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Phytoremediation with Sunflower (*Helionthus annus*) and Its Capacity for Cadmium Removal in Contaminated Soils

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ABSTRACT: This study assessed the phytoremediation potential of sunflowers for removing cadmium from the soil around a paint manufacturing industry in Eleyele, Ibadan. Background levels of Cd in the topsoil and subsoil were determined. The site was divided into two plots. Organo-mineral fertilizer (OMF) was applied to the first plot, which served as the experimental plot, while the second plot was without OMF and served as the control. Concentrations of cadmium in the plants were determined using an Atomic Absorption Spectrophotometer. Baseline mean Cd contents were 29.23 mg/kg and 33.30 mg/kg for topsoil and subsoil, respectively. Over the planting period, the sunflower plants removed 53.1% and 51.6% of Cd from the topsoil and subsoil in the test plot, while 40.65% and 47.80% were removed from the topsoil and subsoil, respectively, in the control. Cd absorption from the contaminated soils was found to be translocated to all parts of the sunflower. The concentrations of Cd in the sunflower parts were as follows: root system (10.70 mg/kg), shoot (8.17 mg/kg), leaves (6.43 mg/kg), and seeds (2.52 mg/kg) for the test plot. For the control plots, Cd in the root, shoot, leaves, and seeds were 7.60 mg/kg, 7.43 mg/kg, 4.75 mg/kg, and 2.03 mg/kg, respectively. The study confirmed that sunflowers have the potential to remediate Cd from contaminated soil, and this potential was enhanced by the application of OMF.

KEYWORDS: Contaminated soil; sunflower; phytoremediation; cadmium; organo-mineral fertilizer (OMF).

1. Introduction

Environmental pollutants are chemicals of natural or synthetic origin released into the environment due to natural or anthropogenic activities, which may impose undesirable effects on the environment, humans, or target organisms [1]. Heavy metals are part of the inorganic pollutants and may include Lead (Pb), Cadmium (Cd), Zinc (Zn), Copper (Cu), Chromium (Cr), and others such as Mercury (Hg), Arsenic (As), Nickel (Ni), and Cobalt (Co). These toxic heavy metals and trace elements are dispersed in soil, aquatic ecosystems, and other natural environments. Weathering, decomposition, dissolution, combustion of fuel, and volcanic eruptions contribute largely to heavy metal deposits [2-3]. Human activities also generate enormous quantities of these metals that penetrate various strata of the soil. Anthropogenic sources of heavy metals include industrial mining, agricultural activities, and the processing of wastes [2]. Industrial wastes, whether in the form of solid, liquid, or gaseous products, often contaminate the soil, air, and water, causing physical, chemical, or biological damage to the land [4]. When toxic substances concentrate heavily on the land, they can harm humans and the environment directly or indirectly [4]. Chemical contaminants of the soil have caused plant toxicity, human poisoning from contaminated food crops, and chemical attacks on houses and other structures [5].

Cadmium is a heavy metal with a wide range of industrial uses. A typical application is in paint making, where it is used to preserve and add color to an object or surface by using pigmented coatings. Cadmium creates brilliant yellow, orange, and maroon pigments in paints and coatings [6]. Such coatings have found applications in artwork finishing, industrial coatings, and as driving aid markers, even as preservatives. However, some of the paint pigments are toxic, particularly those used in cadmium paint. Asemave and Anhwange [7] discussed the utility of lead and cadmium for interior paints. The elements are also used in the production of batteries, paint/dyes, plastics, steel and steel products. They are also used in soldering brass/bronze, foundries, and in the manufacturing of ammunitions associated with lead and its products. Cadmium is toxic and can occur from volcanic emissions on neighboring vegetation. It is not critical or essential for plant growth, but under certain conditions, it can accumulate in some plants to levels that are hazardous to animals and humans. The chemistry of cadmium reaction in the soil is not well understood, but its uptake is influenced by the presence of organic matter, silicate clay, and hydrous oxides of iron and aluminum, as well as poor air aerations [8]. Cadmium uptake is high in acidic soils and is reduced when the soil is limed. It is a hazardous air pollutant that enters plants and animals from soil and water. Cadmium has inhibitory effects on antioxidant processes that interact with the sulfuric group of essential enzymes. Chronic exposure to cadmium has therefore been associated with a wide range of diseases, including heart disease, anemia, skeletal weakening, and depressed immune system responses. At extreme levels, it causes ‘Itai – Itai,’ a disease characterized by brittle bones and intense pain [9].

