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Influence of pH Variation on Lead Uptake and Accumulation in *Raphanus raphanistrum* and *Brassica napus* Grown in Spiked and Limed Agricultural Soils of Moiben Sub-County, Kenya

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Abstract

This study assessed Pb uptake and distribution in *Raphanus raphanistrum* (RR) and *Brassica napus* (BN) grown in agricultural soils from Moiben Sub-County, Kenya, under three soil treatments: Pb-spiked soil (to ≈1000 mg/kg), non-spiked soil, and spiked soil amended with lime (to achieve pH≈7.4). Pb concentrations were quantified using Atomic Absorption Spectrophotometry (AAS), and the Bioaccumulation Factor (BAF) was calculated for roots, stems, leaves and seeds. Data were analyzed using SPSS v25. Descriptive statistics (means, standard deviations) were computed for Pb concentrations in soil and plant tissues. One-way ANOVA tested differences among treatments (control, spiked, limed), with Tukey's HSD applied for post hoc comparisons. Results showed that *Raphanus raphanistrum* accumulated mean Pb concentrations of 1043.80 ± 18.34 mg/kg in spiked soils, 25.49 ± 0.39 mg/kg in non-spiked soils, and 548.24 ± 17.75 mg/kg in spiked and limed soils. *Brassica napus* followed a similar trend, with significantly higher Pb accumulation in spiked compared to non-spiked soils, while liming reduced uptake by nearly 50%. In both species, roots exhibited the highest BAF across treatments, while stems consistently recorded the lowest. In spiked soils, the accumulation trend was roots > seeds > leaves > stem, whereas in limed soils it shifted to roots > leaves > seeds > stem, with overall BAF values reduced to <1. Although liming effectively reduced Pb uptake, both *Raphanus raphanistrum* and *Brassica napus* accumulated Pb levels in edible parts above FAO/WHO permissible limits (0.3 mg/kg for leafy vegetables, 0.1 mg/kg for root/tuber crops, and 0.2 mg/kg for cereals and oilseeds), raising concerns over food safety. The findings highlight the influence of soil amendments on metal bioavailability and underscore the phytoremediation potential of RR and BN, particularly in Pb-contaminated soils.

Keywords: Lead uptake, bioaccumulation factor, soil amendment, phytoremediation

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Introduction

Soil contamination by heavy metals represents a pervasive and persistent threat to global environmental health, food security and human safety. Among these toxic elements, lead (Pb) is one of the most widespread and hazardous due to its historical use in gasoline, paints, pesticides, and industrial processes (Wuana & Okieimen, 2011). Unlike organic pollutants, Pb is non-biodegradable and can accumulate in soils for centuries, posing long-term risks (Chandwani et al., 2023). Intensive agricultural practices have directly and indirectly contributed to elevated levels of Pb in soils through several pathways, including the historical long-term application of phosphate fertilizers and the use of Pb-arsenate pesticides that were widely applied in orchards and high-value crops before being banned (Akenga et al., 2020a; Gupta et al., 2014).

In Uasin Gishu County, intensive farming and prolonged application of inorganic fertilizers and pesticides have heightened the risk of soil contamination. In Moiben Sub-County, farmlands irrigated using water from River Moiben receive runoff containing agrochemical residues, which has been linked to elevated concentrations of heavy metals. Studies conducted in the region report that both soils and vegetables, especially kales grown along the river, contain lead levels surpassing FAO/WHO limits (Akenga et al., 2020a). Additional local assessments revealed that Pb concentrations in irrigation water and soils from Moiben often exceed background levels and, in some cases, surpass international safety thresholds (Akenga et al., 2020a; Akenga et al., 2020b). These findings validate the choice of Moiben as a suitable study site and underscore the need to understand Pb mobility and plant uptake in its agricultural systems.

Evidence from other parts of Kenya further supports the national relevance of this issue. Studies have documented excessive levels of lead, cadmium, and zinc in soils and vegetables from markets and farms in major urban and peri-urban areas (Choge et al., 2018). Such contamination patterns indicate that heavy-metal pollution is not localized but part of a broader environmental challenge linked to agricultural inputs, waste mismanagement, and polluted irrigation water.

Lead contamination presents serious public health risks. Chronic exposure, even at low concentrations, has been associated with neurological and cognitive impairments in children, and cardiovascular, renal, and reproductive disorders in adults (World Health Organization, 2024; Lanphear et al., 2024). Because Pb is non-biodegradable and persists in the environment, it readily enters the food chain through plant uptake, threatening human and animal health. This makes monitoring and mitigation of Pb in agricultural soils a key environmental and public health concern in Kenya.

