF	BCF Rt	BCF Sht	Cd TF	BCF Rt	BCF Sht	Zn TF	BCF Rt	BCF Sht	Ni TF
Control	0.23	0.12	0.50	0.40	0.25	0.63	0.74	0.82	1.11	0.31	0.19	0.60
MS1	0.28	0.16	0.58	0.29	0.19	0.66	0.38	0.53	1.40	0.29	0.19	0.64
MS2	0.30	0.18	0.59	0.32	0.22	0.68	0.39	0.54	1.39	0.30	0.20	0.67
MS3	0.30	0.15	0.51	0.33	0.20	0.61	0.39	0.54	1.39	0.31	0.19	0.62
MS4	0.33	0.20	0.61	0.38	0.26	0.68	0.41	0.57	1.39	0.30	0.20	0.67
ANOVA (P)	0.041	0.033	0.018	0.027	0.022	0.046	0.011	0.008	0.004	0.038	0.030	0.049

Note: **TF > 1** (indicates effective translocation to shoots; **BCF_{root} ~0.3–0.4** with **TF < 1** (suggests root sequestration useful for **phytostabilization**. **BCF_{root} (Rt)** = Root/Soil Pre; **BCF_{shoot} (Sht)** = Shoot/Soil_Pre; **TF** = Shoot/Root.

4. Discussion

The present study assessed the early growth performance, heavy metal uptake, and phytoextraction potential of *Solanum nigrum* seedlings cultivated in soils collected from different mechanic sites in Wudil, Kano. The findings revealed significant variations in seedling emergence, vigor, biomass accumulation, and metal accumulation across contaminated and uncontaminated soils. These results provide important insights into the adaptive growth strategies of *S. nigrum* in heavy metal-polluted environments and its potential role in the phytoremediation of contaminated soils.

4.1 Growth and vigor of *S. nigrum* under metal stress

The growth data obtained during this research demonstrated that, seedling emergence was highest in the control soil and progressively declined with increasing contamination levels, with the lowest emergence recorded in soil from mechanic site C. Similarly, plant height, canopy width, leaf number, and dry matter yield significantly decreased in contaminated soils compared to the control. This reduction was consistent with reports that heavy metals, particularly lead (Pb), cadmium (Cd), zinc (Zn), and nickel (Ni), may disrupt physiological and metabolic processes in plants, leading to impaired seed germination and growth inhibition (Chibuike & Obiora, 2014; Mosa et al., 2016; Asiminicesei et al., 2024). The delayed days to emergence observed in contaminated soils further suggested that, metal-induced oxidative stress, may hampers enzymatic activities essential for seedling establishment (Ahmad et al., 2015). Despite these growth constraints, *S. nigrum* seedlings still survived and produced measurable biomass across all contaminated soils, demonstrating a degree of tolerance. Tolerant plants are often characterized by metal-binding proteins, antioxidant defense systems, and compartmentalization mechanisms that allow them to survive in contaminated substrates (Nagajyoti et al., 2010; Riyazuddin et al., 2021). This adaptability underscores the potential of *S. nigrum* as a candidate for phytoremediation, particularly for stabilization and extraction of metals from polluted soils.

4.2 Soil metal reduction and remediation efficiency

Analysis of pre- and post-harvest soil samples revealed significant reductions in heavy metal concentrations across all contaminated sites, with the highest removal efficiencies recorded in mechanic site C. By contrast, the control soil showed only marginal reductions, indicating that the observed decreases in contaminated soils were largely attributable to plant uptake rather than natural attenuation. These findings aligned with the previous studies that have demonstrated the effectiveness of hyperaccumulator species in significantly reducing soil heavy metal loads through uptake and sequestration in plant tissues (Wuana & Okieimen, 2011; Mahar et al., 2016; Guo et al., 2024). The significant results for percentage reduction further confirmed that, *S. nigrum* actively contributed to metal removal. The observed reduction rates were

comparable to other known phytoremediation species such as *Amaranthus hybridus* and *Brassica juncea* that have been documented for their ability to extract Pb, Cd, and Zn from polluted environments (Ali *et al.*, 2013; Uday *et al.*, 2021). This indicates that, *S. nigrum* could serve as an alternative low-cost and ecologically sustainable option for remediating mechanic site soils, which are notorious hotspots of metal contamination due to indiscriminate disposal of spent oils, batteries, and metallic scraps.