In many developing countries, urban centers may appear indifferent to farming on lands contaminated with industrial wastes and heavy metals like lead and cadmium due to land scarcity. It is therefore necessary to promote the removal of heavy metals, where possible, to make the land secure for human habitation and use. The management of contaminated soils and a polluted environment can fall into two categories: first, how the soil can be used sustainably for cultivation, and second, the development of suitable technology to remove pollutants or contaminants from the soil or the environment. Phytoremediation is a novel biological process found to be environmentally friendly, inexpensive, and very effective [10-11]. Phytoremediation is capable of providing a solution to the problem of pollutant removal from the environment. Yan et al. [12] defined phytoremediation as the use of green plants to remove pollutants from the environment, rendering them harmless. The ability of certain plants to possess a high power of absorption of dissolved minerals or elements from the soil essentially underscores the principle of phytoremediation. Transport processes in some plants are well developed, having specialized roots and well-developed xylem tissue able to conduct or transport materials from the root up the shoot and finally to the leaves. To absorb mineral salts efficiently, roots must grow in well-aerated soils [13]. According to Yan et al. [12], scientific records dated back to 1885 show that some plants accumulate high levels of metals in their leaves. Adewole et al. [14] and Yan et al. [12] carried out research on Thlaspicea sulencens and maize (Zea mays) to compare strategies of phytoremediation on industrially and agriculturally contaminated soil. Yan et al. [12] worked on the phytoremediation of lead using sunflower and EDTA and found out that the root of sunflower showed great ability to retain lead. Adewole [15] worked on the ability of sunflower (Helianthus spp.) to accumulate Pb, Cd, and Zn in various parts of the plant. Also, the remediation of soil contaminated by some heavy metals using sunflower plants has been demonstrated [16]. This present study aims to determine the extent of cadmium accumulation in various plant parts, namely roots, shoot, leaves, and seed of sunflower plants grown in contaminated soil. The effort is to evaluate the sunflower phytoremediation potential in accumulating cadmium from soil contaminated with paint. Cadmium pigments are known for their ability to withstand high temperature and pressure without fading, hence their application in the paint industry.

2. Materials and Methods

2.1. Study area.

The study area was the Askar Paint Manufacturing site located at Latitude 7.416352N and Longitude 3.856693E in Eleyele, Ibadan, Oyo State, Nigeria. This paint industry has been operating on the premises for over four decades. Within the factory, four major raw materials are utilized for paint production: The primary substance serves as a binder, fixing raw materials such as polyvinyl chloride. The second category comprises pigments responsible for characteristic coloration, including metal oxides of iron, manganese, zinc, chromium, etc. Extenders, the third set of materials, are used to increase the bulk of the product volume or quantity, with kaolin and carbonate being essential components. Additives, the fourth major substances, play various roles, each contributing to improving the quality of the paint product. Some additives include biocides, antimicrobial substances that prevent the growth of microorganisms on the paint, preserving its quality on painted surfaces. Another additive is the rheological agent, promoting the flow of paint material on walls and other solid surfaces, though it may contain heavy metals such as lead, cadmium, cobalt, and others. Untreated wastewater from the paint manufacturing industry is directly discharged into the surrounding environment, posing a risk of contamination with heavy metals such as cadmium. For the experimental field, a section of the premises where the factory's effluent is directly discharged into the surrounding piece of land was selected.

2.2. Sourcing sunflower seeds.

Sunflower (*Helianthus annuus*) seeds were sourced from the Institute of Agricultural Research and Training (IAR&T), Obafemi Awolowo University, Ife. The Funtua variety of Sunflower was used.

2.3. Test plot preparation.

The study site had dimensions of 7.7 m x 5 m. The land was divided into six plots of 2 m x 2 m each, with a 0.5m distance provided as space between each block and boundary. The plots were labeled A to F. The experiment followed a randomized complete block design with each treatment replicated three times. The test plots were treated with organo-mineral fertilizer (OMF), while the control experiment (OMF not applied) served as a baseline. OMF was used to enhance soil fertility, subsequently promoting plant growth and yield [17]. OMF was applied to the test plots two weeks after planting.

