

Lead absorption capacity in different parts of plants and its influencing factors: a systematic review and meta-analysis

lulu jia (✉ jl1348838200@163.com)

Mudanjiang Medical University

Hongkun Ma

Mudanjiang Medical University

Yue Guan

Mudanjiang Medical University

Lina Zou

Mudanjiang Medical University

Lan Jiang

Mudanjiang Medical University

Yongzheng Hang

Mudanjiang Medical University

Xiaoyan Feng

Mudanjiang Medical University

Xiaowei Ren

Mudanjiang Medical University

Yuting Tian

Mudanjiang Medical University

Hongzhi Pan

Shanghai University of Medicine and Health Sciences

Shengzhong Rong

Mudanjiang Medical University

Research Article

Keywords: meta-analysis, heavy metals, plants, lead metal absorption, accumulation

Posted Date: August 12th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1852447/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

People pose a serious risk by eating plants contaminated with lead in their soil. Lead enrichment in different parts of plant roots, stems, and leaves is controversial. Accordingly, a meta-analysis was conducted to investigate the ability of different plants to enrich lead and the main factors for lead absorption. The results of this study indicated that all parts of plants accumulated significantly lead. The concentrations of lead in different parts of root, stem and leaf were analyzed, and it was found that these concentrations followed an order of root > stem > leaf. Alkaline soil was beneficial to lead absorption by plants in this study. Significant differences were found in lead enrichment ability among vegetables, gramineae and trees. When the lead concentration in soil was higher than 20mg/kg, the lead absorption in different parts of roots, stems, and leaves was more. Lead is most absorbed in trees (e.g., *ulmus pumila* and *murraya paniculate*). It is the least in gramineae (e.g., rice, maize plants, and sweet sorghum). It is argued that this study is beneficial to select vegetables suitable for absorption of heavy metals from polluted soil. This study can help to clarify the ability of a variety of plant parts to enrich lead and the factors for lead enrichment in plants, so as to propose more reasonable lead pollution control strategies and guide people to make healthy choices when choosing edible plants.

1. Introduction

With the rapid development of industrialization, environmental pollution has aroused great attention from the public. Soil heavy metal pollution is a serious ecological problem at present. Since it is not easy to degrade, it can trigger serious health crisis. Heavy metal pollution is exacerbated by urbanization, industrialization, waste gas, waste water and residues, and excessive use of chemical fertilizers and pesticides (Page et al., 2014; Robinson et al., 2008; Zhivotovsky et al., 2011). Among the above heavy metals, lead is not only highly toxic, but can also be absorbed and accumulated by different plants. Lead can accumulate in the food chain and harm human health (Pan et al., 2016). Little concentrations of lead can damage the nervous, enzymatic, endocrine, immune, skeletal, as well as circulatory systems. Others can make disorders in the lung, kidney, and liver and some are carcinogenic (Emamverdian et al., 2015).

Grains, vegetables and other medicinal plants are an essential part of our diet. They are the major components of the human diet and are capable of providing protein, dietary fiber, vitamins, antioxidants, and other beneficial substances for the human body (Slavin et al., 2012). Lead contamination is undoubtedly one of the most concerned issues of the safe production of edible vegetables. Heavy metals can be absorbed through the roots, stems, and leaves of plants and are concentrated in plants. It has been reported that vegetable intake is the main source of lead for most people (Zhuang et al., 2009). Existing studies have found high levels of lead in green leafy vegetables (Pan et al., 2016). Studies have suggested that the content of lead in celery root is approximately 50 times that in stem, and the content of lead in leaves is nearly 9 times that in stem (Meng et al., 2013). The ability of different plants to accumulate lead is controversial. Zunaidi, AA et al. suggested that the lead enrichment ability of Brassicaceae in different parts of root, stem and leaf follows an order of leaf > stem > root (Zunaidi et al., 2021). Zhang Wentao et al. suggested that the concentration of lead in *Ipomoea aquatica* Forsk is root > stem > leaf, and the concentration of lead in *Artemisia selengensis* Turcz is root > leaf > stem (Zhang et al., 2010). Thus, the differences of lead absorption capacity of different plants in soil should be clarified. Accordingly, to clarify the enrichment ability of different plants to lead can be more helpful to the prevention of lead pollution, and guide people's diet and food processing.

Besides, the ability of green plants to absorb lead from soil is often dependent on the plant itself, as well as the physical and chemical properties of the soil, pH of the soil, the soil organic matter content, plant species and soil lead concentration. Lead accumulates easily in plants when it is bioavailable, and soil properties significantly affect the mobility and availability of lead in soil. The decrease of soil pH value also facilitates the migration of Pb from root to bud and improves the availability of lead (Xalxo et al., 2018). Romero-freire et al. highlighted that lead availability in soil is controlled by pH and carbonate content (Romero-Freire et al., 2015). Mleczek et al. suggested that there is a correlation between the accumulation of lead in plants with different tissues and the physical and chemical properties of soil (Mleczek et al., 2009). It has been confirmed that the lead concentration in rice grains is significantly correlated with soil pH and organic matter content (Zhao et al., 2020).

Although numerous studies have examined differences in lead uptake by different plants, most have reached qualitative conclusions, instead of quantitative conclusions. In other words, they lack systematic synthesis and reliable conclusions. Lead in soil can be enriched and absorbed by different parts of plants, whereas different studies have found that the ability of plants in different parts to enrich lead is controversial. Thus, the strength of the ability of plants in different parts to enrich lead was evaluated through a meta-analysis, and the factors for the ability of plants in different parts to enrich lead were analyzed in this study. At present, there have still been rare meta-analyses on the absorption of heavy metal lead by plants in different parts, and there have been scarce studies

elaborating its mechanism systematically, so this study was conducted to provide more data support and lay a theoretical basis. A meta-analysis was conducted to summarize lead absorption in different plants. (1) The lead absorption capacity of different vegetables was analyzed and compared to provide a reference for future research. (2) The differences of lead absorption in roots, stems, and leaves of different parts of plants were compared. (3) Based on the change trend of lead absorption in various vegetables, reasonable suggestions were provided for vegetable planting.

2. Methods

2.1 Documentation indexing

We collected all the data from the Web of Science(WOS), PubMed, Google Scholar and the China National Knowledge Infrastructure (CNKI) for the period 2005–2021(The library will be built until October 4, 2021). First, we identified a number of key words, including “vegetables”, “plants”, “lead/Pb”, “absorption of lead/Pb”, “uptake of lead/Pb”, “heavy metal”. In addition, we only consulted complete articles from which all data were made available for analysis. Besides, citation lists of the retrieval results were checked to find other related researches, and we scanned the reference section of the papers found in this search for additional, undetected, relevant publications.

2.2 Research and data selection

Inclusion criteria: (1) A publication had to report lead concentration ($\pm$ SD and sample size) in plant parts (root, stem, leaf) of plants growing in contaminated soils; (2) The objects of studies contained plants; (3) There are similar literature research methods; (4) The literature contains detailed data on the physical and chemical properties of soils. (5) In order to accurate analysis, all measurement units were transformed into the dry-weight unit (mg/kg).

Exclusion criteria: (1) Any substance that can affect lead absorption (such as EDTA, soil amendments, plant growth regulators and surfactants); (2) The original data of lead concentration cannot be extracted in the literature; (3) We did not include unpublished data, newspapers with poor data quality, review article, books, clinical trial studies, incomplete literature or articles that were only summaries of previous literature; (4) Different parts of the plant were treated with different concentrations of lead.