Phyto-accumulation involves both plant physiology and soil physiochemical properties regarding toxic metals that need extraction. Soil pH is a crucial factor influencing the solubility, mobility, and bioavailability of lead in agricultural systems. Acidic conditions increase Pb solubility, promoting uptake by plants, while liming raises soil pH, causing Pb immobilization through precipitation and adsorption onto soil colloids (Kabata-Pendias, 2011; Wan et al., 2019). Managing soil pH through liming is therefore recognized as an effective remediation strategy to reduce heavy-metal uptake and prevent entry into the food chain. Evaluating pH variations under spiked and limed conditions can reveal how soil chemistry alters Pb availability and plant absorption patterns.

The study selected *Raphanus raphanistrum* (wild radish) and *Brassica napus* (canola) due to their known tolerance to heavy metals and rapid growth characteristics. These species have demonstrated significant potential for phytoremediation an eco-friendly approach that uses plants to remove or immobilize contaminants in soils. *B. napus* is widely recognized for its ability to extract lead and other metals through phytoextraction, while *R. raphanistrum* effectively stabilizes or accumulates metals depending on environmental conditions (Grispen et al., 2006; Zeremski et al., 2021; Sherif et al., 2024). Their high tolerance allows them to survive in contaminated soils, and their physiological responses make them suitable candidates for either phytoextraction (metal removal via harvestable tissues) or phytostabilization (immobilization in roots). Measuring bioaccumulation factors (BAF) across different tissues provides insights into these functional roles and their implications for food safety. Hence, this research examined Pb uptake and tissue distribution *in R. raphanistrum* and *B. napus* cultivated in Pb-spiked, non-spiked and limed agricultural soils from Moiben Sub-County, Kenya. The study was guided by the following objectives: (1) to determine the influence of liming-induced pH variation on Pb bioavailability in agricultural soils from Moiben; (2) to assess the differential Pb accumulation patterns across various plant tissues (roots, stems, leaves, and seeds); and (3) to evaluate the food safety implications and the phytoremediation potential of these two species. The findings are intended to contribute essential data for developing sustainable soil management practices and evidence-based strategies to mitigate Pb contamination risks in agricultural systems.

Materials and Methods

Study Area

The study was carried out in Moiben Sub-County, Uasin Gishu County, Kenya (Figure 1). The Sub-County lies between latitude 0.51670°N – 0.79740°N and longitude 35.28330°E – 35.38760°E. It is characterized by fertile agricultural soils, a temperate climate with mean annual rainfall of 1000–2000 mm, and moderate temperatures below 21°C. Moiben is predominantly an agricultural region with both small- and large-scale farming, mainly producing maize, wheat, beans, and horticultural crops. The area covers 769.8 km² and had a population of 181,338 in the 2019 census (KNBS, 2019).

