Efficacy of Cocoa Pod Ash and Educational Outreach in Reducing Pb and Cr Bioavailability in Tropical Vegetable Farming Systems

Peter Sanjo ADEWALE
peter.adewale@uniosun.edu.ng
Osun State University
Oluwatoyin Lydia Dada
Saint Louis University

Research Article

Keywords: Sustainability, Pb, Cr, Soil Management, Lead, Pollution, Amaranthus hybridus

Posted Date: June 29th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9876339/v1

Additional Declarations: No competing interests reported.

Abstract

Heavy metal contamination in agricultural soils poses significant risks to food safety and public health, particularly in tropical vegetable farming systems where smallholder farmers lack access to expensive remediation technologies. This study investigated the efficacy of cocoa pod ash and educational outreach in reducing Pb and Cr bioavailability in *Amaranthus hybridus* cultivation in Nigeria. A randomized controlled trial with a split-plot experimental design was employed, involving 140 vegetable farmers who participated in an environmental education programme. Soil and vegetable samples were collected from experimental pots treated with varying application rates of cocoa pod ash and goat manure (0.7, 1.5, and 2.2 rates), with Pb and Cr concentrations determined using atomic absorption spectrophotometry. Results revealed that the educational intervention significantly improved farmers' knowledge of heavy metal pollution, with those reporting 'no knowledge' declining from 63% pre-intervention to 16% post-intervention. Cocoa pod ash applied at the highest rate (2.2) was most effective in reducing both Pb and Cr uptake in Amaranthus hybridus, achieving the lowest concentrations (0.050 Mg/kg for both metals), while goat manure at low rates (0.7) unexpectedly increased metal bioavailability. The combination of cocoa pod ash and goat manure at moderate rates (1.5) also demonstrated effective metal immobilization. Despite knowledge gains, adoption barriers including financial constraints (43%) and limited market access (32%) persisted. The study concludes that integrating cocoa pod ash application with targeted educational outreach offers a scalable, cost-effective strategy for mitigating heavy metal contamination in tropical vegetable farming systems, though structural support mechanisms remain essential for widespread adoption.

Introduction

Heavy metal contamination in agricultural systems is an escalating global concern due to its detrimental effects on food safety, public health, and environmental stability. Recent global estimates indicate that 14–17% of agricultural land worldwide approximately 242 million hectares is contaminated with toxic metals such as lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg), affecting up to 1.4 billion people living in high-risk areas (Adewale et al., 2023). These metals are persistent in nature; once introduced into soil, they can remain active for decades, entering the food chain through crops grown in contaminated soil and posing significant health risks including neurological disorders, kidney damage, and cancer (Chakraborty et al., 2020). As agricultural practices evolve toward more sustainable models, addressing heavy metal contamination has become a critical focus, particularly in tropical regions where smallholder farmers depend on safe soil for their livelihoods and where year-round cultivation intensifies metal uptake risks.

Among emerging remediation technologies, organic soil amendments particularly biochar and ash derived from agricultural waste have gained prominence as cost-effective, locally available solutions for immobilizing heavy metals in contaminated soils. Recent research demonstrates that cocoa pod husk biochar applied at 3% significantly reduces heavy metal bioavailability by converting exchangeable fractions to more stable residual forms, with documented reductions in cadmium (by 58.14%), copper by

(60.24%) and lead by (52.11%) in contaminated agricultural soils (Ajayi et al., 2023). The mechanism involves raising soil pH, increasing cation exchange capacity, and enhancing organic carbon content all of which promote metal adsorption and precipitation, thereby limiting plant uptake (Oladipo et al., 2021). This positions cocoa pod ash and its derivatives as promising nature-based solutions for tropical farming systems where cocoa production generates abundant pod waste.

In Nigeria, the relevance of cocoa pod-based amendments is particularly significant. The country's cocoa sector has long grappled with heavy metal contamination stemming from decades of copper-based fungicide application, raising concerns about export integrity and compliance with European Union safety standards (Adegoke et al., 2020). Research at the Cocoa Research Institute of Nigeria has demonstrated that phosphate rock-based materials can effectively bind with copper contaminants, limiting their mobility at the soil-plant interface and reducing accumulation in cocoa beans (Ogunlade et al., 2019). Extending this logic to vegetable farming systems where lead and chromium contamination pose comparable threats cocoa pod ash represents an untapped, locally abundant resource for mitigating metal bioavailability in soils cultivated with leafy vegetables such as *Amaranthus hybridus*.

However, technological solutions alone are insufficient. The successful adoption of soil remediation practices depends critically on farmers' awareness, technical cognition and capacity to implement best management practices. Research across diverse contexts confirms that farmers' knowledge of soil properties and heavy metal risks has a significant relationship with their awareness that plants absorb toxic elements from contaminated soils (Li et al., 2021). A study of vegetable farmers revealed that despite some awareness of soil physicochemical properties, substantial gaps remain in understanding the pathways through which heavy metals enter the food chain and the health implications of chronic exposure (Wen et al., 2022). Targeted educational interventions are therefore essential to bridge this knowledge gap and empower farmers to adopt remediation practices effectively.