2.3 Data extraction and literature quality evaluation

We reviewed and evaluated each study, eliminating reports and studies with repeatability, poor study quality, low information availability, incomplete data, conference literatures and review literatures. Two independent researchers shall extract the relevant information of each literature that meets the inclusion criteria. If there is any difference, discuss and solve it or request the assistance of a third party to solve it. Data were extracted from text descriptions, tables, and graphs of the original literature. Select the following information from each study: (1) The name of the first author, the year of the experiment, and the place of the experiment; (2) Detailed values of determination of root, stem and leaf concentration ($M \pm SD$); (3) Soil physical and chemical properties (soil pH); (4) The concentration of lead in soil; (5) Sample quantity.

2.4 Statistical Analysis

The overall mean effect size and its bias-corrected 95% confidential interval (CI) of each group were calculated with STATA software version 16.0(Wang et al., 2008). Heterogeneity is identified to determine whether the results of multiple studies can be combined. Weighted mean difference (WMD) and standardized mean difference (SMD) were used as effect indexes for continuous data. Heterogeneity among the included studies was qualitatively analyzed by Chi-Square test ($\alpha = 0.1$), and the source of heterogeneity was quantitatively analyzed by I^2 . The greater the value of I^2 , the higher the heterogeneity(Zhang et al., 2018). If there was heterogeneity between studies ($P < 0.1$, $I^2 > 50\%$), all studies used the random-effect model, and meta regression and subgroup analysis were further used to explore the source of heterogeneity(Sha et al., 2019).

Subgroup analysis was employed to assess the impact of various factors. Part of the larger heterogeneity analysis was combined with factors that may have led to heterogeneity of data in a meta-regression. STATA 16.0 software was used to build a regression model through analysis of the influence of the t-value and P -value to determine heterogeneity of variables. Statistical significance was assumed at $P < 0.05$.

Meta-analysis was employed to revise and eliminate publication bias using funnel plots and the Begg method. The funnel plot shows the symmetrical distribution of scattered points(Schwarzer, et al., 2010). A shearing method was used to eliminate outliers, or other abnormal values, and to fix missing parts along the central part of the funnel plot and both sides of the center(Schwarzer et al., 2010). If publication bias exists, the non-parametric Trim and Fill method is used to correct the publication bias. On the basis of allowing the existence of publication bias, the effect size and significance after modification are estimated by filling and correcting the missing references. The results are compared with the original results to evaluate the reliability of the analysis results.

A sensitivity analysis was used to combine the data and to observe the effect size of the combined values of effect size (ES)(Peng et al., 2018); a 95% CI was used to estimate whether statistically significant changes were produced. It was used to explore the stability of the results. We conducted sensitivity analysis on the 15 literatures included in this study by "excluding the included literatures one by one".

3. Results

3.1 Study search

A total of 1287 studies were yielded through the study search, in which only 15 studies were included, including 11 Chinese studies and four English studies. Details of the included studies are presented in Fig. 1.

3.2 Basic features of studies

Conference studies and retrospective studies with repeatability, poor quality, incomplete data were excluded through the systematic review and the quality evaluation of the respective study. The data extracted and included in this study are listed in Table 1 below.

Table.1 Statistics from 15 published studies

No.	Authors	Year	pH	Concentrations (mg/kg)	Plant	Reference
1	Li Xiaoming	2009	5.9	18.34	rice	(Li et al., 2009)
2	Zhou Ying	2012	6.0	21.24	maize plants	(Zhou et al., 2012)
3	Xue Zhongcai	2020	6.7	52.00	sweet sorghum	(Xue et al., 2020)
4	Liu Qinghai	2019	8.0	9.26	barley	(Liu et al., 2019)
5	Ruyi Yang	2011	4.59	23.27	maize plants	(Yang et al., 2012)
6	A.K.Gupta	2007	7.2	0.70	huanghua	(Gupta et al., 2007)
7	Chen Yanhong	2010	7.5	0.0033	rape	(Chen et al. 2010)
8	Hanaa S.Shehata	2020	8.58	9.08	cucumber	(Shehata et al., 2020)
9	Huilong Xia	2009	5.29	21.23	sugarcane	(Cheng et al., 2009)
10	Huang Kaifeng	2009	7.54	0.17	zizania latifolia	(Huang et al., 2009)
11	Zhang Yongchao	2011	7.9	30.43	ulmus pumila	(Zhang et al., 2011)
12	Zhao Yangdi	2018	6.2	37.58	murraya paniculata	(Zhao et al., 2019)
13	Feng Gongneng	2008	8.39	6.24	green peppers	(Feng et al., 2008)
14	Xiang Yanci	2010	6.21	12.36	rape	(Yang et al., 2010)
15	Huang Baojian	2010	5.9	28.52	ipomoea aquatica forsskal	(Zhang et al., 2010)

3.3 Differences of lead enrichment ability in different parts of roots, stems, and leaves

Heterogeneity is the differences among all the studies included in the same meta-analysis. The higher the degree of overlap between the confidence intervals, the less possibility there is statistical heterogeneity among the studies; on the contrary, the smaller the degree of overlap between the confidence intervals, the more possibility there is statistical heterogeneity among the studies. This part discusses the enrichment ability of plant roots, stems, and leaves to lead, analyzes the source of heterogeneity, and studies the factors for the absorption of lead in roots, stems, and leaves.

3.3.1 The strength of root-stem enrichment ability

Heterogeneity test was carried out for the included studies. The results of heterogeneity test were $P=0.001$ and $I^2=88.5\%$, thus suggesting that there was strong heterogeneity in the study of root-stem lead enrichment ability, so the random effect model was used for meta analysis. The enrichment capacity of lead in root was significantly higher than that in stem, and the combined effect was statistically significant [SMD=9.51, 95%CI (5.85~13.16), $P<0.001$].

3.3.2 The strength of root-leaf enrichment ability

Heterogeneity test was carried out for the included studies. The results of heterogeneity test were $P=0.001$ and $I^2=87.6\%$, thus suggesting that there was strong heterogeneity in the study of root-leaf lead enrichment ability, so the random effect model was used for meta analysis. The enrichment capacity of lead in root was significantly higher than that in leaf, and the combined effect was statistically significant [SMD=8.62, 95%CI (5.40~11.84), $P<0.001$].

3.3.3 The strength of stem-leaf enrichment ability

Heterogeneity test was carried out for the included studies. The results of heterogeneity test were $P=0.001$ and $I^2=88.7\%$, thus suggesting that there was strong heterogeneity in the study of stem-leaf lead enrichment ability, so the random effect model was used for meta analysis. The enrichment capacity of lead in stem was significantly higher than that in leaf, and the combined effect was not statistically significant [SMD=1.06, 95%CI (-1.21~3.33), $P=0.358$].

3.4 Factors that affect the lead adsorption capacity of plants

3.4.1 Factors for root - stem lead adsorption capacity of plants

3.4.1.1 Soil pH

To study the effect of plants on lead enrichment ability under different pH conditions, pH was assigned into less than 6.5 (acidic), 6.5 ~ 7.5 (neutral), and more than 7.5 (alkaline) for subgroup analysis to explore the source of heterogeneity and analyze the effect of plants on lead enrichment based on different subgroups.