2.4. Soil sampling and preparation before planting.

Before planting sunflowers, soil samples were collected from the experimental field to determine the background concentrations of cadmium. The field was sectioned into four portions to obtain sufficient background data. Soil samples for the topsoil (0– 5 cm) and subsoil (15–30 cm) depths were randomly collected using a soil auger. Composite samples were formed by thoroughly mixing two samples from the same portion. This process yielded four composite samples for both topsoil and subsoil, providing the background levels of heavy metals.

2.5. Planting.

Sunflowers were cultivated in the experimental fields, spaced at 1m x 0.7m on the sub-plots. Planting was done manually by hand, with four seeds per hole at a depth of 3–4 cm. Thinning was performed approximately 12 days after planting [18].

2.6. Soil and plants samples preparation.

Sunflowers were used as a phytoremediation tool for cadmium-contaminated soil. After full growth until seed formation (approximately 105 days), three mature plants were selected from each plot for analysis. Fresh and dry weights were recorded after 48 hours of oven drying at 70 °C. The samples were separated into various parts (root, shoot, leaves, and seeds), and each representative sample from the same plot was bulked together. These samples were thoroughly blended using an electric grinder. Post-harvest soil analyses were conducted on soil samples collected from the field portion where representative plant samples were selected. Soil samples were collected few centimeters away from the uprooted plant samples using a soil auger at depths of 0–15 cm and 15–30 cm. The soil samples were air-dried, ground, and sieved before analysis. Data on physical plant parameters were collected over a period of 15 weeks. In total, 72 samples (plant and soil samples) were analyzed for cadmium.

2.7. Determination of cadmium.

For each 0.5 g of plant and soil sample, 5ml of an acid mixture (concentrated Nitric Acid (HNO_3) and concentrated Perchloric Acid ($HClO_4$)) were added to the digestion tube. The mixture was heated at 250 °C for 2 hours, followed by the addition of 5 ml concentration of H_2SO_4 and further heating to dryness. The digest was allowed to cool, then distilled water was added, and the mixture was filtered. The filtrate was made up to 25ml with distilled water. The concentrations of cadmium in soil and plant digests were determined using Atomic Absorption Spectrophotometer (AAS).

2.8. Statistical analysis.

The data collected were analyzed using SPSS 10 statistical package. Mean values of cadmium in soil and various parts of the sunflower were compared using One-way ANOVA.

3. Results and Discussion

3.1. Cadmium concentration in soil before planting.

The cadmium levels in the topsoil and subsoil were 29.23 ± 9.58 mg/kg and 33.30 ± 14.38 mg/kg, respectively, as shown in Table 1. The obtained cadmium concentrations from the contaminated soil, 29.23 ± 9.58 mg/kg in the topsoil and 33.30 ± 14.39 mg/kg in the subsoil, indicate that cadmium is a naturally occurring metal in the Earth's crust. Typically, the average cadmium content in the Earth's crust is reported to range from 0.1 to 25 mg/kg [19]. Higher concentrations of cadmium are commonly associated with zinc sulfide ores and, to a lesser extent, with lead and copper ores [2]. The presence of cadmium in the Askar Paint premises, ranging from about 29.23 mg/kg to 33.30 mg/kg, exceeds the natural range (0.1 to 0.5 mg/kg), suggesting the existence of an additional contamination source. These cadmium levels in the soil surpass the World Health Organization's permissible limits [20]. Garba and Abubakar [19] have reported cadmium concentrations of up to 500 mg/kg in industrial environments, emphasizing that elevated cadmium values in the environment, beyond the natural range, result from point source pollution associated with various industrial processes such as mining, metallurgical operations, electroplating, and the use of certain paints, pigments, and dyes. Understanding the distribution of initial and post-harvest soil levels of lead and cadmium in both experimental and control fields provides valuable insights into the impact of these contaminants.

Table 1. Cadmium levels in the soil before use.