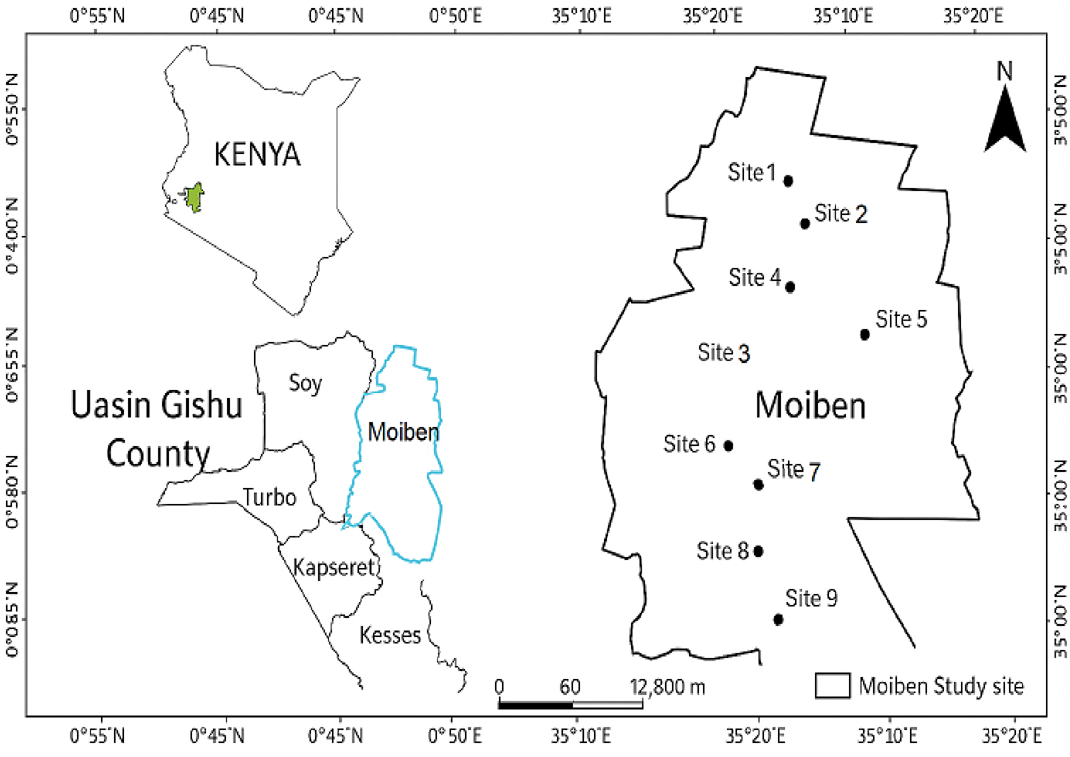

Figure 1: Study area map of Moiben

Soil Sampling

Composite soil samples were randomly collected from nine farms across five sites (Chepkanga, Kaprobu, Moiben, Ngoisa, and Kosyin Technical) within Moiben Sub-County. This broad sampling strategy aimed to capture the range of agricultural practices and potential contamination levels across the Sub-County.

At each farm, three sampling points were selected within 10×10 m2 quadrants. Soil was collected from the topsoil layer at a depth of 5–15 cm using a clean auger. The sub-samples were pooled, thoroughly homogenized, and reduced to a final sample size of approximately 1 kg by the quartering method. Each sample was packed in a labeled paper bag and transported to the University of Eldoret Biotechnology Laboratory for processing.

Collection of Plant Materials

Wild plants of *Raphanus raphanistrum* (RR) and *Brassica napus* (BN) were collected around soil sampling points and identified using taxonomic keys (Mabberley, 2021) and herbarium specimens. Plant tissues (roots, stems, leaves, and seeds) were separated, bagged, and transported for laboratory processing and Pb analysis.

Seed Collection and Preparation

Mature, viable seeds of RR and BN were collected from local populations. The seeds were air-dried at 25–45∘C and stored at room temperature.

To ensure high and uniform germination for the greenhouse trial, germination tests were performed using seeds collected from Site 6 (Atanas Farm), which was selected due to its accessibility and relatively high background Pb concentration in the field soil. Germination was promoted by pre-treatment with gibberellic acid (GA_3) and potassium nitrate (KNO_3) solutions prior to sowing.

Soil pH Determination

Soil pH was determined following US EPA Method 9045D, using a soil-to-water/$CaCl_2$ ratio of 1:2.5. Measurements were taken with a calibrated Desk pH meter (PHS-3D) in triplicate.

Soil Spiking with Lead

Soils from Site 6 (Atanas Farm), which were moderately contaminated and accessible, were selected for greenhouse trials. A total of 250 kg of soil was collected, homogenized, air-dried, and sieved (2 mm). Soils were spiked with $Pb(NO_3)_2$ to achieve a concentration of 1000 mg Pb/kg. Based on molar mass calculations, 3.5 g of $Pb(NO_3)_2$ dissolved in 1000 mL distilled water was applied to 3 kg soil per pot. Spiked soils were incubated for 24 hours to allow Pb equilibration.

Soil Liming (pH Adjustment)

To evaluate pH influence, agricultural lime ($CaCO_3$) was applied to raise soil pH from 4.15 to ~7.4. Based on lime requirement guidelines (Brady & Weil, 2008), 50 g of $CaCO_3$ was added to 3 kg soil per pot. Limed soils were incubated for one week with periodic mixing and moistening.

Experimental Design

The greenhouse trial was conducted using a total of 24 pots (3 kg soil each) arranged in a Completely Randomized Design (CRD). The experiment consisted of three main treatments, each replicated four times (n=4) for both species as indicated in Table 1.

Table 1: Experimental Design of the Greenhouse Trial Showing Treatments and Replicates

Treatment	Soil Preparation	*Raphanus raphanistrum* (RR)	*Brassica napus* (BN)
Control	Unspiked, unlimed Site 6 soil	4 pots	4 pots
Spiked	Pb-spiked soil (1000 mg Pb/kg)	4 pots	4 pots
Limed	Pb-spiked soil + $CaCO_3$	4 pots	4 pots

Pre-soaked seeds were sown at 2 cm depth. To minimize competition and ensure measurable Pb accumulation per plant, the pots were thinned to one healthy seedling per pot one week after emergence.

Plant Growth and Harvest

Germination was monitored weekly until 100% emergence. Plants were grown for three months, after which roots, stems, leaves, and seeds were harvested, sun-dried, ground, and prepared for Pb analysis.

Soil Digestion and Pb Analysis

Soils were digested using HNO_3, HF, and $HClO_4$ following U.S. EPA Method 3050B. Pb concentrations were determined using Atomic Absorption Spectrophotometry (AAS, model AI1200) with standard calibration.

Plant tissues were digested using microwave-assisted digestion with HNO_3 and H_2O_2, following Huang (2004). Pb content was quantified using AAS Analyst 400 at 217.0 nm, calibrated with Pb standard solutions (1–20 mg/L).