The total root-stem heterogeneity was $P<0.001$ and $I^2=88.5\%$. When pH was less than 6.5 ($P<0.001$, $I^2=82.4\%$); when pH was 6.5 to 7.5 ($P=0.001$, $I^2=86.4\%$); and when pH was higher than 7.5 ($P=0.105$, $I^2=47.7\%$). Subgroup analysis was conducted after the establishment of pH subgroups. It was found that the heterogeneity of the two groups with $pH<6.5$ and $pH\ 6.5\sim7.5$ remained nearly unchanged, and the heterogeneity of $pH>7.5$ decreased compared with the total heterogeneity. Only when the heterogeneity of the three subgroups decreased significantly, it is concluded that they are the source of root-stem heterogeneity. The above results reveal that pH value is not the source of heterogeneity of root-stem lead enrichment.

When $pH<6.5$ [SMD = 6.36 95%CI (2.38 ~ 10.34) $P<0.05$] and $pH>7.5$ [SMD = 14.33 95%CI (9.01 ~ 19.65) $P<0.001$], a significant statistical difference was found in root-stem lead enrichment ability. When pH was 6.5 ~ 7.5 [SMD = 12.57 95%CI (-6.94 ~ 32.07) $P>0.05$], there was no significant difference in the enrichment ability of lead in root-stem. When $pH\sim7.5$, root-stem absorption of lead was favorable. Moreover, a subgroup analysis was conducted to verify whether soil pH affects the root-stem absorption of lead. The results reveal that alkaline soil is more conducive to the root-stem absorption of lead, followed by neutral soil and acid soil.

3.4.1.2 Soil lead concentration

According to the included studies, soil lead concentration was divided into $<20\text{mg/kg}$ and $>20\text{mg/kg}$ for subgroup analysis. The results indicated that lead concentration $<20\text{mg/kg}$ ($I^2=90.2\%$, $P<0.001$), $>20\text{mg/kg}$ ($I^2=86.2\%$, $P<0.001$), and the above two subgroups had relatively high heterogeneity, which may not be the source of total heterogeneity.

The concentration of lead was less than 20mg/kg [SMD = 9.57 95%CI (4.68 ~ 14.16) $P < 0.001$], more than 20mg/kg [SMD = 11.77 95%CI (3.93 ~ 19.62) $P < 0.05$]. As indicated by the results, there was a significant statistical difference in soil lead concentration during root-stem absorption of lead. When the lead concentration in soil was higher than 20mg/kg, the lead absorption in root and stem increased significantly.

3.4.1.3 Different plant types

In this study, the plants were assigned into gramineae, vegetables and trees to analyze the differences of lead enrichment ability in roots, stems, and leaves, and to make subgroup analysis to explore the source of heterogeneity.

The results reveal that lead enrichment in roots-stems achieves statistical significance in three types of gramineae, vegetables and trees. And trees were more conducive to the absorption of lead in roots-stems, followed by vegetables, and gramineae had the weakest ability of lead enrichment.

The gramineae [SMD = 8.21 95%CI (2.93 ~ 13.49) $P < 0.05$], vegetables [SMD = 9.60 95%CI (3.19 ~ 16.02) $P < 0.05$] and trees [SMD = 37.06 95%CI (-22.61 ~ 96.72) $P < 0.05$], a significant statistical difference was found in root-stem lead enrichment ability. And trees were more conducive to the absorption of lead in root-stem, followed by vegetables, and gramineae had the weakest ability of lead enrichment.

3.4.2 Factors for root - leaf lead adsorption capacity of plants

3.4.2.1 Soil pH

The division of pH in this part is similar to that of root-stem. The total root-leaf heterogeneity was $P < 0.001$ and $I^2 = 87.6\%$. When pH was less than 6.5 ($P < 0.001$, $I^2 = 77.7\%$); when pH was 6.5 to 7.5 ($P = 0.015$, $I^2 = 76.1\%$); and when pH was higher than 7.5 ($P = 0.138$, $I^2 = 42.5\%$). These above results reveal that pH value is not the source of heterogeneity of root-leaf lead enrichment.

When $pH < 6.5$ [SMD = 7.68 95%CI (3.43 ~ 11.94) $P < 0.05$] and $pH > 7.5$ [SMD = 14.81 95%CI (8.98 ~ 20.63) $P < 0.001$], a significant statistical difference was found in root-leaf lead enrichment ability. When pH was 6.5 ~ 7.5 [SMD = 1.29 95%CI (-1.73 ~ 4.31) $P > 0.05$], there was no significant difference in the enrichment ability of lead in root-leaf. The results reveal that alkaline soil was more conducive to the root-leaf absorption of lead, followed by acidic soil and neutral soil.

3.4.2.2 Soil lead concentrations

According to the included studies, lead concentration was assigned into $< 20\text{mg/kg}$ and $> 20\text{mg/kg}$ for subgroup analysis, and the source of heterogeneity of root-leaf lead enrichment was explored. The results indicated that lead concentration $< 20\text{mg/kg}$ ($I^2 = 91.2\%$, $P < 0.001$), $> 20\text{mg/kg}$ ($I^2 = 81.1\%$, $P < 0.001$), and the above two subgroups had relatively high heterogeneity, which may not be the source of total heterogeneity.

The concentration of lead was less than 20mg/kg [SMD = 10.22 95%CI (4.99 ~ 15.44) $P < 0.001$], more than 20mg/kg [SMD = 7.10 95%CI (2.60 ~ 11.59) $P < 0.05$]. The results showed that the concentration of lead ions significantly affected the enrichment of lead in root-leaf. Moreover, when soil lead concentration was less than 20mg/kg, the root-leaf uptake of lead was higher.

3.4.2.3 Different plant types

The results indicated that gramineae ($I^2 = 77.9\%$, $P < 0.001$), vegetables ($I^2 = 92.8\%$, $P < 0.001$) and trees ($I^2 = 75.2\%$, $P < 0.05$), and the above three subgroups had relatively high heterogeneity, which may not be the source of total heterogeneity.

The gramineae [SMD = 5.206 95%CI (1.73 ~ 8.38) $P < 0.05$] and vegetables [SMD = 10.16 95%CI (3.27 ~ 17.04) $P < 0.05$], a significant statistic difference was found in root-leaf lead enrichment ability. The trees [SMD = 37.66 95%CI (-10.21 ~ 85.52) $P > 0.05$], there was no significant difference in the enrichment ability of lead in root-leaf. The results suggest that trees are more conducive to the absorption of lead in root-leaf of plants, followed by vegetables, and gramineae exhibits the weakest ability to concentrate lead.

3.4.3 Factors for stem - leaf lead adsorption capacity of plants

3.4.3.1 Soil pH

The pH division is the same as before. The total root-leaf heterogeneity was $P < 0.001$ and $I^2=88.7\%$. When pH was less than 6.5 ($P < 0.001$, $I^2=79.4\%$); when pH was 6.5 to 7.5 ($P=0.001$, $I^2=85.7\%$); and when pH was greater than 7.5 ($P=0.001$, $I^2=92.7\%$). These above results reveal that pH value was not the source of the heterogeneity of stem-leaf lead enrichment.

When pH < 6.5[SMD=1.21 95%CI (-1.08~3.50) $P=0.05$], pH > 7.5[SMD=2.10 95%CI (-5.37~4.32) $P=0.05$] and pH was 6.5~7.5[SMD=-0.52 95%CI (-5.37~4.32) $P > 0.05$], there was no significant difference in the enrichment ability of lead from root-stem. The results showed that alkaline soil was more conducive to the uptake of lead in stem and leaf of plants, followed by acid soil and neutral soil.

3.4.3.2 Soil lead concentrations

According to the included studies, soil lead concentration was divided into < 20mg/kg and > 20mg/kg for subgroup analysis. The results indicated that lead concentration < 20mg/kg ($I^2=91.1\%$, $P < 0.001$), > 20mg/kg ($I^2= 82.7\%$, $P < 0.001$), and the above two subgroups had relatively high heterogeneity, which may not be the the source of total heterogeneity.