Elements	Mean (mg/kg)
Cadmium in Topsoil	29.23 ± 9.58
Cadmium in Subsoil	33.30 ± 14.39

3.2. Fresh and dry weight of sunflower plants after planting.

In Table 2, the mean fresh and dry weights of sunflower plants in both control and test experiments are detailed. In the test experiments, the fresh weights (in grams) of sunflower plant parts—root, shoot, leaves, and seeds—were 158.97 ± 67.83, 852.15 ± 253.80, 313.06 ± 164.33, and 122.47 ± 45.14, respectively. Similarly, the dry weights (in grams) after oven drying were 40.31 ± 10.15, 139.19 ± 115.13, 94.12 ± 37.06, and 36.13 ± 20.28 for root, shoot, leaves, and seed parts, respectively, in the test experiments. In the control experiment, the fresh weights (in grams) for root, shoot, leaves, and seeds were 120.44 ± 82.63, 706.51 ± 226.65, 290.28 ± 132.46, and 130.75 ± 82.14, respectively. The corresponding dry weights (in grams) were 30.58 ± 19.10, 169.82 ± 73.46, 81.33 ± 32.08, and 38.93 ± 21.76 for root, shoot, leaves, and seeds, respectively.

Table 2. Distribution of the mean fresh and dry weight of sunflower plant.

Plant Part	Fresh weight (g)		Dry weight (g)	
	Control	Test	Control	Test
Root	120.44±82.63^{ab}	158.97±67.83^{b}	30.58±19.10^{a}	40.31±10.15^{a}
Shoot	706.51±226.65^{b}	852.15±253.80^{b}	169.82±73.46^{a}	139.19±115.13^{a}
Leaves	290.28±132.46^{ab}	313.06±164.33^{b}	81.33±32.08^{a}	94.12±37.06^{a}
Seeds	130.75±28.14^{b}	122.47±45.14^{b}	38.93±21.76^{a}	36.13±20.28^{a}

3.3. Cadmium concentration in soils after planting.

The cadmium concentration of the soils before and after the cultivation of sunflower plants are shown in Table 3. Before the remediation process, the cadmium levels (mg/kg) in the topsoil and subsoil of the test experimental plots were 28.17 ± 1.15 and 32.53 ± 3.87, respectively. In the control plots, the cadmium levels (mg/kg) before remediation were 29.63 ± 0.12 in the topsoil and 35.03 ± 4.10 in the subsoil. After the remediation process in the test experiment, the cadmium concentrations (mg/kg) in the topsoil and subsoil were 16.78 ± 1.54 and 17.07 ± 3.89, respectively. In the control experiments after remediation, the cadmium concentrations (mg/kg) in both topsoil and subsoil were 13.59 ± 1.55 and 16.95 ± 2.64, respectively. Utilizing sunflower demonstrated a mean cadmium level in the control experiment topsoil, with initial and post-harvest levels of 29.63 ± 0.12 and 13.59 ± 1.55 mg/kg, respectively. In the subsoil, the initial and post-harvest values were 35.03 ± 4.10 and 16.95 ± 2.64 mg/kg. For the test experiment, the initial values were 28.17 ± 1.15 and 32.53 ± 3.87 mg/kg for the topsoil and subsoil, respectively. The mean post-harvest values were 16.78 ± 1.54 mg/kg for the topsoil and 17.07 ± 3.89 mg/kg for the subsoil. These results indicate that sunflower effectively removed cadmium from both the topsoil and subsoil using the organo-mineral fertilizer prepared by the authors [21]. Numerous studies have reported the phytoremediation potential of various plant species, including *Helianthus* sp., *Zea mays*, *Solanum* sp., with greater efficiency achieved through specific techniques and growth-promoting inputs [22].

Table 3. Cadmium levels in experimental soil samples planted with sunflower (*H. annus).*

Soil Layer	Cd Before Remediation		Cd After Remediation	
	Control	Test	Control	Test
Topsoil	29.63±0.12^{c}	28.17±1.15^{c}	13.59±1.55^{a}	16.78±1.54^{b}
Subsoil	35.03±4.10^{b}	32.53±3.87^{b}	16.95±2.64^{a}	17.07±3.89^{a}