Despite growing evidence that cocoa pod ash can immobilize heavy metals in contaminated soils, existing research has focused predominantly on cadmium and copper in cocoa plantations, with limited attention to lead and chromium in vegetable cropping systems. Furthermore, while studies have demonstrated the technical efficacy of organic amendments under controlled conditions, few have investigated their effectiveness when combined with educational outreach aimed at improving farmers' understanding of heavy metal dynamics and their capacity to implement remediation practices independently. In the context of Ipetu-Ijesa, where *Amaranthus hybridus* constitutes a dietary staple and smallholder farmers lack access to expensive remediation technologies, no known study has systematically evaluated the integrated impact of cocoa pod ash application and targeted environmental education on reducing Pb and Cr bioavailability in soil and subsequent crop uptake. This gap leaves farming communities without evidence-based, locally appropriate strategies for mitigating heavy metal contamination and safeguarding consumer health. Therefore, this study evaluates the efficacy of cocoa pod ash a readily available agricultural by-product in the region in reducing lead and chromium bioavailability in tropical vegetable farming systems, alongside educational outreach designed to enhance farmers' technical cognition and adoption of safe soil management practices.

Methodology

Research Design: Experimental design was used for this study. The study employed a randomized controlled trial (RCT) approach with a split-plot experimental design to assess the impact of environmental education and sustainable soil management practices on reducing lead (Pb) contamination in *Amaranthus hybridus* (a commonly consumed leafy vegetable).

Population of the Study: The target population of the study consisted of all vegetable farmers in the Ipetu-Ijesa area of Osun State.

Sample and Sampling Method: A simple random sampling technique was used to select soil and vegetables.

Research instrument: Instruments that were used in data collection included soil samples, and vegetable samples from the experimental plots. All sampling equipment used for collecting vegetable and soil samples were made of stainless steel. The equipment was thoroughly cleaned before use and between successive sample collections. Sealable bags were used as sample containers for soil and vegetables, and all sample containers were labelled appropriately.

Validity of the instrument: Repeated analyses of the vegetable and soil samples were carried out to validate the analytical procedures.

Reliability

Reliability was defined as the extent to which an instrument measured the features it was designed to measure and yielded consistent results over time. To ensure the reliability of the results of the experimental study, all necessary steps, precautions, and procedures were followed. Samples were carefully handled to avoid contamination. Reagents of standard analytical grades were used, and glassware was properly cleaned throughout the experiment. Deionised water was used, and correction of instrument readings was carried out by reagent blank determinations.

Procedures for data collection: Data were collected from vegetable farmers through a survey questionnaire titled Environmental Education and Heavy Metal Awareness (EEHM) Questionnaire. This was done to determine the effect of environmental education on the level of awareness and knowledge of Pb pollution in Amaranthus hybridus. Moreover, the concentration of Pb residues in soil and Amaranthus hybridus was quantified to determine the effects of soil amendments on heavy metal uptake in the crop. Soil and Amaranthus hybridus samples were collected from experimental pots.

Soil for the pot experiment was collected from the top 0–10 cm layer of a cultivated area. Compost used for the experiment was produced at Osun State University, Ipetu-Ijesa. The organic-based fertilizer (goat droppings) for the study was obtained from the Ipetu-Ijesa community in Osun State. Pb and Cr acetate was used as the soil contaminant at variable concentrations. The seeds of Amaranthus hybridus for the experiment were obtained from the Ipetu-Ijesa market. The experiment consisted of four levels of lead: 0, 400, 800, and 1200 mg Pb kg^{-1}, applied in the form of a solution along with different rates of organic-based (goat droppings) fertilizers. It was a factorial experiment laid out in a completely randomized design (CRD). Each treatment was replicated three times, resulting in a total of 12 experimental units.

Seed viability Test: The viability status of the seeds of Amaranthus hybridus was determined using the germination method. Twenty seeds of the test plant were randomly selected and spread on water-moistened cotton wool in a Petri dish, which was then covered with its lid. This procedure was replicated three times and left for five days. The total number of seeds that sprouted was counted on the fifth day and expressed as a percentage.

Preparation of Pb and Cr Contaminant Standard Solution and Application

The Pb and Cr were added to the soil as Pb [$Pb(CH_3COO)_2 \cdot 3H_2O$]. and Cr acetate [$Cr_2(CH_3COO)_4(H_2O)_2$]. The standard solutions were prepared by weighing lead and Cr acetate individually at variable concentrations: 0, 400, 800, and 1200 mg Pb kg^{-1} (corresponding to 0, 0.732, 1.464, and 2.196 g, respectively) using a weighing balance. Each individual concentration was dissolved in a conical flask with a small amount of water and then quantitatively transferred to a measuring cylinder. The volume was made up to 1000 mL with water to obtain solutions of 0 (control), 400, 800, and 1200 mg Pb L^{-1} and Cr L^{-1}. Thus, one litre of water was used to dissolve each Pb and Cr concentrations. The prepared Pb and Cr acetate standard solutions at these variable concentrations were applied to the soil and properly standardized before the sowing of Amaranthus hybridus seeds.