The concentration of lead was less than 20mg/kg [SMD=3.02 95%CI (-0.56~6.60) $P=0.05$], more than 20mg/kg [SMD=-0.58 95%CI (-3.38~2.22) $P=0.05$]. As indicated by the results, there was not the source of heterogeneity of lead enrichment in stem-leaf. Moreover, when soil lead concentration was less than 20 mg/kg, the stem-leaf uptake of lead was higher.

3.4.3.3 Different plant types

The results indicated that gramineae ($I^2=82.4\%$, $P < 0.001$), vegetables ($I^2= 92.6\%$, $P < 0.001$) and trees ($I^2=93.3\%$, $P < 0.001$), and the above three subgroups had relatively high heterogeneity, which may not be the source of total heterogeneity.

The gramineae [SMD=0.38 95%CI (-2.21~2.98) $P=0.05$], vegetables [SMD=2.21 95%CI (-1.72~6.13) $P=0.05$] and trees [SMD=2.74 95%CI (-26.90~32.38) $P=0.05$]. There was no significant difference in the enrichment ability of lead in stem-leaf. The results suggest that trees are more conducive to the uptake of lead in stem-leaf of plants, followed by vegetables and gramineae.

3.5 Publish biased analysis

As the research objects of meta-analysis are published studies, the conclusions of meta-analysis are susceptible to publication bias even if good retrieval strategies are adopted. The common methods to diagnose publication bias consist of funnel plot, Egger regression and Bgger regression(Egger, et al., 1997). Egger regression method was adopted in this study to detect publication bias, and the results obtained are listed in Table 2. As depicted in the figure below, root-stem and root-leaf studies were scattered to the right of the central baseline of the funnel plot, thus suggesting publication bias. The stem-leaf studies were scattered around the center baseline of the funnel plot near the top, basically arranged along the center line, thus revealing no publication bias. However, the funnel plot was affected by the sample size of the original study and needed the in-depth evidence of Egger test. The data listed in the table showed that the continuous correction asymmetry coefficients of root-stem, root-leaf and stem-leaf Egger test were 3.466, 3.314, and 2.270, respectively, and T values were 5.54($P < 0.001$), 5.11 ($P < 0.001$), and 2.05 ($P > 0.05$), respectively, thus suggesting that there was publication bias in root-stem and root-leaf studies, whereas there was no publication bias in stem-leaf studies.

Table.2 The results of publication bias for each group used in the meta-analysis

Method	Group	B	SE	t	P/t	[95% CI]
Egger's test	Root - stem	3.466	0.625	5.54	0.000	2.15 4.82
	Root - leaf	3.314	0.648	5.11	0.000	1.92 4.71
	Stem - leaf	2.720	1.326	2.05	0.061	-0.15 5.59

3.6 Meta-regression analysis

Meta-regression is an analysis method adopted to explore the size and source of heterogeneity among different studies(Sutton et al., 2008), primarily used to study whether there is a linear correlation between variables/covariables and the combination effect, as well as the direction and size of such correlation(Baker et al., 2009).

3.6.1 Root-stem meta-regression analysis

The results were analyzed by multivariate meta-regression analysis due to the heterogeneity of root-stem enrichment ability ($I^2=88.5\%$, $P<0.001$). Covariates included pH, regional distribution, lead concentration, and plant types, as listed in Table 3. At the same time, the above four covariables were used for meta regression, and the results showed that the t value of the four covariables reached 1.92($P=0.055$), -0.56 ($P=0.572$), 1.32($P=0.188$), 0.51 ($P=0.670$). Multivariate regression was adopted to explore the heterogeneity of root-stem lead enrichment. The results reveal that the four covariables are not the source of heterogeneity of lead enrichment in root and stem of plants($P>0.05$).

3.6.2 Root-leaf meta-regression analysis

The results were analyzed by multivariate meta-regression analysis due to the heterogeneity of root-leaf enrichment ability ($I^2=87.6\%$, $P<0.001$). Covariates included pH, regional distribution, lead concentration, and plant types, as listed in Table 3. At the same time, the above four covariables were used for meta regression, and the results showed that the t value of the four covariables reached 1.23 ($P=0.218$), -1.29 ($P=0.199$), 0.32 ($P=0.746$), 1.44 ($P=0.151$). Multivariate regression was adopted to explore the heterogeneity of root-leaf lead enrichment. The results reveal that the four covariables are not the source of heterogeneity of lead enrichment in root and leaf of plants ($P>0.05$).

3.6.3 Stem-leaf meta-regression analysis

The results were analyzed by multivariate meta-regression analysis due to the heterogeneity of root-stem enrichment ability ($I^2=88.7\%$, $P<0.001$). Covariates included pH, regional distribution, lead concentration, and plant types, as listed in Table 3. At the same time, the above four covariables were used for meta regression, and the results showed that the t value of the four covariables reached -0.90 ($P=0.369$), -1.94 ($P=0.052$), -2.19 ($P=0.028$), 0.77 ($P=0.444$). Multivariate regression was adopted to explore the heterogeneity of stem-leaf lead enrichment. The results reveal that the three collaborators are the source of heterogeneity of lead enrichment in stem and leaf of plants ($P>0.05$). However, soil lead concentration may be the source of lead enrichment in stem and leaf of plants ($P>0.05$).

The results reveal that heterogeneity is caused by the above variables rather than a single variable, so outliers and strong impact points of the study should be analyzed to study the source of heterogeneity. Next, a sensitivity analysis is conducted.

Table.3 Meta regression analysis of 4 covariables

group	covariables	B	SE	t	$P>t$	[95% CI]
root-stem	Soil pH	6.8	3.54	1.92	0.055	(-0.14 13.75)
	Regional	-2.47	4.38	-0.56	0.572	(-11.06 6.11)
	Concentrations	8.25	6.28	1.32	0.188	(-4.04 20.61)
	Plant tpyes	1.99	3.9	0.51	0.610	(-5.66 9.65)
root-leaf	Soil pH	4.64	3.77	1.23	0.218	(-2.74 12.02)
	Regional	-6.22	4.84	-1.29	0.199	(-15.70 3.26)
	Concentrations	2.02	6.24	0.32	0.746	(-10.21 14.26)
	Plant tpyes	6.15	4.29	1.44	0.151	(-2.25 14.55)
stem-leaf	Soil pH	-2.1	2.33	-0.9	0.369	(-6.67 2.48)
	Regional	-6.14	3.16	-1.94	0.052	(-12.33 0.06)
	Concentrations	-8.58	3.91	-2.19	0.028	(-16.25 -0.91)
	Plant tpyes	2.06	2.69	0.77	0.445	(-3.21 7.33)

3.7 Sensitivity analysis

A sensitivity analysis was conducted to determine whether heterogeneity was caused by a single research factor, and a study elimination method was adopted. Root-stem, root-leaf and stem-leaf sensitivity analyses were conducted respectively, as presented in the figure below. After the exclusion of Ruyi Yang(Yang et al., 2012), A.K. Gupta(Gupta et al., 2007), Hanaa S Shehata(Shehata et al.,

2020) and Li Xiaoming(Li et al., 2009), sensitivity analysis was conducted, and the results indicated that: τ^2 value changed from 31.2643 to 39.3844, I^2 value changed from 88.5–64.6%, [SMD = 13.649, 95%CI(8.465 18.833), $P = 0.002$], thus revealing that the studies of Ruyi Yang(Yang et al., 2012), A.K. Gupta(Gupta et al., 2007), Hanaa S Shehata(Shehata et al., 2020) and Li Xiaoming(Li et al., 2009) do not affect the stability of the results.

