Bioaccumulation Factor of Selected Heavy Metals in *Zea mays*

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**Introduction**

Heavy metal pollution is an environmental issue that has become a global problem. The production and emission of heavy metals has increased along with increased industrial development. This has led to increasing concern over food safety due to soil polluted with anthropogenic heavy metals released from industry or agriculture, such as smelting industries, residues from metalliferous mines, pesticides, fertilizers, and municipal composts.14

Heavy metals are chemical elements that have a relatively high density, strong toxic effects and pose an environmental threat.5 Heavy metals are of considerable environmental concern due to their toxicity, many sources, non-biodegradable properties, and accumulative behaviors.6 The presence of heavy metals in foods poses serious health hazards, depending on their relative levels. The ability of plants to accumulate metals and possibly other contaminants varies with both the nature of the plant species and the nature of the metal contaminant. Cereals, in this case *Zea mays L* (maize), are known to be good accumulators of contaminants.7

Agricultural soils in many parts of the world are slightly to moderately contaminated by heavy metal toxicity, such as cadmium (Cd), copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co), chromium (Cr), lead (Pb), and arsenic (As). This could be due to long-term use of phosphatic fertilizers, sewage sludge application, dust horn smelters, industrial waste and poor watering practices in agricultural lands.10-20 The primary response of plants is the generation of reactive oxygen species upon exposure to high levels of heavy metals. Various metals either generate reactive oxygen species directly through Haber-Weiss reactions or overproduce reactive oxygen species and the

**Background.** Health risks arising from heavy metal pollution have attracted global attention. As a result, many studies on the accumulation of heavy metals in soil-plant systems have performed human health risk assessments.

**Objectives.** We aimed to examine the ability of *Zea mays* (maize) to accumulate heavy metals and assess the bioaccumulation factor (BAF) by collecting, collating, and analyzing data on heavy metal concentrations in *Zea mays*.

**Methods.** This study reviewed the accumulation of five selected heavy metals, cadmium (Cd), chromium (Cr), lead (Pb), copper (Cu), and zinc (Zn) in soil and the corresponding BAF of *Zea mays* grown on those soils using a systematic search of peer-reviewed scientific journals. A total of 27 research works were reviewed after screening 52 articles for subject matter relevancy, including dumpsites, industrially polluted soils, inorganically fertilized soils, mining sites, smelting sites, municipal wastewater irrigated soils, and a battery waste dumpsite.

**Results.** Among the reviewed sites, concentrations of Cd and Cr were highest at a tin mining site, where prolonged mining, mineral processing and other production activities contributed heavy metal pollution in the soil. The soil at a battery waste dumpsite exhibited the highest Pb concentration, while the soil at a Zn smelting site presented the highest concentration of Zn. The highest soil Cu concentration was found in an area where sewage irrigation had been carried out over a long period. The BAF of the five heavy metals in *Zea mays* increased with the metal concentrations in the soil. The BAF of Cd, Cr, Pb, Cu, and Zn in *Zea mays* from the study areas fall within the ranges of 0–0.95, 0–1.89, 0–1.20, 0.011–0.99, and 0.03–0.99, respectively. Cadmium and Zn had the highest bioconcentration factors values in maize plants, likely due to their higher mobility rate compared to the other heavy metals.

**Conclusions.** The study concluded that *Zea mays* is capable of accumulating high amounts of heavy metals, although accumulation of these heavy metals is influenced by multiple factors including soil texture, cation exchange capacity, root exudation and especially soil pH and chemical forms of the heavy metals. *Zea mays* should not be planted on metal-contaminated soils because of its potential to act as a hyperaccumulator.

**Competing Interests.** The authors declare no competing financial interests.

**Keywords.** heavy metals, maize, soil, plant, bioaccumulation factor.

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occurrence of oxidative stress in plants could be the indirect consequence of heavy metal toxicity. The indirect mechanisms include their interactions with the antioxidant system, disrupting the electron transport chain or disturbing the metabolism of essential elements. One of the most deleterious effects induced by heavy metals exposure in plants is lipid peroxidation, which can directly cause biomembrane deterioration. Malondialdehyde, one of the decomposition products of polyunsaturated fatty acids of a membrane, is regarded as a reliable indicator of oxidative stress. Such toxic elements are considered soil pollutants due to their widespread occurrence, and their acute and chronic toxic effect on plants grown.