Data Analysis

Data were processed in Microsoft Excel and analyzed using SPSS v25. Descriptive statistics (means, standard deviations) were computed for Pb concentrations in soil and plant tissues. A One-way Analysis of Variance (ANOVA) was used to test for significant differences in Pb uptake among the three treatments (Control, Spiked, Limed). Tukey's HSD post hoc test was applied to identify specific pairs of treatments that differed significantly. A significance threshold of $p<0.05$ was used for all statistical tests.
The Bioaccumulation Factor (BAF) was calculated for each plant tissue as a measure of Pb uptake efficiency:

$$\mathrm{BAF} = \frac{C_{plant}}{C_{soil}}$$

Where C_{plant} is Pb concentration in plant tissue (mg/kg) and C_{soil} is total Pb concentration in soil (mg/kg). A significance threshold of $p < 0.05$ was used.

Results and Discussion

Lead uptake in experimental plants (*Raphanus raphanistrum* and *Brassica napus)* grown in lead spiked and limed agricultural soils

Plants grown in ordinary soils collected from site 6, with a pH of 4.15 ± 0.02 and spiked with lead nitrate accumulated significantly higher levels of lead into the plant roots compared to both the plants grown in non-spiked soils (control) and the soils that were spiked with lead and limed with calcium carbonate to raise the pH (Figure 2).

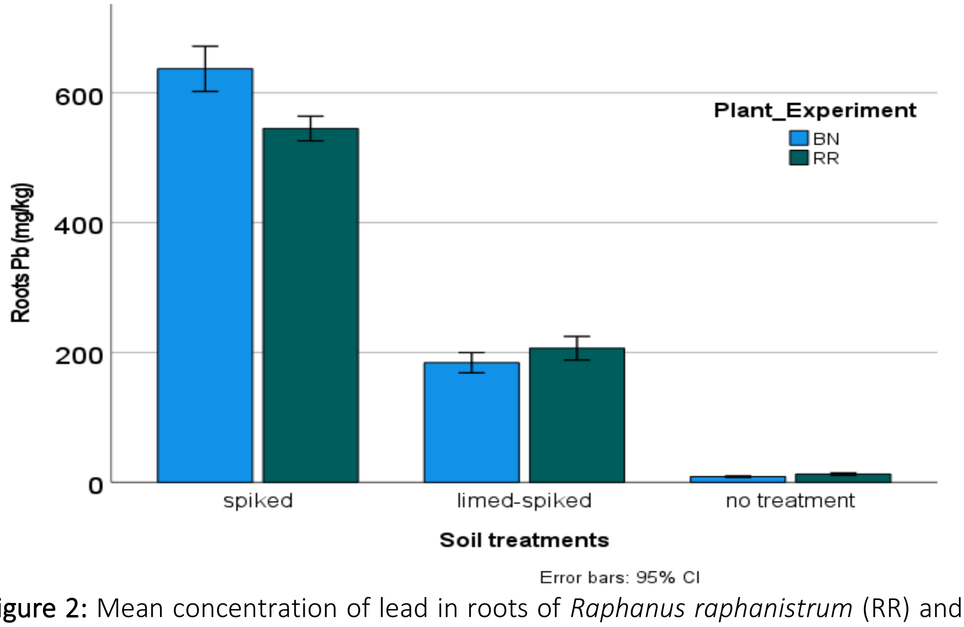

Figure 2: Mean concentration of lead in roots of *Raphanus raphanistrum* (RR) and *Brassica napus* (BN) plants in spiked, limed-spiked and not spiked soils

The results indicate that soil pH plays a critical role in regulating lead (Pb) bioavailability and uptake by plants. In this study, *Raphanus raphanistrum* and

Brassica napus grown in strongly acidic soils (pH 4.15) spiked with lead nitrate accumulated significantly higher Pb concentrations in their roots compared to plants grown in control soils or in Pb-spiked soils that were limed with calcium carbonate. The higher uptake in acidic conditions can be attributed to increased Pb solubility and mobility at low pH, which enhances root absorption (Bolan et al., 2014). Conversely, liming raised soil pH, leading to Pb precipitation and reduced bioavailability, thereby lowering accumulation in plant tissues (Gupta et al., 2014). These findings align with previous studies highlighting liming as an effective strategy for immobilizing heavy metals in contaminated soils (Zhang et al., 2020).

Roots

The root tissues of both BN and RR served as the primary sink for Pb across all treatments, confirming their role as the initial barrier and main sequestration site for heavy metals in plants (Pourrut et al., 2011). However, significant differences were observed under highly contaminated conditions.