4. Discussion

In this study, 15 studies were included to analyze the strength of lead enrichment ability in different parts of roots, stems, and leaves. Based on the results of meta-analysis, the accumulation capacity of heavy metal lead in a variety of plant parts is different. There were significant differences in lead enrichment ability between root, stem, and leaf plants, the enrichment capacity of lead in roots was significantly higher than that in stems and leaves. The above results indicated that the enrichment ability of different plants to lead primarily followed an order of root > stem > leaf, thus suggesting that plant roots were the main organ of lead enrichment. The heavy metals in the soil first enter the plant through the root of the plant, so the content of heavy metals in the root of the plant is significantly higher than that in the stem and leaf, and the toxic effect of heavy metals on the plant largely acts on the root(Gong et al., 2020). Accordingly, to reduce the damage of heavy metals to human health, people can select plants with less root surface area and short roots to take in nutrients. Sun Zhaohai et al. found that lead is easy to accumulate in plant roots and difficult to transport to stems and leaves(Sun et al., 2005). ozser et al. investigated the accumulation of heavy metals in willow trees and found that the accumulation rate of lead in willow roots and twigs is significantly higher than that in stems and leaves(Tózsér et al., 2017). Cloutier-hurteau et al. (Kacálková et al., 2015) and Kacalkova et al. (Cloutier-Hurteau et al., 2014) drew the same conclusion that lead is primarily accumulated in roots, with higher concentrations in roots than in stems and leaves. The above results are similar to the conclusions of this study. It is found that lead is mainly accumulated in the roots of different plants, and the concentration of lead is relatively low during the transportation from root to stem and leaf. The possible reason for the difference in accumulation rates between plant tissues is the limited transport of lead between roots and stems, and leaves(Brekken et al., 2004; Dahmani-Muller et al., 2000). The restrictive migration of lead from roots to stems and leaves can be clarified by the metal exclusion mechanism in roots that plants avoid damage during photosynthesis. Plant root tissue exhibits a strong ability to enrich lead, so residents can select plants with developed roots to meet the nutritional needs of human body. Furthermore, most of the lead amount is absorbed in the roots since root is the first organ to expose this metal during transport to the biomass of plants. The transport of heavy metals from the soil to the roots is a complex process affected by numerous factors (e.g., soil characteristics, environmental conditions, vegetative, physiological, and biochemical characteristics of roots). The transport of heavy metals from roots to stems, branches, and leaves is controlled by plant physiology, which determines the most metals entering the food chain.

After the discussion of the sources of heterogeneity and the analysis of the factors for the absorption of lead in roots, stems, and leaves of plants, this study suggests that alkaline soil is more conducive to the absorption and enrichment of lead in roots, stems, and leaves of selected plants. pH value is one of the important factors for the effectiveness of metal. At high pH, lead ions exist as insoluble oxides (hydroxides) and are hardly absorbed by plants. When pH value is low, competition between organic acids and H^+ will result in ion replacement by H_3O^+ , thus increasing the possibility of enrichment and absorption of heavy metals in plants(Tilman & Lehman, 2001). Acidity contributes to the absorption of heavy metal lead in plant. Found through study review, the study of Li et al. suggested that slightly acidic water with pH of 5.6 ~ 6.5 is conducive to the absorption of heavy metals by plants(Li et al., 2015). In general, the concentration of heavy metals in soil is negatively correlated with pH(Lesage et al., 2007). Previous studies have revealed that soil pH is negatively correlated with the absorption and accumulation of pepper lead, thus affecting the migration and bioavailability of lead (Shi et al., 2021). Safari et al. have suggested a significant correlation between lead content in rice grains and soil pH(Safari et al., 2015). Chao et al. revealed that lead uptake and accumulation by rice decrease with the increase of soil pH(Chao et al., 2018). Several studies have suggested that the absorption, transportation and accumulation of lead by tea plant organs are affected by soil conditions. With the decrease of pH, the absorption of lead by different organs of tea plant significantly increases(Chen et al., 2010). Xu Wenxin et al. have revealed that soil pH is negatively correlated with Pb uptake by *Brassica chinensis*, and the plant lead content is higher in acidic soil, thus revealing that Pb is more easily absorbed by crops in acidic soil with low pH(Xu et al., 2018). The amount of lead in vegetables is opposite to the pH value of the soil(Sun et al., 2005). However, this study suggests that alkaline soils absorb more lead. The possible reason is the small number of studies in this study.

In addition, significant differences were found in lead absorption among trees, vegetables and gramineous plants. Through the meta-analysis of this study, we found that trees > vegetables > gramineous plants. Trees and other types of plants have larger roots and larger specific surface areas than vegetables and gramineous plants, so they are capable of absorbing more lead.

The meta-analysis was conducted for the remaining studies, and the changes of the combined effect magnitude were small, and the heterogeneity did not change significantly ($I^2=50\%$), thus suggesting that the results of this study are relatively stable. In this study, no change in statistical significance was found after studies with higher heterogeneity were excluded. The heterogeneity is caused by a combination of factors, rather than by a single factor. Despite the heterogeneity of this study, the results of sensitivity analysis suggest that the results of this study are relatively stable.

Based on the results of our meta-analysis, we highlight a new observation that plants are also capable of accumulating lead in different parts of roots, stems, and leaves. The concentration of lead in different parts of root, stem and leaf was investigated, and it was found that root > stem > leaf. The results reveal that the major factors for the absorption of lead in plants are soil pH, various plants and soil lead concentration in descending order. Soil pH also significantly affects lead enrichment in roots, stems, and leaves. This suggests that there is a relationship between lead accumulation and soil pH in the pH range studied. Alkaline soil is conducive to lead absorption by plants in this study. Plant type also had a significant effect on lead accumulation in roots, stems, and leaves. Various plants have different absorption capacity of lead, which mainly shows that the absorption capacity of trees is the strongest, followed by vegetables, and the ability of gramineae to enrich lead is the weakest. There was publication bias in this study. Despite the heterogeneity of this study, the results obtained are relatively stable. The results of this study will be conducive to guiding the correct selection of edible plants, guiding the safe production of edible green plants, strengthening the effective management of agricultural contaminated soil, and supporting data for the formulation of contaminated soil management policy. Notably, plants and roots are prone to accumulation of toxic metals (e.g., lead and cadmium), so they can be used for environmental biological monitoring as a tool to evaluate the extent of soil contamination.

The mechanisms and pathways of accumulation of heavy metal lead in a variety of plant parts remain unclear. The limitations of this study are presented as follows. (1) A small number of studies were included in the meta-analysis, most of which were Chinese studies. Few English studies were included. (2) During the study of different plant types, it was found that there have been rare studies involving vegetables. (3) The quality of the included studies should be improved. (4) Less data are included in the study of soil physical and chemical properties.

Declarations

Ethical Approval

Not applicable.

Consent to Participate

All the authors of this article agree to participate.