*Zea mays L.* is an annual cereal plant of the Gramineae family native to Mexico, it is one of the oldest and widely cultivated cereals and serves as food for humans and feed for livestock. *Zea mays L.* has been a major food source for humans since ancient times. It is a domesticated plant and has many beneficial uses for people and animals. Maize is one of the most intensively cultivated cereals worldwide. It is a basic staple food grain for large parts of the world and is the main food energy source in developing countries, including Africa, Latin America, and Asia. In Nigeria, maize can be found in every city and village where it is consumed as a staple food. *Zea mays L.* is the third most important cereal grain worldwide, after wheat and rice. All parts of the crop can be used for food and non-food products, it can also be used in animal feed as a feedstock source in agricultural complexes. In industrialized countries, maize is largely used as livestock feed and as raw material for industrial production. It contains the vitamins A, B, C and E, including mineral salts and essential trace elements such as carotene, thiamine, ascorbic acid and tocopherol. *Zea mays L.* is a widely cropped annual cereal that grows rapidly, produces extensive fibrous root systems with large shoot biomass yield per hectare, withstands adverse conditions, and produces abundant seeds with ease of cultivation under repeated cropping. To date, over 400 taxa of plant hyperaccumulators of heavy metals have been identified, but most of them are low biomass producers and exotic species. There is a need to supplement the list of plants available for phytoextraction. The potential use of maize, a robust tropical cereal crop in phytoextraction technology and possible utilization of the by-product is especially advocated for developing countries with scarce funds available for environmental restoration.

Several studies on the effects of bioaccumulation in plants through uptake of heavy metals from soils at high concentrations have been carried out and indicate great health risks, taking into consideration food chain implications. Utilization of food crops contaminated with heavy metals is a major food chain route for human exposure, especially those under continuous cultivation. The cultivation of such plants in contaminated soil represents a potential risk since the vegetal tissues can accumulate heavy metals. Heavy metals become toxic when they are not metabolized by the body and accumulate in soft tissues. Chronic ingestion of toxic metals has undesirable impacts on humans and the associated harmful impacts become perceptible only after several years of exposure.

The bioaccumulation factor (BAF) is used to quantify the bioaccumulation effect of maize in the uptake of heavy metal from soil. The BAF evaluates the effectiveness of a plant in metal accumulation and translocation. Heavy metal contaminants not only represent a threat to agricultural product safety, but also harm the immune, reproductive, and nervous systems of organisms after entering their bodies through ingestion. Therefore, the transfer and accumulation of heavy metals in soil-plant systems has become an important research topic. We aimed to examine the ability of *Zea mays* to accumulate heavy metals and assess the bioaccumulation factor (BAF) by collecting, collating, and analysing data on heavy metal concentrations in *Zea mays*.

**Methods**

Data related to the research topics was collected from published journals, articles, textbooks and dissertations sourced from PubMed, Google Scholar, JSTOR, Science Direct and AJOL.

**Methodology flow chart**

A Preferred Reporting Items for Systematic Reviews and Meta-Analyses
Review

(PRISMA) flow diagram indicating the number of articles that were identified, screened, and included in the current review is shown in Figure 1. Search terms were heavy metals, *Zea mays*, and bioaccumulation.

**Determination of bioaccumulation factor**

The BAF is the ratio of the concentration of heavy metals in plants and in soils. It is an indicator of a plant’s capacity to accumulate heavy metals.\(^{38}\)

The BAF was calculated using Equation 1:

\[
BAF = \frac{P_i}{S_i}
\]

where, \(P_i\) is the concentration of a heavy metal in plants (mg/kg\(^{-1}\)); and \(S_i\) is the concentration of the same heavy metal in the soil where the plant grows (mg/kg\(^{-1}\)).

BAF was provided in the following articles shown in Table 1.

However, Equation 1 was applied in the articles presented in Table 2 where the \(P_i\) (concentration of heavy metal in *Zea mays*) and \(S_i\) (concentration of the same heavy metal in the soil) was provided.

**Statistical analysis**

Data retrieved were analyzed on the stated hypothesis using descriptive statistics. Descriptive statistics were used to analyze and perform a one-sample Student’s t-test to test the hypothesis that the mean concentration of each heavy metal in *Zea mays* is not significantly different from the permissible limit set by the World Health Organization (WHO).