In the acidic Pb-Spiked soil, BN roots accumulated a mean Pb concentration of 637.12±24.32 mg/kg, which was significantly higher than the 545.14±12.67 mg/kg accumulated by RR roots. This result demonstrates a species-specific difference in the capacity for Pb absorption, suggesting that BN may possess slightly more efficient root uptake mechanisms or favorable root morphology that enhances metal acquisition in acidic, bioavailable conditions (Ali et al., 2013). This tendency characterizes BN as a stronger root sequesterer compared to RR under acidic stress. As expected, the lowest concentrations were recorded in the non-Spiked control soils (BN:8.84±0.78 mg/kg; RR:12.61±1.24 mg/kg), unequivocally confirming that soil contamination level is the primary determinant of root Pb accumulation (Kopittke et al., 2010).

The application of lime to the Pb-Spiked soil dramatically reduced the mean Pb accumulation in the roots of both species, validating its effectiveness as a remediation strategy. In the limed soil, BN roots contained 184.27±10.1 mg/kg, and RR roots contained 206.61±10.81 mg/kg. Crucially, the difference in accumulation between the two species in the limed soil was no longer statistically significant. This indicates that the pH-induced reduction in Pb bioavailability—by immobilizing the metal in the soil matrix (Zhou et al., 2014)—effectively overrode the inherent species-specific differences in initial root uptake capacity. These findings strongly highlight liming as a crucial management practice for mitigating Pb uptake in crops, transforming the strategy from one of high root sequestration (BN in spiked soil) to effective phytostabilization for both species.

Stem

Figure 3 shows concentration of lead in stems of BN and RR plants grown in lead spiked soil, spiked and limed soil and ordinary agricultural soil (control). RR stems accumulated significantly more lead as compared to those of BN, with a mean concentration of 88.17 ± 8.23 mg/kg and 48.14 ± 6.69 mg/kg respectively in lead spiked soil. In the limed soils, RR accumulated significantly higher levels of lead in the stem (52.61 ± 12.56 mg/kg) as compared to BN (32.83 ± 3.65 mg/kg).

The observed data indicate that *Raphanus raphanistrum* (RR) accumulated significantly higher concentrations of lead (Pb) in stems compared to *Brassica napus* (BN) under both spiked and limed soil conditions. In Pb-spiked soils, RR stems contained 88.17 ± 8.23 mg/kg, nearly twice the concentration in BN stems (48.14 ± 6.69 mg/kg), suggesting that RR may possess a greater capacity for Pb translocation from roots to shoots (Ali et al., 2013). Similarly, in limed soils, RR continued to accumulate more Pb (52.61 ± 12.56 mg/kg) than BN (32.83 ± 3.65 mg/kg), though liming reduced overall Pb uptake, consistent with reports that higher soil pH decreases Pb bioavailability (Zhou et al., 2014). These results highlight species-specific differences in Pb partitioning, with RR showing stronger stem accumulation, a trait relevant for phytoremediation strategies (Yoon et al., 2006).

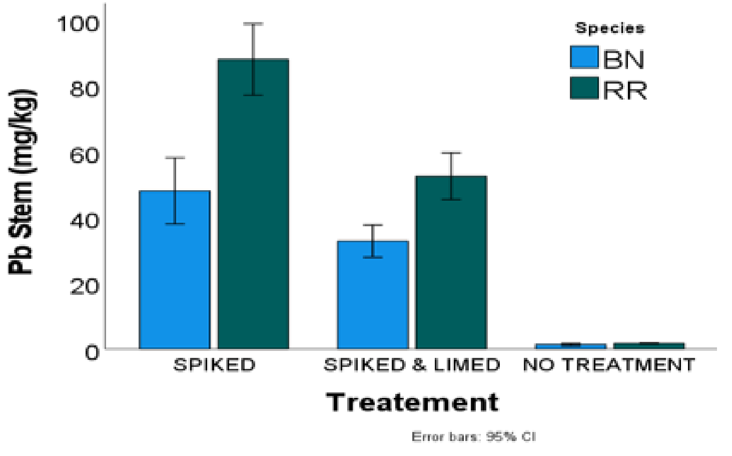

Figure 3: Mean concentration of Lead in stem of *Raphanus raphanistrum* (RR) and *Brassica napus* (BN) plants in spiked, limed-spiked and not spiked soils

Leaves

Figure 4 shows the concentration of lead in leaves of RR and BN plants grown in three soil treatments. In spiked agricultural soil, BN accumulated more lead (269.81 ± 34.8 mg/kg) in leaves as compared to RR (210.73 ± 38.6 mg/kg) although the difference was not significant.