Consent to Publish

All authors of this article agree to publish this article.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Lulu Jia, Lina Zou, Yue Guan, Lan Jiang, Yongzheng Hang, Xiaoyan feng, Xiaowei Ren, Yuting Tian, Hongzhi Pan, Shengzhong rong and Hongkun Ma. The first draft of the manuscript was written by Lulu Jia and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (82173568, 81773480, 81973097, 81703269). Natural Science Foundation of Heilongjiang Province (QC2018120). Foundation for Doctoral Research of Mudanjiang Medical University (2021-MYBSKY-009, 2021-MYBSKY-001).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Baker, W., White, C., Cappelleri, J., Kluger, J., & Coleman, C. (2009). Understanding heterogeneity in meta-analysis: the role of meta-regression. *International Journal of Clinical Practice*, 63(10), 1426-1434. doi:10.1111/j.1742-1241.2009.02168.x.
2. Brekken, A., & Steinnes, E. (2004). Seasonal concentrations of cadmium and zinc in native pasture plants: consequences for grazing animals. *The Science of the total environment*, 326, 181-195. doi:10.1016/j.scitotenv.2003.11.023.
3. Chao, X., Qian, X., Han-Hua, Z., Shuai, W., Qi-Hong, Z., Dao-You, H., & Yang-Zhu, Z. (2018). Effect of biochar from peanut shell on speciation and availability of lead and zinc in an acidic paddy soil. *Ecotoxicology and Environmental Safety*, 164, 554-561. doi:10.1016/j.ecoenv.2018.08.057.
4. Chen, Y. X., Xu, J., Yu, M. G., Chen, X. C., & Shi, J. Y. (2010). Lead contamination in different varieties of tea plant (*Camellia sinensis* L.) and factors affecting lead bioavailability. *Journal of the Science of Food and Agriculture*, 90(9), 1501-1507. doi:10.1002/jsfa.3974.
5. Chen Yanhong, Su Xiaohong, Huang Zhiyong. Absorption and Accumulation Characteristics of Rape to Heavy Metals in Soil [J]. *Subtropical plant science*, 2010, 39(4): 14-17. doi:10.3969/j.issn.1009-7791.2010.04.005.
6. Cheng, H. X. A. X. C. A. W. (2009). *Uptake and Growth Response of Saccharum Officinarum to Lead Pollution in Soil*. <https://d.wanfangdata.com.cn/conference/ChZDb25mZXJlbnNITmV3UzlwMjJwMjJyEgtDQzAyOTYxMzk5OBoBwTnc2xuaXg%3D>.
7. Cloutier-Hurteau, B., Turmel, M., Mercier, C., & Courchesne, F. (2014). The sequestration of trace elements by willow (*Salix purpurea*)—which soil properties favor uptake and accumulation? *Environmental Science and Pollution Research International*, 21(6), 4759-4771. doi:10.1007/s11356-013-2450-y.
8. Dahmani-Muller, H., van Oort, F., Gélle, B., & Balabane, M. (2000). Strategies of heavy metal uptake by three plant species growing near a metal smelter. *Environmental pollution (Barking, Essex : 1987)*, 109(2), 231-238. doi:10.1016/s0269-7491(99)00262-6.
9. Egger, M., Davey Smith, G., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ (Clinical Research Ed.)*, 315(7109), 629-634. doi:10.1136/bmj.315.7109.629.
10. Emamverdian, A., Ding, Y., Mokhberdoran, F., & Xie, Y. (2015). Heavy metal stress and some mechanisms of plant defense response. *TheScientificWorldJOURNAL*, 2015, 756120. doi:10.1155/2015/756120.
11. Feng Gongneng, Chen Aihui, Liu Hanwen, et al. Effects of Pb on the Growth Characteristics of Solanaceae Vegetables[J]. *Anhui Agricultural Sciences*, 2008, 36(34): 14862-14863,14868. doi:10.3969/j.issn.0517-6611.2008.34.016.
12. Gong, Z., Xiong, L., Shi, H., Yang, S., R.Herrera-Estrella, L., Xu, G., . . . Zhu, J.-K. (2020). Plant abiotic stress response and nutrient use efficiency. *Science China(Life Sciences)*, 63(05), 635-674.
13. Gupta, A., & Sinha, S. (2007). Phytoextraction capacity of the *Chenopodium album* L. grown on soil amended with tannery sludge. *Bioresource Technology*, 98(2), 442-446. doi:10.1016/j.biortech.2006.01.015.
14. Huang Kaifeng, Jiang Jiezeng. Study on Accumulation and Partition of Cd²⁺ and Pb²⁺ in *Zizania latifolia*[J]. *The Yangtze river vegetable*, 2009, 14): 45-48. doi:10.3865/j.issn.1001-3547.2009.14.016.
15. Kacálková, L., Tlustoš, P., & Száková, J. (2015). Phytoextraction of risk elements by willow and poplar trees. *International Journal of Phytoremediation*, 17, 414-421. doi:10.1080/15226514.2014.910171.
16. Lesage, E., Rousseau, D. P., Meers, E., Tack, F. M., & De Pauw, N. (2007). Accumulation of metals in a horizontal subsurface flow constructed wetland treating domestic wastewater in Flanders, Belgium. *Science of the Total Environment*, 380(1-3), 102-115. doi:10.1016/j.scitotenv.2006.10.055.
17. Li, J., Yu, H., & Luan, Y. (2015). Meta-Analysis of the Copper, Zinc, and Cadmium Absorption Capacities of Aquatic Plants in Heavy Metal-Polluted Water. *International Journal of Environmental Research and Public Health*, 12(12), 14958-14973. doi:10.3390/ijerph121214959.
18. Li Xiaoming, Yin Yunlong, Huang Yujie , et al.Effects of Lead Pollution in Soil and on Leaf on Distribution and Accumulation of Lead inRice[J]. *Soil*, 2009, 41(04): 556-561.
19. Liu Qinghai. Effects of Barley Growth and Lead Accumulation by Stress Lead[J]. *Xizang Agricultural Science and Technology*, 2019, 41(03): 29-33.