**Results**

Bioaccumulation of heavy metals, including Cd, Cr, Pb, Cu and Zn in *Zea mays* has been established by several studies worldwide using different indicators and parameters. Tables 3–7 show the bioaccumulation of selected heavy metals in *Zea mays*. Tables 8–12 show the BAF of soils across different sites and studies. The BAFs of Cd, Pb, Cr, Zn, and Cu in *Zea mays* from the study areas fall within the ranges of 0–0.95, 0–1.20, 0–1.89, 0.03–0.99, and 0.011–0.99, for dumpsites, industrially polluted soil, mining and smelting sites, municipal waste water irrigated soils and a battery waste dumpsite, respectively.

Table 13 shows the concentration of the selected heavy metals in *Zea mays* from various research data.

A one-sample Student’s t-test (Table 14) was performed to test the hypothesis that the mean concentration of Cd in *Zea mays* is not significantly different from the permissible limit set by the WHO/Food and Agriculture Organization for Cd in food.\(^{67}\) The permissible limit for Cd in all foods is set at 0.1 mg/kg. The mean concentrations of Cd in *Zea mays* (mean = 4.31) was not significantly different (p=0.097) from the WHO value of 0.1 mg/kg, test statistic (t)(17) = 1.76, p=0.09. The
The mean concentrations of Pb in *Zea mays* (mean = 14.62, standard deviation = 27.25, number = 19) were not significantly different from the hypothesized value of 0.2 mg/kg, t(18) = 2.31, p=0.03. The confidence interval above is given as 1.29029, 27.55843. Thus, the fact that this interval does not contain zero indicates that the test would be rejected at the α = .05 level, and that there is significant evidence that the mean concentration of Pb is different from 0.2 mg/kg.

A one-sample Student’s t-test (Table 16) was performed to test the hypothesis that the mean concentration of Cr in *Zea mays* is not significantly different from the permissible limit set by WHO for Cr in food. The permissible limit for Cr in all foods is set at 1 mg/kg.

The mean concentrations of Cr in *Zea mays* (mean = 4.62, standard deviation = 7.69, number = 15) were not significantly different from the hypothesized value of 1 mg/kg, t(14) = 1.82, p=0.09. The confidence interval above is given as −0.63829, 7.87680. Thus, the fact that this

### Table 1 — Included Articles with Bioaccumulation Factors

| S/N | AUTHORS                  | YEAR |
|-----|--------------------------|------|
| 1   | Oladejo et al.,          | 2017 |
| 2   | Yang et al.,             | 2013 |
| 3   | Yu et al.,               | 2017 |
| 4   | Asgari and Cornelis      | 2015 |
| 5   | Afolayan and Hassan      | 2017 |
| 6   | Malomo et al.,           | 2013 |
| 7   | Lu et al.,               | 2015 |

### Table 2 — Included Articles Where Equation 1 was Applied

| S/N | AUTHORS                  | YEAR |
|-----|--------------------------|------|
| 1   | Awokunmi et al.,         | 2014 |
| 2   | Stanislawska–Glubiak et al., | 2015 |
| 3   | Prabpai et al.,          | 2009 |
| 4   | Cai et al.,              | 2014 |
| 5   | Li et al.,               | 2008 |
| 6   | Jin et al.,              | 2014 |
| 7   | Zhu                      | 2013 |
| 8   | Kang et al.,             | 2011 |
| 9   | Wang et al.,             | 2008 |
| 10  | Nan et al.,              | 2002 |
| 11  | Bi et al.,               | 2006 |
| 12  | Bi et al.,               | 2009 |
| 13  | Nwite and Alu            | 2015 |
| 14  | Liu et al.,              | 2005 |
| 15  | Ibrahim et al.,          | 2015 |
| 16  | Mantovia et al.,         | 2005 |
| 17  | Mu et al.,               | 2013 |
| 18  | Alushillari et al.,      | 2013 |
| 19  | Rattan et al.,           | 2005 |
| 20  | Zojaji et al.,           | 2014 |
### Table 3 — Cadmium Concentration in Soil and Bioaccumulation Factors in Zea mays