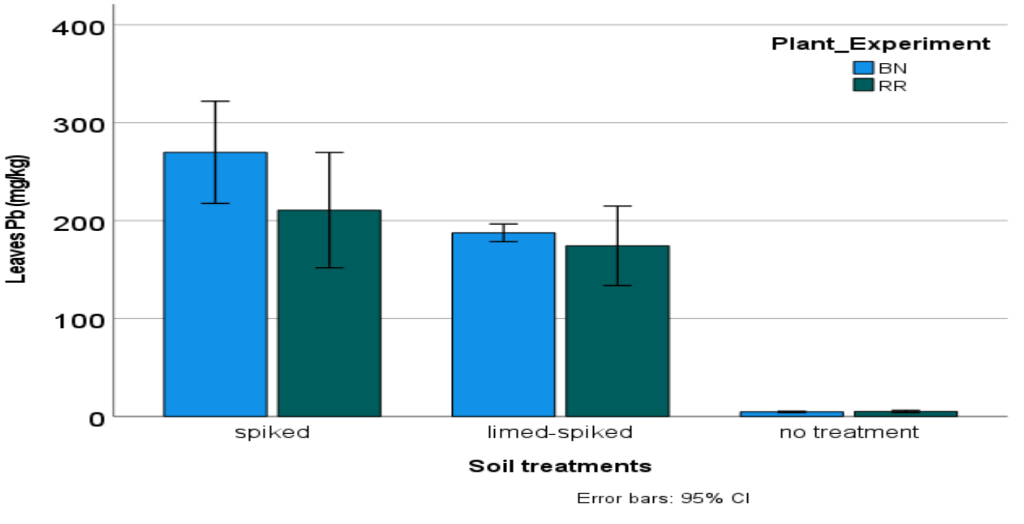

Figure 4: Mean concentration of lead in leaves of *Raphanus raphanistrum* (RR) and *Brassica napus* (BN) plants in spiked, limed-spiked and not spiked soils

For spiked and limed soil, BN leaves also accumulated more Pb (187.58 ± 6.62 mg/kg) as compared to that of RR (174.37 ± 24.68 mg/kg). For the controls, RR accumulated more lead (5.165 ± 0.76 mg/kg) compared to BN (4.7 ± 0.51 mg/kg). Generally, the means for all the treatments were not significantly different.

The results show that both *Brassica napus* (BN) and *Raphanus raphanistrum* (RR) accumulated substantial amounts of lead (Pb) in their leaves under Pb-spiked and limed conditions, though differences between the two species were not statistically significant. In Pb-spiked soils, BN leaves had slightly higher Pb concentrations (269.81 ± 34.8 mg/kg) than RR (210.73 ± 38.6 mg/kg), suggesting a marginally greater translocation efficiency to aerial tissues (Chunilall et al., 2005). Similarly, under limed soils, BN leaves contained 187.58 ± 6.62 mg/kg compared to RR at 174.37 ± 24.68 mg/kg, consistent with studies showing that liming reduces Pb bioavailability but does not eliminate uptake (Zhou et al., 2014). Interestingly, in control soils, RR accumulated slightly more Pb than BN, indicating species-specific physiological differences. Overall, both species demonstrate strong foliar Pb accumulation, which is important in evaluating phytoremediation potential (Yoon et al., 2006).

Seeds

Brassica napus (BN) seeds generally accumulated more lead as compared to RR seeds across the soil treatments (Figure 5). For the controls (no treatment), RR plants accumulated more lead (5.99 ± 0.15 mg/kg) than BN (5.66 ± 0.62 mg/kg) although the difference was not significant. In spiked agricultural soil, BN seeds recorded a significantly higher concentration of lead (348.75 ± 18.37 mg/kg) compared to RR (214.77 ± 16.86 mg/kg). In limed soil, BN accumulated more lead (130.98 ± 7.41 mg/kg) as compared to RR (114.66 ± 6.54 mg/kg) but the difference was not significant.