Substrate Analysis: The standard properties of the soil, cocoa pod ash, and goat dropping were determined before use in the experiment. Analyses for the characterization of the substrates (air-dried soil, cocoa pod ash, and goat dropping) were conducted as follows: the pH in water was measured in a 1:5 (v/v) ratio using a pH meter (Mettler-Toledo, Greifensee, Switzerland). The cation exchange capacity, determined as the sum of base cations, was measured on an MP-AES 4200 Spectrometer (Agilent Technologies, Santa Clara, CA, USA) at pH 7.0 after extraction with 1 M ammonium acetate. The total organic carbon (TOC) and total nitrogen (TN) contents in the soil and compost were measured using the EnviroTOC Cube analyzer (Elementar Analysensysteme GmbH, Langenselbold, Germany).

Experimental Design

Two pot experiments were set up in square plastic pots of approximately 1 L volume. The first experiment (EX 1) was carried out using only cocoa pod ash and goat dropping. A 10% amount of RBC (v/w) was mixed with the entire volume of compost. In the second experiment (EX 2), a mix of 90% compost and 10% agricultural manure biochar (called MIX), at a dose of 30% (v/w), was applied to the soil and thoroughly mixed with the whole volume of the pot.

Samples of soil and *Amaranthus hybridus* were collected following the sampling procedure described earlier. A soil auger was used to drill holes to the required depth for collecting soil samples. Accumulated soils were removed from time to time to prevent loose materials from falling back into the hole when removing the auger. The soil auger was forced into the soil, and after reaching the desired depth, it was slowly removed. The samples were collected into polythene bags, labelled, and properly tied.

Good practices for the transport of samples were followed. Each sample of *Amaranthus hybridus* and soil was placed inside a sealed waterproof bag. The containers holding the soil and plant samples were sealed carefully and kept cool throughout transportation to the laboratory. The *Amaranthus hybridus* and soil samples were air-dried separately. Thereafter, they were crushed in a mortar and passed through a 2 mm sieve. The crushed-sieved fractions of the soil and plants that were greater than 2 mm were rejected and discarded. The physicochemical properties of the soil were determined according to ISO standards. These included pH, total organic carbon (TOC), cation exchange capacity (CEC), and total Kjeldahl nitrogen (TKN).

pH Determination: The pH of the soil samples from all the locations was determined using a glass electrode pH meter. Ten grams of each sample of the air-dried soil that passed through the 2-mm sieve were weighed into a standard 50-mL beaker. Twenty millilitres of a solution containing 0.01 M $CaCl_2$, prepared in a 1:2 ratio (soil: 0.01 M $CaCl_2$), were added and allowed to stand for about half an hour. The contents were then stirred with a glass rod. The glass-electrode pH meter was inserted, and the reading was taken for each sample.

Exchangeable cations (ECE)

Exchangeable Na, K, Ca, and Mg in the soil samples across the study locations were determined in the laboratory. The soil samples were air-dried, and 5 g of the air-dried soil were weighed and sieved through a 2-mm sieve. The portion that passed through the sieve was transferred into a 100-mL centrifuge tube. Three millilitres of ammonium acetate were added, and the mixture was shaken for about 2 hours, then centrifuged at 2000 revolutions per minute for 5 minutes. The clear supernatant was decanted and kept in a 100-mL volumetric flask. Another 30 mL of ammonium acetate solution were added to the residue, stirred for 30 minutes, and centrifuged again. The supernatant was transferred into the same 100-mL volumetric flask. This process was repeated, after which the flask was made up to the mark with ammonium acetate solution. The exchangeable cations were then determined from this extract.

Electrical Conductivity (EC): Electrical conductivity (EC) is defined as the concentration of soluble salts in soil samples at a specific temperature. The measurement of EC of the soil samples was carried out in the laboratory using a conductivity meter. The meter was first calibrated and then cleaned with deionised water. Ten millilitres of H_2O were added to 10 g of soil. The soil and water were thoroughly mixed and then allowed to settle for half an hour (FAO, 2020). After 30 minutes, the electrical conductivity was measured and recorded.

Determination of Organic C in the samples: The determination of organic carbon in the soil samples was done following the Walkley-Black method. A representative portion of each soil sample was air-dried, ground, and passed through a 0.5 mm sieve. One gram (1.00 g) of the sieved soil was weighed and transferred into a 250 mL Erlenmeyer flask. Ten millilitres (10 mL) of $K_2Cr_2O_7$ solution were measured using a pipette and then transferred into each flask, swirling to disperse the soil. Twenty millilitres (20 mL) of concentrated H_2SO_4 were also measured and pipetted, directing the stream into the suspension. The soil was mixed with the reagents and left in the flask to stand. The flask was rotated gently and allowed to stand on a double-fold cardboard paper for half an hour.

After this period, 100 mL of distilled water were added. Three drops of indicator were then added, and the mixture was titrated with ½ ferrous sulphate solution. The endpoint was taken at the point where the solution changed from greenish to dark green. A few additional drops of ferrous sulphate were added until the colour sharply changed again from blue to red under reflected light against a white paper background.

To standardize the dichromate, a blank titration was performed in the same manner but without soil.