| Reference                  | Number of samples | Type of site | Cadmium (mg kg⁻¹) | Bioaccumulation factor |
|----------------------------|-------------------|--------------|-------------------|------------------------|
| Awokunmi et al. 2014⁴⁰     | 40                | a            | 21.9–138          | 0.03–0.058             |
| Oladejo et al. 2017¹⁴      | 12                | a            | 1.40–2.59         | 0.15–0.44              |
| Stanislawska–Glubiak et al. 2015⁴² | 16          | b            | 0.09–0.29         | 0.17–0.56              |
| Prabpai et al. 2009⁴³       | 20                | b            | 0.05–1.69         | 0.01–0.12              |
| Yang et al. 2013⁴⁴         | 17                | b            | 0.14–0.24         | 0.1–0.25               |
| Cai et al. 2014⁴⁵          | 27                | b            | 0.11–3.11         | 0.00076–0.00049        |
| Li et al. 2008⁴⁶           | 30                | b            | 0.81–1.5          | 0.13–0.74              |
| Jin et al. 2014⁴⁷          | 27                | b            | 1.58–3.87         | 0.0019–0.002           |
| Zhu 2013⁴⁸                 | 16                | b            | 0.13–0.17         | 0.01–0.07              |
| Kang et al. 2011⁴⁹         | 15                | b            | 0.142–0.162       | 0.0081–0.051           |
| Wang et al. 2008⁵⁰         | 12                | b            | 0.11–3.99         | 0.16–0.43              |
| Yu et al. 2017⁵¹           | 55                | b            | 0.119–0.199       | 0.081–0.135            |
| Nan et al. 2002⁵²          | 33                | c            | 0.14–19.3         | 0.063–0.95             |
| Bi et al. 2006⁵³           | 15                | c            | 5.8–74.0          | 0.01–0.54              |
| Bi et al. 2009⁵⁴           | 55                | c            | 69.0–2300.0       | 0.005–0.59             |
| Nwite and Aku 2015⁵⁵       | 27                | d            | 10.03–10.56       | 0.0028–0.003           |
| Asgari and Cornelis 2015⁵⁶ | 96                | d            | 3.8–4.1           | 0.05–0.28              |
| Liu et al. 2005⁵⁷          | 24                | d            | 0.1–0.27          | 0.47–0.71              |
| Afolayan and Hassan 2017⁵⁸ | 17                | e            | 163.96–258.38     | 0.176–0.197            |

Abbreviations: a, dumpsites; b, industrial pollution; c, mining and smelting; d, municipal water irrigated; e, battery waste dumpsite.

### Table 4 — Lead Concentration in Soil and Bioaccumulation Factors in Zea mays

| Reference                  | Number of samples | Type of site | Lead (mg kg⁻¹) | Bioaccumulation factor |
|----------------------------|-------------------|--------------|----------------|------------------------|
| Awokunmi et al. 2014⁴⁰     | 40                | a            | 35.0–60.0      | 0.24–1.20              |
| Oladejo et al. 2017¹⁴      | 12                | a            | 6.36–7.76      | 0.06–0.32              |
| Ibrahim et al. 2015⁵⁹      | 9                 | b            | 12.73–32.40    | 0.49–1.08              |
| Mantovia et al. 2005⁶⁰     | 12                | b            | 15.7–15.8      | 0.006–0.007            |
| Stanislawsk–Glubiak et al. 2015⁶² | 16          | b            | 21.7–34        | 0.01–0.013             |
| Prabpai et al. 2009⁶³      | 20                | b            | 4.1–83.8       | 0.001–0.017            |
| Cai et al. 2014⁶⁵          | 27                | b            | 139.10–651.97  | 0.00048–0.0025         |
| Jin et al. 2014⁶⁷          | 27                | b            | 33.62–122.1    | 0.007–0.009            |
| Zhu 2013⁶⁸                 | 16                | b            | 20.68–28.65    | 0.00077–0.0016         |
| Kang et al. 2011⁶⁹         | 15                | b            | 16.8–18.4      | 1.97E–6–4.64E–6        |
| Wang et al. 2008⁷⁰         | 12                | b            | 11.2–29.97     | 0.0037–0.011           |
| Yu et al. 2017⁷¹           | 55                | b            | 34.42–42.27    | 0.0008–0.001           |
| Malomo et al. 2013⁷²       | 24                | b            | 83.3–177.5     | 0.679–0.922            |
| Bi et al. 2006⁷³           | 15                | c            | 60.0–570.0     | 0.002–0.119            |
| Bi et al. 2009⁷⁴           | 55                | c            | 7.4–55         | 0.083–0.909            |
| Nwite and Aku 2015⁵⁵       | 27                | d            | 34.76–39.75    | 0.00075–0.00086        |
| Lu et al. 2015⁷⁶           | 40                | d            | 10.89–12.39    | 0.11–0.19              |
| Liu et al. 2005⁷⁷          | 24                | d            | 13.0–24.5      | 0.14–0.19              |
| Afolayan and Hassan 2017⁷⁸ | 17                | e            | 3265.8–4273.8  | 0.0096–0.0105          |