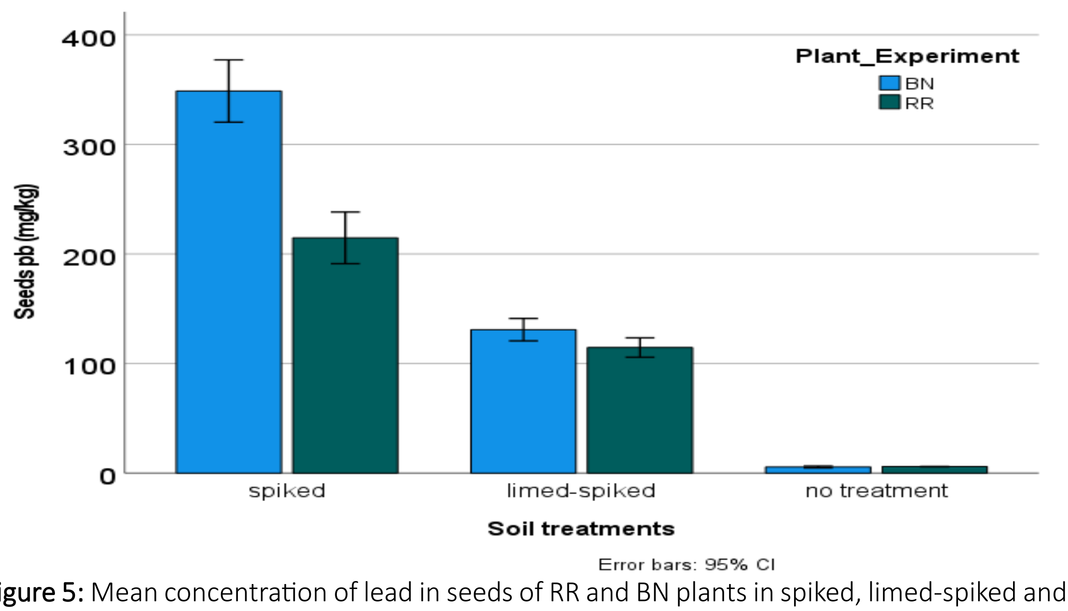

Figure 5: Mean concentration of lead in seeds of RR and BN plants in spiked, limed-spiked and not spiked soils

The results indicate that *Brassica napus* (BN) seeds accumulated consistently higher concentrations of Pb than *Raphanus raphanistrum* (RR) across most treatments, highlighting species-specific differences in Pb translocation to reproductive tissues. In Pb-spiked soils, BN seeds showed significantly greater Pb levels (348.75 ± 18.37 mg/kg) compared to RR (214.77 ± 16.86 mg/kg), suggesting that BN may have a stronger tendency to allocate Pb into seeds, which raises concerns regarding food-chain contamination (Sharma & Dubey, 2005). Liming reduced Pb concentrations in both species, but BN still accumulated more Pb (130.98 ± 7.41 mg/kg) than RR (114.66 ± 6.54 mg/kg), aligning with studies that liming decreases metal mobility yet does not completely prevent uptake (Zhou et al., 2014). In controls, RR seeds contained slightly higher Pb, though without significance, reflecting natural variability. Overall, BN demonstrated higher Pb accumulation potential in seeds compared to RR (Yoon et al., 2006).

Total mean lead concentration of *Brassica napus* (BN) and *Raphanus raphanistrum* (RR) in different soil treatments

The mean concentration of lead in *Brassica napus* grown in spiked soil was 1303.8200 ± 16.53 mg/kg, non-spiked 20.5500 ± 0.09 mg/kg and spiked and limed 565.6600 ± 13.02 mg/kg are shown in Table 2.

Table 2: Mean concentration of lead in all plants parts of *Brassica napus* (BN) and *Raphanus raphanistrum* (RR) grown in different soil treatments

Treatments	N	BN mean (mg/kg)	RR mean (mg/kg)
Spiked	4	1303.82 ± 16.53[a]	1043.8025 ± 18.34[b]
Limed and Spiked	4	565.66 ± 13.02[a]	548.24 ± 17.75[a]
No Treatment	4	20.55 ± 0.09[a]	25.4875 ± 0.39[b]

(Mean ± SD). Means with different superscript across the rows are significantly different (P<0.05)

Raphanus raphanistrum (RR) grown in spiked soils exhibited a mean lead concentration of 1043.80 ± 18.34 mg/kg, in non-spiked soils 25.4875 ± 0.39 mg/kg, and in spiked and limed soils 548.24 ± 17.75 mg/kg. This reveals significant mean differences in lead concentrations in the two plants in two soil treatments, specifically between spiked soils and non-spiked soils. Spiked while limed soils mean values for both plants had no significant difference.

The findings show that *Raphanus raphanistrum* (RR) roots accumulated markedly higher Pb concentrations in spiked soils (1043.80 ± 18.34 mg/kg) compared to non-spiked soils (25.49 ± 0.39 mg/kg), confirming the strong influence of soil contamination levels on Pb uptake. Such substantial differences emphasize the root's role as the primary sink for heavy metals, consistent with studies highlighting root accumulation as the first line of Pb immobilization in plants (Pourrut et al., 2011). In spiked and limed soils, Pb concentrations in RR roots decreased to 548.24 ± 17.75 mg/kg, suggesting that liming effectively reduced Pb bioavailability by immobilizing metal ions in soil (Zhou et al., 2014). However, no significant difference was observed between RR and BN in limed treatments, indicating that soil amendment reduced interspecies variation in Pb uptake.

Bioaccumulation

The bioaccumulation of lead in the different plant parts across the soil treatments is shown in Figure 6.