20. Meng Jun, Xie Yinjun. Study on the Relationship Between Enrichment of Elements in Celery and Growth Environment [J]. The food industry, 2013, 07: 149-152.
21. Mleczek, M., Magdziak, Z., Rissmann, I., & Golinski, P. (2009). Effect of different soil conditions on selected heavy metal accumulation by *Salix viminalis* tissues. *J Environ Sci Health A Tox Hazard Subst Environ Eng*, 44(14), 1609-1616. doi:10.1080/10934520903263645.
22. Page, K., Harbottle, M., Cleall, P., & Hutchings, T. (2014). Heavy metal leaching and environmental risk from the use of compost-like output as an energy crop growth substrate. *The Science of the total environment*, 487, 260-271. doi:10.1016/j.scitotenv.2014.04.021.
23. Pan, X., Wu, P., & Jiang, X. (2016). Levels and potential health risk of heavy metals in marketed vegetables in Zhejiang, China. *Sci Rep*, 6, 20317. doi:10.1038/srep20317.
24. Peng, X., Deng, Y., Peng, Y., & Yue, K. (2018). Effects of biochar addition on toxic element concentrations in plants: A meta-analysis. *The Science of the total environment*, 970-977. doi:10.1016/j.scitotenv.2017.10.222.
25. Robinson, B., Bischofberger, S., Stoll, A., Schroer, D., Furrer, G., Roulier, S., Schulin, R. (2008). Plant uptake of trace elements on a Swiss military shooting range: uptake pathways and land management implications. *Environmental pollution (Barking, Essex : 1987)*, 153(3), 668-676. doi:10.1016/j.envpol.2007.08.034.
26. Romero-Freire, A., Martin Peinado, F., & van Gestel, C. (2015). Effect of soil properties on the toxicity of Pb: assessment of the appropriateness of guideline values. *Journal of Hazardous Materials*, 289, 46-53. doi:10.1016/j.jhazmat.2015.02.034.
27. Safari, Y., Delavar, M., Zhang, C., Esfandiarpour-Boroujeni, I., & Owliaie, H. (2015). The influences of selected soil properties on Pb availability and its transfer to wheat (*Triticum aestivum* L.) in a polluted calcareous soil. *Environmental Monitoring and Assessment*, 187(12), 773. doi:10.1007/s10661-015-5001-9.
28. Schwarzer, G., Carpenter, J., & Rücker, G. (2010). Empirical evaluation suggests Copas selection model preferable to trim-and-fill method for selection bias in meta-analysis. *Journal of Clinical Epidemiology*, 63(3), 282-288. doi:10.1016/j.jclinepi.2009.05.008.
29. Sha, Z., Li, Q., Lv, T., Misselbrook, T., & Liu, X. (2019). Response of ammonia volatilization to biochar addition: A meta-analysis. *The Science of the total environment*, 655, 1387-1396. doi:10.1016/j.scitotenv.2018.11.316.
30. Shehata, H. S., & Galal, T. M. (2020). Trace metal concentration in planted cucumber (*Cucumis sativus* L.) from contaminated soils and its associated health risks. *Journal Of Consumer Protection And Food Safety*, 15(3), 205-217. doi:10.1007/s00003-020-01284-z.
31. Shi, J., Xu, Q., Zhou, Z., Wu, X., Tong, J., Cai, Q., . . . Shi, J. (2021). Controlling Factors and Prediction of Lead Uptake and Accumulation in Various Soil-Pepper Systems. *Environmental Toxicology and Chemistry*, 40(5), 1443-1451. doi:10.1002/etc.4997.
32. Slavin, J., & Lloyd, B. (2012). Health benefits of fruits and vegetables. *Advances in nutrition (Bethesda, Md.)*, 3(4), 506-516. doi:10.3945/an.112.002154.
33. Sutton, A., & Higgins, J. (2008). Recent developments in meta-analysis. *Statistics in Medicine*, 27(5), 625-650. doi:10.1002/sim.2934.
34. Sun Zhaohai, Zheng Chunrong, Zhou Dongmei, et al. Effects of soil Pb pollution on growth of *Brassica chinensis* and *Ipomoea aquatica* and urease activities[J]. Rural ecological environment, 2005, 01: 38-43.
35. Tilman, D., & Lehman, C. (2001). Human-caused environmental change: impacts on plant diversity and evolution. *Proceedings of the National Academy of Sciences of the United States of America*, 98(10), 5433-5440. doi:10.1073/pnas.091093198.
36. Tózsér, D., Magura, T., & Simon, E. (2017). Heavy metal uptake by plant parts of willow species: A meta-analysis. *Journal of Hazardous Materials*, 336, 101-109. doi:10.1016/j.jhazmat.2017.03.068.
37. Wang, D., Mou, Z., Zhai, J., Zong, H., & Zhao, X. (2008). [Application of Stata software to test heterogeneity in meta-analysis method]. *Zhonghua liu xing bing xue za zhi = Zhonghua liuxingbingxue zazhi*, 29(7), 726-729.
38. Xalxo, R., & Keshavkant, S. (2018). Hydrolytic enzymes mediated lipid-DNA catabolism and altered gene expression of antioxidants under combined application of lead and simulated acid rain in Fenugreek (*Trigonella foenum graecum* L.) seedlings. *Ecotoxicology (London, England)*, 27(10), 1404-1413. doi:10.1007/s10646-018-1996-3.
39. Xiang Yanci, Xiang Yang, Guan Chunyun, et al. Effects of Cd/Pb interaction and amendment with sewage sludge on growth and accumulation of Cd and Pb by oilseed rape grown in contaminated soils [J]. Journal of Hunan University of Science and Technology (Natural Science), 2010, 25(1): 125-128. doi:10.3969/j.issn.1672-9102.2010.01.027.

40. Xu Wenxin, Li Yan, Dai Yunchao, et al. Determination and prediction of lead uptake by *Brassica chinensis* [J]. *Journal of Agro-Environment Science*, 2018, 37(08): 1584-1591.
41. Xue Zhongcai, Du Ruiheng, Li Shizhong. The Safe Utilization Technology of Pb-contaminated Farmland Using Sweet Sorghum [J]. *Journal of agronomy*, 2020, 10(7): 50-55.
42. Yang, R., Liu, L., Zan, S., Tang, J., & Chen, X. (2012). Plant species coexistence alleviates the impacts of lead on *Zea mays* L. *Journal of Environmental Sciences (China)*, 24(3), 396-401. doi:10.1016/s1001-0742(11)60721-3.
43. Zhang, L., Jing, Y., Xiang, Y., Zhang, R., & Lu, H. (2018). Responses of soil microbial community structure changes and activities to biochar addition: A meta-analysis. *The Science of the total environment*, 643, 926-935. doi:10.1016/j.scitotenv.2018.06.231.
44. Zhang Wentao, Guo Shirong, Huang Jianhe. Enrichment characteristics of Lead and copper in different parts of *Aquatic* and *Artemisia pan* [J]. *Jiangsu Agricultural Sciences*, 2010, 5): 424-426. doi:10.3969/j.issn.1002-1302.2010.05.164.
45. Zhang Yongchao, Chen Cungen, Zhong Faming, et al. Distribution and Accumulation of Lead and Cadmium in *Ulmus pumila* [J]. *Journal of Northwest Forestry College*, 2011, 26(5): 6-11.
46. Zhao Ajuan, ZENG Weiai, CAI Hailin, et al. Correlation analysis of heavy metal content in tobacco leaf and soil and physicochemical properties in Changsha tobacco growing area [J]. *Acta Tabacaria Sinica*, 2020, 26(05): 90-97. doi:10.16472/j.chinatobacco.2019.395.
47. Zhao Yangdi. Effects of Pb Stress on Accumulation Capacity and Physiological Metabolism of *Murraya exotica* L [J]. *The north garden*, 2019, 4): 92-98. doi:10.11937/bfyy.20182686.
48. Zhivotovsky, O., Kuzovkina, J., Schulthess, C., Morris, T., Pettinelli, D., & Ge, M. (2011). Hydroponic screening of willows (*Salix* L.) for lead tolerance and accumulation. *International Journal of Phytoremediation*, 13(1), 75-94. doi:10.1080/15226511003671361.
49. Zhou Ying, Li Guochen, ZHANG Hong, et al. Effects of atmospheric and soil lead on lead accumulation in maize plants and its contribution to maize seed [J]. *Chinese Journal of Ecology*, 2012, 31(09): 2299-2304.
50. Zhuang, P., McBride, M., Xia, H., Li, N., & Li, Z. (2009). Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. *The Science of the total environment*, 407(5), 1551-1561. doi:10.1016/j.scitotenv.2008.10.061.
51. Zunaidi, A., Lim, L., & Metali, F. (2021). *Brassica juncea* Transfer of heavy metals from soils to curly mustard ((L.) Czern.) grown in an agricultural farm in Brunei Darussalam. *Heliyon*, 7(9), e07945. doi:10.1016/j.heliyon.2021.e07945.