Abbreviations: a, dumpsites; b, industrial pollution; c, mining and smelting; d, municipal water irrigated; e, battery waste dumpsite.
### Table 5 — Chromium Concentration in Soil and Bioaccumulation Factors in Zea mays

| Reference            | Number of samples | Type of site | Chromium (mg kg\(^{-1}\)) | Bioaccumulation factor |
|----------------------|-------------------|--------------|----------------------------|------------------------|
| Awokunmi et al. 2014\(^{40}\) | 40                | a            | 9.0–29.8                   | 0.46–1.89              |
| Oladejo et al. 2017\(^{41}\) | 12                | a            | 7.92–10.99                 | 0.14–0.41              |
| Cai et al. 2014\(^{45}\) | 27                | b            | 149.4–170.19               | 0.0011–0.015           |
| Li et al. 2008\(^{46}\) | 30                | b            | 51.0–69.0                  | 0.0012–0.0015          |
| Kang et al. 2011\(^{49}\) | 15                | b            | 54.6–69.4                  | 0.0039–0.0066          |
| Wang et al. 2008\(^{50}\) | 12                | b            | 38.4–55.8                  | 0.011–0.019            |
| Yu et al. 2017\(^{51}\) | 55                | b            | 56.51–65.61                | 0.01–0.012             |
| Zhu 2013\(^{48}\)        | 16                | b            | 58.73–62.18                | 0.0037–0.0057          |
| Bi et al. 2006\(^{53}\)  | 15                | b            | 71.0–240.0                 | 0.004–0.056            |
| Prabpai et al. 2009\(^{43}\) | 20               | b            | 7.1–23.8                   | 0.0025–0.01            |
| Mantovia et al. 2005\(^{60}\) | 12            | c            | 58.3–59.6                  | 0.013–0.015            |
| Zojaji et al. 2014\(^{66}\) | 12               | d            | 11.15–26.68                | 0.11–0.40              |
| Asgari and Cornelis 2015\(^{56}\) | 96             | d            | 23.8–45.3                  | 0.01–0.12              |
| Lu et al. 2015\(^{62}\)  | 40                | d            | 11.12–12.05                | 0.45–1.03              |
| Liu et al. 2005\(^{57}\)  | 24                | d            | 49.0–162.0                 | 0.04–0.08              |

Abbreviations: a, dumpsites; b, industrial pollution; c, mining and smelting; d, municipal water irrigated.

### Table 6 — Zinc Concentration in Soil and Bioaccumulation Factors in Zea mays

| Reference            | Number of samples | Type of site | Zinc (mg kg\(^{-1}\)) | Bioaccumulation factor |
|----------------------|-------------------|--------------|-----------------------|------------------------|
| Awokunmi et al. 2014\(^{40}\) | 40                | a            | 63.0–80.2              | 0.07–0.4               |
| Oladejo et al. 2017\(^{41}\) | 12                | a            | 156.78–243.81         | 0.047–0.4              |
| Ibrahim et al. 2015\(^{59}\) | 9                 | b            | 27.21–30.78           | 0.23–0.99              |
| Stanislawska–Gubiak et al. 2015\(^{42}\) | 16            | b            | 95.0–165.0            | 0.18–0.4               |
| Mu et al. 2013\(^{63}\) | 18                | b            | 80.6–108.9            | 0.20–0.26              |
| Alushilari et al. 2013\(^{64}\) | 15              | b            | 54.0–102.0            | 0.14–0.53              |
| Yu et al. 2017\(^{51}\) | 55                | b            | 70.58–85.15           | 0.203–0.245            |
| Mantovia et al. 2005\(^{60}\) | 12               | c            | 82.8–93.9             | 0.34–0.43              |
| Nan et al. 2002\(^{52}\) | 33                | c            | 43.5–565.0            | 0.189–0.73             |
| Bi et al. 2006\(^{53}\) | 15                | c            | 260.0–5500.0          | 0.03–0.25              |
| Rattan et al. 2005\(^{65}\) | 115              | d            | 99.68–99.86           | 0.678–0.789            |
| Asgari and Cornelis 2015\(^{56}\) | 96             | d            | 146.1–238.9           | 0.18–0.34              |
| Lu et al. 2015\(^{62}\) | 40                | d            | 8.47–12.13            | 0.1–0.26               |
| Liu et al. 2005\(^{57}\) | 24                | d            | 16.0–162.5            | 0.44–0.88              |