The formula below was used to calculate the result:

% Organic C in soil (air-dry basis) = ((me K2Pb2O2-meFeSO4) * 0.003*100*(f))/(g of air-dry soil)

\ Where f (correction factor) was taken to be 1.33. me = Normality of solution * mL of solution used.

Soil Organic Matter (SOM) Determination: Determination of the SOM in the samples was calculated using % Organic C x 1.729.

Determination of N in Soil

The Regular Macro-Kjeldahl method was used for the determination of total nitrogen. Ten grams (10 g) of each soil sample (air-dried and ground to pass through a 0.5 mm sieve) were weighed and transferred into a 500 mL Macro-Kjeldahl flask. Twenty millilitres (20 mL) of distilled water were added, and the flask was swirled for a few minutes. The contents were allowed to stand for about half an hour. Subsequently, 10 g of K_2SO_4 and approximately one tablet of mercury (as a catalyst) was added, followed by 30 mL of concentrated H_2SO_4. The flasks were heated gently at low heat until the water evaporated and frothing ceased. The heat was then increased and digestion continued until the digest became clear. Once the digest cleared, the heat was removed, and the flasks were allowed to cool. After cooling, 100 mL of distilled water were gradually added to each flask. The digests were then transferred into another set of clean flasks, leaving the sand particles behind. The sand residues were washed with 50 mL portions of distilled water four times, and the washings were transferred into the same flask containing the digest.

For distillation, 50 mL of H_3BO_3 indicator solution was added into a 500 mL flask, which was then placed under the condenser. Distillation was carried out, keeping the condenser cool by allowing sufficient cold water to flow through to control heating, reduce frothing, and prevent suck-back. Distillation was stopped once the distillate had been collected for the determination of NH_4-N. The NH_4-N in the distillate was determined by titration with 0.01 N standard hydrochloric acid. The endpoint was identified by a colour change from green to pink. Finally, the percentage nitrogen in each sample was calculated.

Determination of Soil and Vegetable Pb and Cr Residues

Soil and Amaranthus hybridus samples were air-dried in the laboratory. The samples were then crushed and sieved using a 2 mm sieve, and particles greater than 2 mm were discarded. A 0.25 g portion of each processed sample was weighed into a 50 mL flask, and 10 mL of concentrated HNO_3 was added. The mixtures were left to cold digest overnight in a fume cupboard. The following morning, the mixtures were heated for approximately half an hour in a microwave. After heating, the samples were allowed to cool at room temperature for several minutes. Subsequently, 10 mL of double-distilled water was added to each flask, and the mixtures were filtered through a 0.45µm cellulose filter. The concentrations of the heavy metal Pb and Cr in each sample were determined using an atomic absorption spectrophotometer (AAS), following procedures and standards outlined by the American Public Health Association (APHA).

Method of data analysis

Descriptive statistical tools were used to analyse the quantitative data. Inferential statistical analytical tools were applied to draw conclusions about the population characteristics based on the information generated from the sample size. All experiments and measurements were performed in triplicates. Data were presented as mean values with standard deviation (SD).

RESULT

Demographic Characteristics of the Respondents

All 140 participants completed both pre-test and post-test assessments, ensuring full engagement and providing a robust foundation for comparative analysis. The largest proportion of respondents falls within the 31–50 years age bracket, representing the most economically productive demographic (Table 1). Respondents under 30 years constitute the minority, indicating moderate youth engagement in farming. Half of the respondents (50%) completed secondary education, while 39% attained tertiary education. Only 11% had primary education only. This relatively high educational level enhances participants' capacity to understand and apply agricultural innovations (Table 1). A substantial 74% of respondents have farmed for over 10 years, reflecting considerable agricultural experience. Only 9% are relatively new (less than five years), which may influence openness to adopting new practices. The majority (74%) cultivate both food and cash crops, indicating diversified farming systems that manage risk and enhance food security. 14% focus exclusively on cash crops, while 11% grow only food crops (Table 1).

Table 1
Revised Consolidated Demographic Characteristics Table

Variable	Category	Frequency (n)	Percentage (%)
Age Group	< 30 years	40	33
	31– and above years	100	67
	Total	140	100
Education Level	Primary	15	11
	Secondary	70	50
	Tertiary	55	39
	Total	140	100
Farming Experience	< 5 years	13	9
	5–10 years	24	17
	> 10 years	103	74
	Total	140	100
Crop Type	Both food and cash crops	104	74
	Cash crops only	20	14
	Food crops only	16	11
	Total	140	100

Analysis of participants Knowledge, awareness, Attitude and Practices on soil and vegetable pollution

Table 2 presents the frequency distribution of respondents' knowledge, attitudes, and practices before and after participation in the environmental education program. Prior to the intervention, 63% of farmers had no knowledge of heavy metal pollution, 17% associated it specifically with lead (Pb), and 20% reported limited awareness. No respondents identified heavy metals as general harmful pollutants or soil contaminants. Following the program, awareness improved substantially: 23% accurately described heavy metals as harmful, 18% recognized them as soil pollutants, 7% became familiar with the term 'heavy metal,' and those with no knowledge declined to 16%. Regarding perceived effects on agriculture, pre-intervention responses included soil contamination (46%), no idea (46%), biodiversity loss or crop damage (26%), slow growth or reduced yields (14%), and environmental or health risks (26%). Post-intervention, respondents cited soil contamination (34%), environmental and health risks (18%), and biodiversity loss or crop damage (14%). The proportion reporting no idea decreased sharply to 7%.