3.4. Cadmium concentration in sunflower plants after planting.

In Table 4, the cadmium concentrations in various parts of the sunflowers after the test and control experiments are presented. The mean cadmium concentrations (mg/kg) in the plants from the test experiments are 10.70 ± 0.52, 8.17 ± 1.92, 6.43 ± 1.29, and 2.52 ± 0.10 for the root, shoot, leaves, and seed parts, respectively. In the control experiment, the mean cadmium levels (mg/kg) obtained were 7.60 ± 2.68, 7.43 ± 3.54, 4.75 ± 0.53, and 2.03 ± 0.78 for root, shoots, leaves, and seeds, respectively. Phytoremediation of metal-contaminated soil relies on the use of plants to extract and translocate metal to their harvestable parts. The goal of phytoremediation is to reduce the concentration of metal in contaminated soil to conform to regulatory levels within a reasonable time frame. The extraction process through phytoremediation depends on the ability of the selected plant to grow and accumulate metal under the specific climate and soil conditions of the site being remediated [12]. The various percentages of cadmium removed from the background level of the contaminated soil reveal the phytoremediation capabilities of sunflower plants. The root systems of plants are crucial for absorbing nutrients needed for plant growth from the soil. Similarly, when metals and other substances, including cadmium, are absorbed from the soil by plants through their roots, they are translocated upward and distributed into all plant tissues. The distribution of cadmium in various parts of sunflower reveals its exceptional natural metal-accumulating capacity (hyper-accumulator) and high-biomass characteristics [12, 14]. Different sunflower cultivars may perform differently in removing cadmium from soils under varying environmental factors such as soil types and climatic conditions [23]. These findings indicate that the concentration of cadmium in sunflower is higher in the root system and shoot system compared to other parts of the plant. This aligns with the findings of Sadiq et al. [24], who investigated the vulnerability of sunflower germination and metal translocation under heavy metal contamination. Metal-tolerant plants generally accumulate high levels of metals in their tissues. The use of plants in the remediation of heavy metals is primarily to reduce appreciable levels of metal contaminants in the soil. To achieve this, it becomes imperative to employ plants that have the ability to accumulate such contaminants, especially if the remediation needs to reach the subsoil. Sunflowers, being bio-accumulators, possess a well-developed root system that can reach subsoil levels [12]. The plants also have a substantial leaf size that allows for transpiration, facilitating absorption from the soil through the roots

Table 4. Distribution of cadmium in sunflower plant for test and control experiment.

Experimental Unit	Root	Shoot	Leaves	Seeds
Test	10.70 ± 0.52^{c}	8.17 ± 1.92^{b}	6.43 ± 1.29^{b}	2.52 ± 0.10^{a}
Control	7.60 ± 2.68^{b}	7.43 ± 3.54^{b}	4.75 ± 0.54^{ab}	2.03 ± 0.78^{a}

Means±std in the same row with different superscripts are significantly different at $P<0.05$

3.5. Percentage of cadmium removal by sunflower plants.

The percentage of cadmium removal by the sunflower plant in the topsoil and subsoil of the test and control experiments are shown in Table 5. The sunflower was efficient enough to remove 53.1% of cadmium from the topsoil and 51.6% from the subsoil in the test experiment; while 40.6% and 47.8% cadmium were removed in the control experiment from the topsoil and subsoil. These results showed that sunflower exhibited phytoremediation potential from the topsoil and subsoil. The metal hyper-accumulation potentials of sunflower and their high biomass indeed provided them with the power to extract heavy metals from contaminated soil into their tissues [12]. Sunflower can, thus, be employed in heavy metal removal at larger sites as governmental and non-governmental interventions for environmental cleanup. Phytoremediation using sunflower can be done in a short time-frame, is environment-friendly with minimal disturbances and is a low cost approach.

Table 5. Percentage of cadmium removed by phytoremediation with sunflower plants.

Crop sample cultivated plot/treatment	Soil type	Mean cadmiusm levels and standard deviation		% Removed
		Initial	Post-harvest	
Sunflower (test)	Top	28.96±1.27	13.59±1.54	53.1
Sunflower (test)	Sub	35.03±4.09	16.95±2.64	51.6
Sunflower (control)	Top	28.23±1.27	16.78±1.53	40.6
Sunflower (control)	Sub	32.66±4.09	17.06±3.88	47.8

4. Conclusions

The study demonstrated that the prolonged discharge of untreated paint wastes and effluents containing heavy metals, including hazardous materials like cadmium, into the soil serves as a significant source of pollution. Additionally, it confirmed the capacity of Sunflower to accumulate cadmium in their tissues, showcasing their role as hyperaccumulators. The distribution of cadmium in Sunflower showed a higher concentration in the roots, followed by the shoots and leaves, potentially correlating with the transport flow distance of heavy metals from the soil to the plant. As a recommendation, the phytoremediation capacity of Sunflower should be harnessed to address industrial pollutants such as cadmium in contaminated soils.

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Competing Interest

The authors declare that they have no competing interest.

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