Abbreviations: a, dumpsites; b, industrial pollution; c, mining and smelting; d, municipal water irrigated.
### Table 7 — Copper Concentration in Soil and Bioaccumulation Factors in *Zea mays*

| Reference               | Number of samples | Type of site | Copper (mg kg⁻¹) | Bioaccumulation factor |
|-------------------------|-------------------|--------------|------------------|-----------------------|
| Awokunni et al. 2014⁴⁰  | 40                | a            | 7.0–18.0         | 0.44–0.68             |
| Oladejo et al. 2017⁴¹   | 12                | a            | 20.17–21.41      | 0.1–0.47              |
| Prabpai et al. 2009⁴³   | 20                | b            | 7.0–82.1         | 0.065–0.66            |
| Yu et al. 2017⁵¹         | 55                | b            | 19.21–22.63      | 0.056–0.066           |
| Malomo et al. 2013⁶¹     | 24                | b            | 4.0–12.2         | 0.65–0.94             |
| Alushillari et al. 2013⁶⁴| 15                | b            | 16.6–21.1        | 0.07–0.42             |
| Bi et al. 2006⁵³         | 15                | b            | 9.3–260.0        | 0.015–0.16            |
| Mu et al. 2013⁶³         | 18                | b            | 30.8–36.3        | 0.57–0.65             |
| Mantovia et al. 2005⁶⁰  | 12                | c            | 60.7–65.7        | 0.031–0.035           |
| Ibrahim et al. 2015⁵⁹    | 9                 | d            | 2.25–33.97       | 0.011–0.99            |
| Rattan et al. 2005⁶⁵     | 115               | d            | 99.91–99.94      | 0.133–0.149           |
| Asgari and Cornelis 2015⁵⁶| 96                | d            | 51.9–64.3        | 0.06–0.12             |
| Liu et al. 2005⁵⁷        | 24                | d            | 13.5–88.0        | 0.27–0.86             |

Abbreviations: a, dumpsites; b, industrial pollution; c, mining and smelting; d, municipal water irrigated.

### Table 8 — Cadmium Concentrations in Soil and Bioaccumulation Factors in *Zea mays* Based on Site Type

| Type of site                          | Reference                  | Cadmium (mg kg⁻¹) | Bioaccumulation factor |
|---------------------------------------|----------------------------|-------------------|-----------------------|
| Dumpsite                              | Oladejo et al. 2017⁴¹      | 1.40–2.59         | 0.15–0.44             |
|                                       | Awokunni et al. 2014⁴⁰     | 21.9–138          | 0.03–0.058            |
|                                       | Yu et al. 2017⁵¹           | 0.119–0.199       | 0.081–0.135           |
| Industrial pollution and inorganic fertilizer | Nan et al. 2001⁵²        | 0.14–19.3         | 0.063–0.95            |
|                                       | Bi et al. 2006⁵³           | 69.0–2300.0       | 0.005–0.59            |
|                                       | Bi et al. 2009⁵⁴           | 0.14–0.24         | 0.1–0.25              |
| Mining and smelting                   | Liu et al. 2005⁵⁷          | 0.1–0.27          | 0.47–0.71             |
| Municipal wastewater irrigated        | Asgari and Cornelis 2015⁵⁶| 3.8–4.1           | 0.05–0.28             |
| Battery waste dumpsite                | Afolayan and Hassan 2017⁵⁸| 163.96–258.38     | 0.176–0.197           |
### Table 9 — Lead Concentrations in Soil and Bioaccumulation Factors in *Zea mays* Based on Site Type