Crop rotation remained the most prevalent practice, reported by 86% pre-intervention and 68% post-intervention. Use of organic amendments remained consistent at 57% across both periods. Conservation tillage was adopted by 20% pre-program and 18% post-programme, indicating limited uptake. Farmers rating themselves as ‘highly effective’ managers increased from 23% pre-intervention to 27% post-intervention. Those reporting ‘very low’ confidence declined markedly from 9% to 2%. When asked about adopting new practices post-programme, responses shifted: ‘Maybe’ increased from 46% to 50%, while ‘Yes’ decreased from 34% to 20%, and "No" fell from 20% to 14%, indicating cautious openness to change.

Improved soil health was identified by 80% pre-program and 73% post-program. Increased crop yields rose from 63% to 68%. Recognition of reduced environmental pollution increased notably from 49% to 64%. Lack of knowledge as a barrier decreased significantly from 71% pre-intervention to 45% post-intervention, demonstrating programme effectiveness. However, persistent barriers included limited financial resources (43% post-program) and restricted market access (32% post-programme), indicating that structural support remains necessary for widespread adoption.

Table 2
Frequency Distribution of Responses (with Percentages)

Category	Response	Experimental Group		Control group	
		Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)
Understanding of Heavy Metal Pollution	It is a harmful/heavy metal	0	23	20	20
	No idea / Nothing	63	16	10	11
	Lead is toxic/polluting	17	9	10	10
	Soil pollutant	0	18	15	18
	Heavy metal	0	7	5	7
	Little knowledge	20	12	40	39
Effects on Agriculture (How do you think heavy metal pollution affects your farm and the environment?)	Through soil contamination	46	34	10	5
	Biodiversity/crop damage	26	14	5	5
	Slow plant growth/reduced yields	14	11	5	5
	Animal/plant uptake	9	9	5	10
	Environmental/health risks	26	18	5	7
	No idea	46	7	70	68
Mitigation Strategies (What practices do you currently use to manage soil health?	Crop rotation	86	68	20	20
	Organic amendments	57	57	60	60
	Conservation tillage	20	18	20	20
Perceived Effectiveness (How confident are you in your ability to manage soil health sustainably? (1–5)	5 (Highly effective)	23	27	30	30
	4 (Effective)	23	27	20	20
	3 (Moderate)	34	27	20	20
	2 (Low)	11	9	20	20
	1 (Very low)	9	2	20	20
Likelihood of Adoption	Maybe	46	50	01	01

(Have you made any changes to your farming practices as a result of participating in EE programs?)	Yes	34	20	0	0
	No	20	14	99	99
Expected Benefits (What benefits do you think sustainable soil management practices can bring to your farm?)	Improved soil health	80	73	10	10
	Increased crop yields	63	68	80	80
	Reduced environmental pollution	49	64	10	10
Barriers to Adoption (What barriers do you face in adopting sustainable soil management practices?)	Lack of knowledge	71	45	70	70
	Limited financial resources	63	43	15	15
	Limited access to markets	43	32	15	15

Soil Physiochemical characteristics

This table presents the physicochemical properties of the soil studied in the vegetable farming system of Ipetu-Ijesa. These parameters are important for assessing soil quality, its suitability for sustainable agriculture, and its role in minimizing chromium pollution. The soil's cation exchange capacity (CEC) for calcium (Ca^{2+}) was measured at 0.664 meq/100g, which is moderate and suggests a reasonable capacity to hold essential nutrients needed for plant growth. Potassium (K^{+}) was recorded at 0.122 meq/100g, and magnesium (Mg^{2+}) at 0.153 meq/100g, indicating nutrient levels that are adequate but could be enhanced for optimal vegetable production (Table 3).

Sodium (Na^{+}) was relatively low at 0.072 meq/100g, which is beneficial because excessive sodium can damage soil structure and reduce crop productivity. The soil pH was found to be 5.8, indicating slightly acidic conditions. This level of acidity is generally suitable for most vegetable crops, although slight liming might be helpful for more pH-sensitive species to bring the soil closer to neutral. Total Organic Carbon (TOC) was measured at 7.65%, a relatively high value that reflects good organic matter content. High organic matter improves soil structure, supports beneficial microbial activity, and can help reduce the bioavailability of heavy metals through complexation (Table 3).

The soil's electrical conductivity (EC) was recorded at 222.2 µS/cm, indicating non-saline conditions. This falls within acceptable limits for vegetable farming and does not pose a risk of salt stress to crops.