Roots had significantly higher bioaccumulation factor in both plants across the soil treatments. Stem recorded the lowest bioaccumulation factor in both plants in all treatments. In spiked and non-spiked soils, there was a higher BAF in seeds as compared to the leaves. In spiked and limed soil treatment, both plants obtained a higher BAF in leaves compared to seeds. In the soils that were limed, bioaccumulation factor was reduced significantly to < 1 in all parts of both plants. RR and BN grown in spiked agricultural soil recorded the same trend of BAF where roots > seeds > leaves > stem, where RR recorded 1.6484 > 0.6494 > 0.6372 > 0.2212 respectively and BN obtained 2.3812 > 1.3034 > 1.0084 > 0.1799. In limed and spiked soil, both plants obtain BAF where roots> leaves>seeds>stem. RR recorded 0.3982 > 0.3360 > 0.2209 > 0.1014 and BN 0.5702 > 0.5605 > 0.4053 > 0.1944 respectively. The controls had a trend was similar to that of spiked agricultural soil where roots > seeds > leaves > stem respectively.

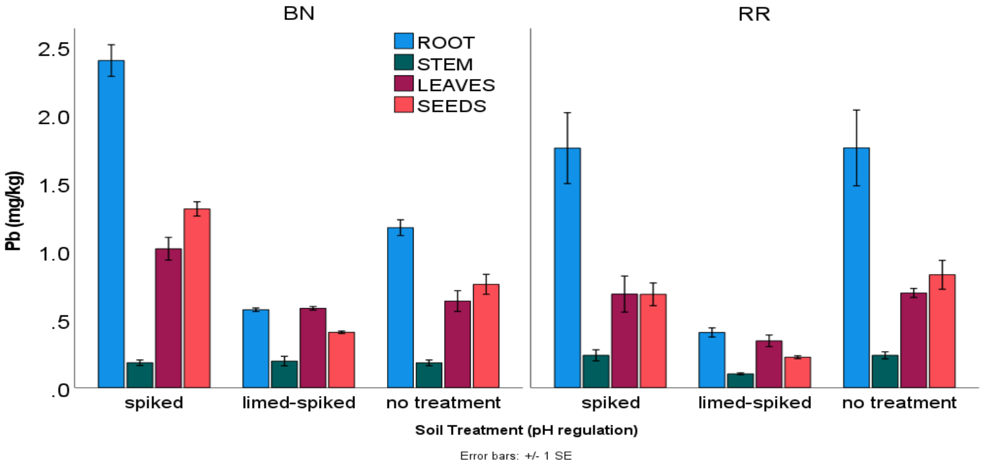

Figure 6: Bioaccumulation factor in the two different plants under three soil treatments

The results indicate that roots exhibited the highest bioaccumulation factor (BAF) in both *Raphanus raphanistrum* (RR) and *Brassica napus* (BN) across all soil treatments, reaffirming the role of roots as the primary site of lead sequestration (Pourrut et al., 2011). Stems consistently showed the lowest BAF values, suggesting limited Pb translocation into vascular tissues. In spiked and non-spiked soils, seeds accumulated more Pb than leaves, whereas in spiked and limed soils, leaves had higher BAF values than seeds, reflecting how liming alters Pb mobility and uptake pathways. Importantly, liming significantly reduced BAF to values < 1 in all plant parts, demonstrating its effectiveness in lowering Pb bioavailability (Zhou et al., 2014).

Conclusions

Based solely on the controlled greenhouse experiment, the study demonstrated that soil pH management is the primary factor controlling lead (Pb) bioavailability and subsequent uptake by crops. The acidification of the soil (initial pH 4.15) significantly enhanced Pb mobility, leading to high accumulation in both *Brassica napus* (BN) and *Raphanus raphanistrum* (RR). Under these highly bioavailable conditions, BN showed higher accumulation in the roots and seeds than RR, suggesting it is a strong root sequesterer and potential phytoextractor. However, the application of lime to raise the pH to near-neutral levels (≈7.4) resulted in a ~50% reduction in Pb uptake in both species, virtually eliminating the interspecies difference in total Pb accumulation. While this liming practice successfully reduced Pb bioavailability, indicated by the Bioaccumulation Factor (BAF) dropping below 1, a critical food safety risk remains: Pb concentrations in the edible tissues of both species still exceeded FAO/WHO safe limits. Therefore, while liming is an effective immobilization strategy, it is insufficient to guarantee crop safety in severely contaminated soils.

Recommendations

The recommends that pH management should be adopted as a general, effective practice for controlling Pb and other cationic metal contamination in acidic agricultural soils. Farmers, particularly those in areas like Moiben Sub-County, should be actively encouraged to test and lime their soils to raise the pH, thereby reducing Pb solubility and minimizing its entry into the food chain. This practice effectively utilizes the Phytostabilization potential of crops. Given the substantial accumulation observed, BN and RR should be evaluated further for their potential use in Phytoextraction programs designed for large-scale cleanup of highly contaminated acidic lands. However, where soil Pb levels are extreme, growing these species for human or animal consumption, even after liming, must be carefully reconsidered. Therefore, further long-term field research is needed to fully assess the efficacy of these species in various Kenyan soil types and cropping systems to establish their sustainability as safe crops or viable remediation options.

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