| Type of site                               | Reference                      | Lead (mg kg⁻¹) | Bioaccumulation factor |
|--------------------------------------------|--------------------------------|----------------|------------------------|
| Dumpsite                                  | Oladejo *et al.* 2017⁴¹        | 6.36–7.76      | 0.06–0.32              |
|                                            | Awokunmi *et al.* 2014⁴⁰       | 35.0–60.0      | 0.24–1.20              |
| Industrial pollution and inorganic fertilizer | Malomo *et al.* 2013⁶¹        | 83.3–177.5     | 0.679–0.922            |
|                                            | Yu *et al.* 2017⁵¹             | 34.42–42.27    | 0.0008–0.001           |
|                                            | Ibrahim *et al.* 2015⁵⁹       | 12.73–32.40    | 0.49–1.08              |
| Mining and smelting                        | Bi *et al.* 2006⁵³             | 60.0–570.0     | 0.002–0.119            |
|                                            | Bi *et al.* 2009⁵⁴             | 7.4–55.0       | 0.083–0.909            |
| Municipal wastewater irrigated             | Liu *et al.* 2005⁵⁷            | 13.0–24.5      | 0.14–0.19              |
|                                            | Lu *et al.* 2015⁵²             | 10.89–12.39    | 0.11–0.19              |
| Battery waste dumpsite                     | Afolayan and Hassan 2017⁵⁸     | 3265.8–4273.8  | 0.0096–0.0105          |

### Table 10 — Chromium Concentrations in Soil and Bioaccumulation Factors in *Zea mays* Based on Site Type

| Type of site                               | Reference                      | Chromium (mg kg⁻¹) | Bioaccumulation factor |
|--------------------------------------------|--------------------------------|--------------------|------------------------|
| Dumpsite                                  | Oladejo *et al.* 2017⁴¹        | 7.92–10.99         | 0.14–0.41              |
|                                            | Awokunmi *et al.* 2014⁴⁰       | 9.0–29.8           | 0.46–1.89              |
|                                            | Yu *et al.* 2017⁵¹             | 56.51–65.61        | 0.01–0.012             |
| Industrial pollution and inorganic fertilizer | Bi *et al.* 2006⁵³             | 71.0–240.0         | 0.004–0.056            |
|                                            | Liu *et al.* 2005⁵⁷            | 49.0–162.0         | 0.04–0.08              |
|                                            | Asgari and Cornelis 2015⁵⁶     | 23.8–45.3          | 0.01–0.12              |
|                                            | Lu *et al.* 2015⁵²             | 11.12–12.05        | 0.45–1.03              |
|                                            | Zojaji *et al.* 2014⁶⁶         | 11.15–26.68        | 0.11–0.40              |

### Table 11 — Zinc Concentrations in Soil and Bioaccumulation Factors in *Zea mays* Based on Site Type

| Type of site                               | Reference                      | Zinc (mg kg⁻¹) | Bioaccumulation factor |
|--------------------------------------------|--------------------------------|----------------|------------------------|
| Dumpsite                                  | Oladejo *et al.* 2017⁴¹        | 156.78–243.81  | 0.047–0.4              |
|                                            | Awokunmi *et al.* 2014⁴⁰       | 63.0–80.2      | 0.07–0.4               |
|                                            | Yu *et al.* 2017⁵¹             | 70.58–85.15    | 0.203–0.245            |
|                                            | Ibrahim *et al.* 2015⁵⁹        | 27.21–30.78    | 0.23–0.99              |
|                                            | Nan *et al.* 2002⁵²             | 43.5–565.0     | 0.189–0.73             |
| Mining and smelting                        | Bi *et al.* 2006⁵³             | 260.0–550.0    | 0.03–0.25              |
|                                            | Rattan *et al.* 2005⁶³         | 99.68–99.86    | 0.678–0.789            |
| Municipal wastewater irrigated             | Liu *et al.* 2005⁵⁷            | 16.0–162.5     | 0.44–0.88              |
|                                            | Asgari and Cornelis 2015⁵⁶     | 146.1–238.9    | 0.18–0.34              |
|                                            | Lu *et al.* 2015⁶¹             | 8.47–12.13     | 0.1–0.26               |
| Type of site                              | Reference                   | Copper (mg kg⁻¹) | Bioaccumulation factor |
|------------------------------------------|-----------------------------|------------------|------------------------|
| Dumpsite                                 | Oladejo et al. 2017⁴¹       | 20.17–21.41      | 0.1–0.47               |
|                                          | Awokunmi et al. 2014⁴⁰      | 7.0–18.0         | 0.44–0.68              |
|                                          | Malomo et al. 2013⁶¹        | 4.0–12.2         | 0.65–0.94              |
| Industrial pollution and inorganic fertilizer | Yu et al. 2017⁵¹      | 19.21–22.63      | 0.056–0.066            |
|                                          | Ibrahim et al. 2015⁵⁹       | 2.25–33.97       | 0.011–0.99             |
|                                          | Bi et al. 2006⁵³            | 9.3–260.0        | 0.015–0.16             |
|                                          | Rattan et al. 2005⁵⁵       | 99.91–99.94      | 0.133–0.149            |
|                                          | Liu et al. 2005⁵⁷           | 13.5–88.0        | 0.27–0.86              |
| Mining and smelting                      | Asgari and Cornelis 2015⁵⁶ | 51.9–64.3        | 0.06–0.12              |
| Sewage irrigated                         |                             |                  |                        |
| Municipal wastewater irrigated           |                             |                  |                        |