Figures

Figure 1

Process of study inclusion

Figure 2

Comparison of root-stem lead enrichment ability

Figure 3

Comparison of root-leaf lead enrichment ability

Figure 4

Comparison of stem-leaf lead enrichment ability

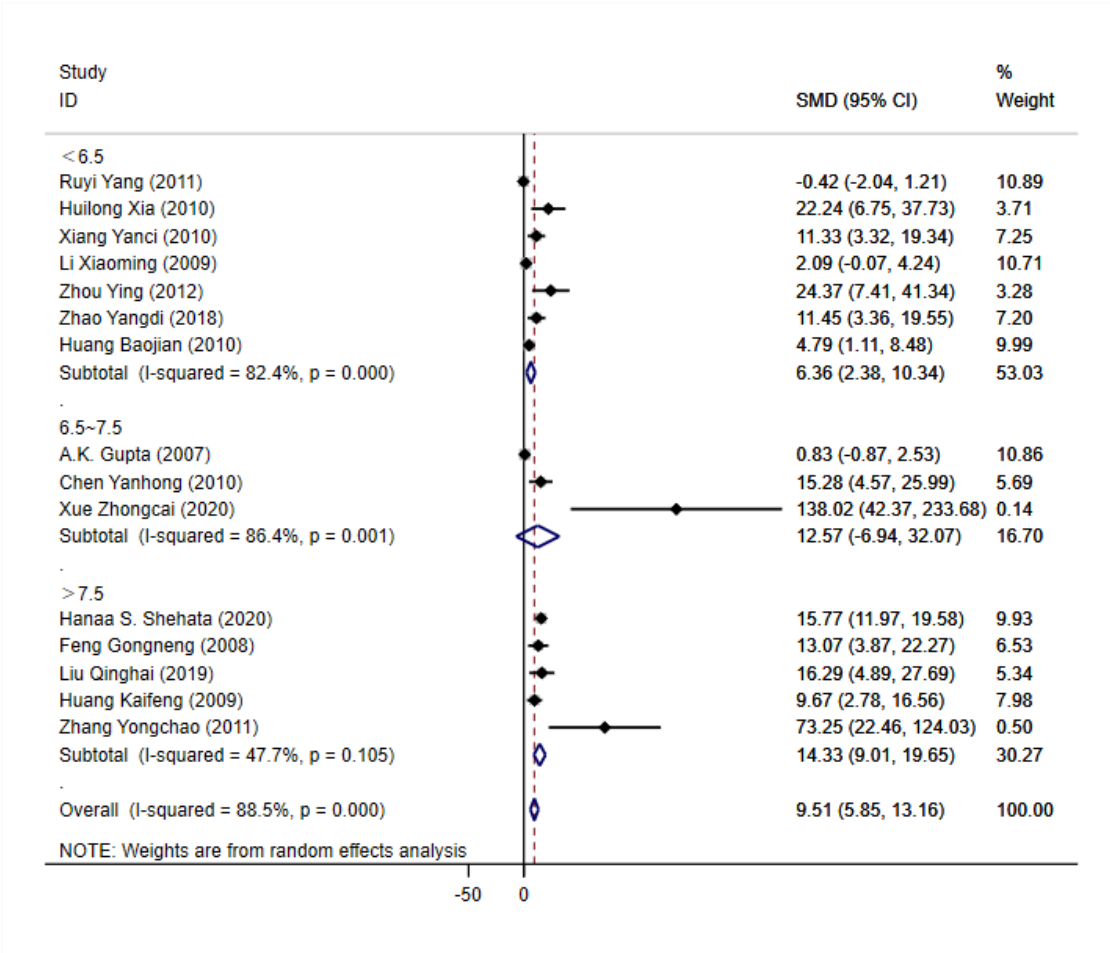


Figure 5
Differences of lead accumulation in root-stem under different pH conditions

Figure 6
Differences of lead accumulation in root and stem under different lead concentrations

Figure 7
Differences of root-stem accumulation of lead in different plant types

Figure 8
Differences of lead accumulation in root-leaf under different pH conditions

Figure 9

Differences of lead accumulation in root and leaf under different lead concentrations

Figure 10

Differences of root-leaf accumulation of lead in different plant types

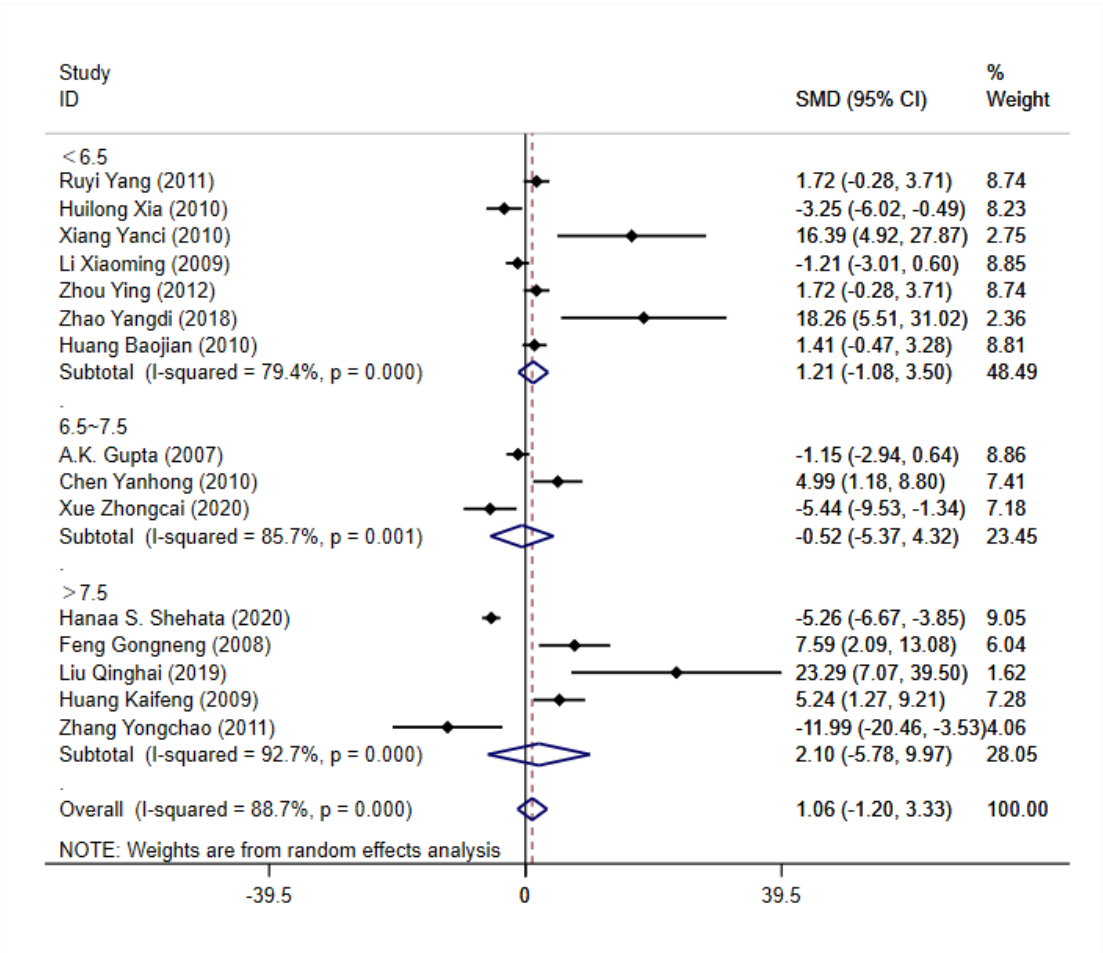


Figure 11

Differences of lead accumulation in stem-leaf under different pH conditions

Figure 12

Differences of lead accumulation in stem and leaf under different lead concentrations

Figure 13

Differences of stem-leaf accumulation of lead in different plant types

Figure 14

Funnel plots for root-stem, root-leaf and stem-leaf publication bias tests

Note: a is the funnel plot of root-stem publication bias; b is the funnel plot of root-leaf publication bias; c is funnel plot of stem-leaf publication bias.

Figure 15

Sensitivity analysis