Table 3
Soil Physiochemical Characteristics

Physiochemical Parameters		**Concentration**
CEC (meg/l00q)	Ca^{2+}	0.664
	K^{+}	0.122
	Mg^{2+}	0.153
	Na^{+}	0.072
	pH	5.8
TOC		7.65%
Conductivity (μ^{scm-1})		222.2
Physiochemical Parameters		Concentration
CEC (meg/l00q)	Ca^{2+}	0.664
	K^{+}	0.122
	Mg^{2+}	0.153
	Na^{+}	0.072
	pH	5.8
TOC		7.65%
Conductivity (μ^{scm-1})		222.2

Concentration of Pb and Cr in the soil

Table 4 presents the concentrations of lead (Pb) and chromium (Cr) in soil samples treated with various organic amendments. The data demonstrate that amendment type, combination, and application rate significantly influence heavy metal mobility and bioavailability in agricultural soils. Lead concentrations across treatments ranged from 0.250 Mg/kg to 0.575 Mg/kg. The highest Pb level (0.575 Mg/kg) was recorded in soil treated with manure cocoa pod ash at the 1.5 application rate. This elevated concentration suggests that certain combinations and doses may enhance lead solubility, potentially through organic matter decomposition that releases bound metals into the soil solution. Conversely, the lowest Pb concentrations (0.250 Mg/kg) were observed in two treatments: cocoa pod ash manure 0.7 and goat manure 2.2. These results indicate that moderate application rates of these amendments effectively immobilize lead, reducing its bioavailability through organic binding, increased microbial activity, or pH modification. Intermediate Pb levels (0.275 Mg/kg) were recorded in cocoa pod ash 2.2 and cocoa pod ash 0.7 treatments, reflecting partial immobilization effects.

Chromium concentrations followed a similar pattern. The highest Cr level (0.575 Mg/kg) occurred in the manure cocoa pod ash 1.5 treatment, consistent with the lead findings and confirming that this specific combination may mobilize rather than stabilize heavy metals. The lowest Cr concentrations (0.250 Mg/kg) were found in the same treatments effective for lead: cocoa pod ash manure 0.7 and goat manure 2.2. This reinforces that moderate application rates of these amendments promote chromium immobilization through organic binding and pH-mediated stabilization. Intermediate Cr levels (0.275 Mg/kg) in cocoa pod ash 2.2 and cocoa pod ash 0.7 treatments indicate partial effectiveness.

Table 4
Concentration of Pb and Cr in the soil sample

Soil samples	Pb (Mg/kg)	Cr (Mg/kg)
Manure cocoa pod ash 1.5	0.400	0.575
Cocoa pod ash manure 0.7	0.450	0.250
CA 2.2	0.375	0.275
Goal manure 2.2	0.350	0.250
Cocoa pod ash 0.7	0.325	0.275
Control	0.025	0.025

Concentration of Pb and Cr in the vegetable sample (Amaranthus hybridus)

The concentrations of lead (Pb) and chromium (Cr) in *Amaranthus hybridus* harvested from soils treated with various organic amendments are presented in Table 5. The data reveal significant variation in heavy metal uptake across treatments, with clear implications for sustainable soil management and food safety. Lead concentrations in vegetable samples ranged from 0.050 Mg/kg to 0.250 Mg/kg across treatments. The highest Pb accumulation (0.250 Mg/kg) occurred in plants grown on soil amended with goat manure at the lowest application rate (0.7). This suggests that insufficient organic matter input may fail to immobilize lead effectively, leaving a larger bioavailable fraction in the soil solution. Similarly, the combined treatment of cocoa pod ash and goat manure at the same low rate (0.7) produced the second-highest Pb concentration (0.200 Mg/kg), reinforcing that suboptimal amendment doses can exacerbate rather than mitigate heavy metal uptake. Conversely, the lowest Pb concentration (0.050 Mg/kg) was recorded in vegetables from plots treated with cocoa pod ash alone at the highest application rate (2.2). This outcome is attributable to the alkalinity of cocoa pod ash, which raises soil pH and promotes lead stabilization through organic binding and reduced solubility. The combination treatment applied at a moderate rate (cocoa pod ash & goat manure 1.5) also yielded relatively low Pb uptake (0.113 Mg/kg), indicating that balanced mixtures at appropriate doses can effectively suppress metal translocation to plant tissues.

The untreated control plot produced vegetables with Pb content (0.075 Mg/kg) lower than several amended treatments. This finding underscores the complexity of metal-soil-plant interactions and sounds a cautionary note: organic amendments, while generally beneficial, must be carefully calibrated to avoid unintended consequences. Chromium concentrations followed an identical pattern. The highest Cr level (0.250 Mg/kg) was observed in plants from the goat manure 0.7 treatment, again implicating low-dose organic matter in enhanced metal mobility. The cocoa pod ash & goat manure 0.7 combination produced the second-highest Cr concentration (0.200 Mg/kg), confirming that inadequate amendment rates may leave chromium bioavailable. The lowest Cr uptake (0.050 Mg/kg) occurred in the cocoa pod ash 2.2 treatment, demonstrating the efficacy of higher application rates of this alkaline amendment in immobilizing chromium. The balanced mixture at 1.5 resulted in moderate Cr accumulation (0.113 Mg/kg), while the control plot (0.075 Mg/kg) again outperformed several amended treatments in limiting metal uptake.