4.3 Heavy metal accumulation in plant tissues

Metal accumulation data revealed that *S. nigrum* accumulated substantial amounts of Pb, Cd, Zn, and Ni in both roots and shoots, with the highest concentrations consistently recorded in plants from mechanic site C. Root tissues generally contained higher concentrations than shoots, suggesting preferential sequestration of metals in roots as a protective mechanism against translocation to aerial parts. This is a common adaptation in tolerant plants, where metals are immobilized in roots to minimize toxicity in photosynthetically active tissues (Sharma & Dubey, 2005). Nevertheless, the translocation of metals to shoots was still significant, with the shoot concentrations reaching high for Pb and Zn in plants from site C. These levels surpassed those found in many edible crops grown in contaminated soils, further confirming *S. nigrum*'s ability to extract and mobilize metals within its biomass (Ghosh & Singh, 2005; Riyazuddin *et al.*, 2021). The differences across sites may be attributed to variations in soil contamination intensity, metal bioavailability, and soil physicochemical properties influencing uptake (Alloway, 2013).

4.4 Phytoextraction indices and remediation strategy

The calculated Bioconcentration Factor (BCF) and Translocation Factor (TF) values have provided a deeper understanding of *S. nigrum*'s remediation mechanism. BCF values < 1 in the roots for Pb, Cd, and Ni, indicating moderate metal accumulation relative to soil concentrations. For Zn, BCF values were higher in shoots and in the roots, suggesting that *S. nigrum* has a stronger affinity for Zn compared to other metals. The TF values were generally < 1 for most metals except Zn, which indicates effective translocation to aerial parts only in the case of Zn.

These results suggested that, *S. nigrum* operates primarily as a phytostabilizer for Pb, Cd, and Ni, immobilizing them in root tissues, while functioning as a phytoextractor for Zn due to its higher mobility and shoot transfer. This dual role is significant for phytoremediation strategy design: while phytostabilization prevents further leaching and metal migration, phytoextraction enables gradual removal of metals through periodic harvesting of biomass (Ghosh & Singh, 2005; Ali *et al.*, 2013; Abdullahi *et al.*, 2025). Therefore, *S. nigrum* could be strategically deployed in contaminated sites where Pb, Cd, and Ni require stabilization, while Zn can be gradually depleted from the soil through extraction.

4.5 Implications for phytoremediation in mechanic sites

Mechanic workshops are globally recognized as localized hotspots of soil pollution, contributing large amounts of Pb, Cd, Zn, and Ni into the terrestrial environment (Yusuf *et al.*, 2018). The results of this study indicated that, *S. nigrum* possesses the resilience to establish in such challenging soils while contributing to meaningful reductions in soil metal burdens. Its relatively fast growth, wide ecological distribution, and dual role in metal stabilization and extraction enhance its potential as a phytoremediation resource, particularly in resource-limited settings where costly engineering remediation approaches may be impractical (Mahar *et al.*, 2016; Abdullahi *et al.*, 2025).

Furthermore, the accumulation of metals in both roots and shoots highlighted during this study was needed for proper biomass management after harvest. The relatively high biomass yield of *S. nigrum* even under stress was a major advantage. After harvest, the contaminated biomass must be managed appropriately, (Tawo, & Mbamalu, 2025). Research into safe disposal methods or, more promisingly, valorization strategies such as using the biomass for bioenergy production (biogas, bio-oil) in controlled facilities where metals may be captured from the residues which could transform a waste stream into a resource, creating a circular economy model for remediation process (Sas-Nowosielska *et al.*, 2004; Thakur *et al.*, 2016).

5. Conclusion

The results demonstrated that, *S. nigrum* seedlings can survive and grow in heavily contaminated mechanic site soils, significantly reduce soil Pb, Cd, Zn, and Ni concentrations, and accumulate substantial amounts of metals in both roots and shoots. The BCF and TF values suggest its suitability for combined phytostabilization and phytoextraction, depending on the target metal. The implications for sustainable remediation of mechanic site soils in Wudil, Kano, and similar urban environments are profound, offering an affordable, eco-friendly strategy to address soil pollution challenges.

It is recommended that, agronomic trials are needed to optimize yield and metal uptake through practices like fertilization, mycorrhizal association, and crop rotation. The most promising path is the application of soil amendments like chelating agents (EDTA) or acidifying agents to increase the bioavailability of less mobile metals like Pb, thereby potentially boosting their phytoextraction efficiency. Furthermore, long-term field studies over multiple seasons are essential to determine the total number of cropping cycles required to reduce soil metal concentrations to safe regulatory levels.

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