Table 5
Concentration of Pb in the vegetable sample (*Amaranthus hybridus*)

Experiment	**Pb (Mg/kg)**	**Experiment**	**Cr (Mg/kg)**
Goat manure 2.2	0.163	Cocoa pod ash & goat manure 1.5	0.113
Goat manure and cocoa pod ash 0.7	0.200	Cocoa pod ash & goat manure 0.7	0.200
Goat manure 0.7	0.250	Cocoa pod ash 2.2	0.05
Cocoa pod ash and goats’ manure 1.5	0.113	Goat manure 2.2	0.163
Cocoa pod ash 0.7	0.088	Cocoa pod ash 0.7	0.088
Cocoa pod ash 1.5	0.075	Goat manure 0.7	0.250
Cocoa pod ash 2.2	0.05	Cocoa pod ash 1.5	0.075

Discussion of Findings

The environmental education program significantly improved farmers' understanding of heavy metal pollution, demonstrating the critical role of targeted educational interventions in agriculture. This result agrees with the finding of Monroe et al., (2019) and Kibwika et al., (2009). Prior to the programme, majority of farmers had no knowledge of heavy metal contamination, with only 17% recognizing lead as toxic. Following the intervention, just 16% remained unaware, while 23% explicitly identified heavy metals as harmful. This substantial knowledge gain aligns with evidence that well-designed environmental education fosters substantial awareness gains among farmers, thereby empowering them to adopt more sustainable practices as found by Monroe et al., (2019) in their study.

Farmers’ attitudes toward the impacts of heavy metals also became more important. Initially, 46% linked heavy metals primarily to soil contamination, while 26% expressed concerns about biodiversity or crop damage. Post-programme, awareness broadened to include biodiversity (14%), plant uptake (9%) and environmental or health risks. This expanded perspective reflects the holistic understanding of soil and ecosystem health necessary for effective environmental management (Keesstra et al., 2016). Furthermore, recognizing heavy metals' entry into the food chain resonates with established concerns about lead accumulation in edible crops and its implications for public health (Alloway, 2013; Gupta et al., 2010).

Despite these knowledge gains, actual shifts in soil management practices were more modest. Crop rotation remained the most commonly reported strategy, though its prevalence declined from 86% to 68%. Organic amendment use held steady at 57%, while conservation tillage showed only a slight increase from 16% to 18%. Notably, farmers reporting they had changed practices specifically as a direct result of the program fell from 34% to 20%, while "maybe" responses rose to 50%. This gap between positive attitudes and concrete behavioural change underscores that although environmental education is critical for raising awareness, actual adoption of sustainable practices often requires extended time frames, ongoing support, and access to necessary resources (Kibwika et al., 2009; Monroe et al., 2019). The modest improvements also reflect that managing heavy metal contamination frequently involves complex interventions that smallholder farmers may perceive as risky or costly (Alloway, 2013).

The study revealed that farmers face both knowledge-related and structural barriers to adopting sustainable practices. Encouragingly, knowledge gaps dropped from 71% pre-intervention to 45% post-intervention, reflecting the program's positive impact and supporting findings that well-designed educational interventions can substantially improve farmers' understanding of environmental challenges (Monroe et al., 2019; Kibwika et al., 2009). However, financial constraints (43%) and limited market access (32%) persisted as significant hurdles. This underscores that mitigating heavy metal risks often requires investments and technical adjustments that exceed the immediate capacities of smallholder farmers (Alloway, 2013). It also aligns with evidence that achieving sustainable soil management is contingent not only on awareness but also on complementary support systems, including financial assistance, infrastructure development, and enabling policies (Keesstra et al., 2016).

The highest lead concentration in soil (0.575 Mg/kg) was recorded in the manure cocoa pod ash 1.5 treatment, suggesting that co-application of organic amendments at elevated rates may enhance Pb retention. This finding is consistent with research showing that combined organic waste applications can increase heavy metal retention through enhanced organic matter content and cation exchange capacity (Zhang et al., 2020). Conversely, lower lead concentrations (0.250–0.275 Mg/kg) in cocoa pod ash 2.2 and cocoa pod ash 0.7 treatments align with evidence that certain bio-based amendments, depending on composition and application rates, can reduce heavy metal bioavailability by promoting adsorption onto soil particles or forming stable complexes (Ahmad et al., 2018). The role of ash in immobilizing heavy metals through pH modification and binding is well documented (Beesley et al., 2011).

Similarly, chromium concentrations followed the same pattern: highest (0.575 Mg/kg) in manure cocoa pod ash 1.5, and lowest (0.250–0.275 Mg/kg) in cocoa pod ash 0.7 and cocoa pod ash 2.2 treatments.

These variations underscore that amendment type and dosage critically influence heavy metal mobility and retention in soil. While organic amendments are widely recognized for improving soil fertility and structure, their interactions with heavy metals must be closely monitored to ensure that soil productivity is enhanced without compromising environmental safety or crop health (Agegnehu et al., 2016; Ghosh et al., 2018).

Amaranthus hybridus accumulated the highest lead concentration (0.250 Mg/kg) in goat manure 0.7 treatments, while the lowest uptake (0.050 Mg/kg) occurred in cocoa pod ash 2.2 treatments. This pattern confirms that organic amendment type significantly influences lead bioavailability and subsequent plant uptake (Agegnehu et al., 2016). The relatively higher uptake under goat manure treatments may be attributed to increased microbial activity and organic matter mineralization, which can enhance heavy metal solubility through organic acid release during decomposition, forming soluble complexes readily absorbed by plant roots (Ghosh et al., 2018; Beesley et al., 2011). Conversely, biochar-rich amendments like cocoa pod ash immobilize heavy metals through adsorption and co-precipitation, reducing bioavailability and uptake (Zhang et al., 2020; Ahmad et al., 2012).

Chromium uptake followed the identical pattern: highest (0.250 Mg/kg) under goat manure 0.7 and lowest (0.050 Mg/kg) under cocoa pod ash 2.2. These findings strongly suggest that higher cocoa pod ash application rates significantly reduce heavy metal uptake, likely through pH neutralization and metal binding (Almotairy, 2024). This aligns with the concept of organic amendments as sustainable agricultural practice for immobilizing heavy metals and reducing bioavailability (Briffa, 2020).

Conclusion

The findings from this study clearly indicate that environmental education plays a critical role in improving farmers' knowledge, attitudes, and practices regarding chromium pollution and sustainable soil management. While certain sustainable practices, such as crop rotation and the use of organic amendments, are already familiar to farmers, the adoption of targeted remediation strategies for heavy metals remains limited. Experimental evidence from this study strongly supports the effectiveness of cocoa pod ash, particularly at higher application rates, in significantly reducing chromium uptake in Amaranthus hybridus crops. Its benefits are likely attributed to its pH-regulating and metal-binding properties, reinforcing its potential as a valuable tool in soil remediation.

Although the educational intervention successfully reduced knowledge-related barriers, financial constraints and market limitations continue to pose significant challenges to the widespread adoption of sustainable practices. Therefore, achieving long-term, sustainable change in addressing heavy metal contamination in agricultural systems will require a multi-faceted approach that combines:

Recommendations

1. Farmers should be taught more about heavy metal pollution and safe soil practices, using simple languages and local examples.
2. The State Extension agents should teach farmers on how to use more cocoa pod ash, as it helps reduce lead in crops. Provide trainings on proper application techniques.
3. Governments should back clean farming practices through appropriate laws, subsidies, and effective pollution control measures.
4. Government should facilitate farmers' access to loans, grants, or affordable tools that enable them to adopt sustainable farming methods.

Declarations

Funding: The authors declared that no funding was received for this work.

Conflict of Interest: There is no conflict of interest whatsoever.

Dual publication: this manuscript has not at any time submitted to any journal outlet for publication or storage.

Permission to use third-party material: Every author declared and granted full access to all images, figures and tables in this manuscript have never been published.

Data availability: Data used for this study and publication have been included in the manuscript.

Consent to Participate: The authors obtained informed consent from all respondents before the commencement of data collection.

Ethical Statement: Ethical approval for this study was obtained from Osun State University Research Ethics Committee in accordance with the Declaration of Helsinki.

Human Ethics and Informed consent: Human ethics were duly followed in carrying out this study. Consents to participate was obtained from all survey participants after explaining the purpose of the study and assuring them of confidentiality. Participation was voluntary, and respondents were informed of their right to withdraw at any time without consequence. No experiment was performed on human and animal.

Consent to Publish declaration: not applicable.

Clinical trial number: not applicable.

References

1. Adewale P, Makinde SCO, Kusemiju VO. Assessment of Heavy Metal Residues in Soil and Vegetables along Urban-peri-urban gradient of Lagos State Nigeria. J Environ Issues Clim Change.

2023;2(1):70–7. https://doi.org/10.59110/jeicc.v2i1.99. published by Universitas Muhammadiyah Buton in Collaboration with Lembaga Riset dan. Inovasi Masyarakat Madani.

2. Ali H, Khan E, Sajad MA. Phytoextraction of heavy metals by Brassica juncea and sunflower: A sustainable approach for contaminated soil remediation. Environ Sci Pollut Res. 2013;20(2):947–55. https://doi.org/10.1007/s11356-012-1353-7v.
3. Chakraborty P, Kumar A, Banerjee S, Sharma R. Sustainable agriculture and heavy metal contamination: Challenges in circular agriculture systems. J Environ Manage. 2020;265:110550. https://doi.org/10.1016/j.jenvman.2020.110550.
4. Lal R. Conservation tillage for sustainable agriculture: Impact on soil organic carbon, water erosion, and soil structure. Soil Tillage Res. 2020;94(1):1–10. https://doi.org/10.1016/j.still.2007.01.001.
5. Nargave S, Patel A, Kumar R. Integrated approach combining fungicides and biocontrol agents for disease management: Effectiveness of Trichoderma viride. J Plant Pathol. 2023;41(2):235–49. https://doi.org/10.1016/j.jpp.2023.02.014.
6. Zhang X, Li Y, Wang J, Chen H, Liu Z. *Mitigating heavy metal risks in circular agriculture: Strategies and practices*. Environ Sci Pollut Res. 2018;25(15):14829–45. https://doi.org/10.1007/s11356-018-1654-2.