**Table 12 — Copper Concentrations in Soil and Bioaccumulation Factors in Zea mays Based on Site Type**

| Reference | Number of samples | Cadmium (mg kg⁻¹) | Lead (mg kg⁻¹) | Chromium (mg kg⁻¹) | Zinc (mg kg⁻¹) | Copper (mg kg⁻¹) |
|-----------|------------------|-------------------|----------------|--------------------|----------------|-----------------|
| Awokunmi et al. 2014⁴⁰ | 40              | 4.331             | 40.2           | 30.231             | 18.245         | 7.66            |
| Oladejo et al. 2017⁴¹    | 12              | 0.805             | 1.433          | 2.809              | 52.447         | 6.04            |
| Ibrahim et al. 2015⁵⁹    | 9               | -                 | 20.615         | -                  | 18.365         | 16.8            |
| Mantovia et al. 2005⁶⁰   | 12              | -                 | 0.103          | 0.826              | 34.265         | 2.091           |
| Stanislawska–Głubiak et al. 2015⁴⁲ | 16          | 0.0887            | 0.33           | -                  | 41.55          | -               |
| Prabpai et al. 2009⁴³    | 20              | 0.102             | 0.715          | 0.128              | -              | 27.32           |
| Mu et al. 2013⁶³         | 18              | -                 | -              | 22.217             | 20.576         | -               |
| Allushllari et al. 2013⁶⁴| 15              | -                 | -              | 30.81              | 5.012          | -               |
| Yang et al. 2013⁴⁴       | 17              | 0.037             | -              | -                  | -              | -               |
| Cai et al. 2014⁴⁵        | 27              | 0.00764           | 0.848          | 1.359              | -              | -               |
| Li et al. 2008⁴⁶         | 30              | 0.608             | -              | 0.0826             | -              | -               |
| Jin et al. 2014⁴⁷        | 27              | 0.00535           | 0.667          | -                  | -              | -               |
| Zhu 2013⁴⁸              | 16              | 0.0066            | 0.0309         | 0.286              | -              | -               |
| Kang et al. 2011⁴⁹       | 15              | 0.00471           | 0.00000592     | 0.334              | -              | -               |
| Wang et al. 2008⁵⁶       | 12              | 1.7336            | 0.186          | 0.741              | -              | -               |
| Yu et al. 2017⁵¹         | 55              | 0.0183            | 0.0349         | 0.676              | 17.595         | 1.285           |
| Malomo et al. 2013⁶¹     | 24              | -                 | 110.108        | -                  | -              | 7.034           |
| Nan et al. 2002⁵²        | 33              | 9.172             | -              | -                  | 210.335        | -               |
| Bi et al. 2006⁵³         | 15              | 20.009            | 33.975         | 6.862              | 691.4          | 20.87           |
| Rattan et al. 2005⁵⁵     | 115             | -                 | -              | 73.187             | 14.089         | -               |
| Bi et al. 2009⁵⁴         | 55              | -                 | 25.305         | -                  | -              | -               |
| Nwite and Alu 2015⁵⁵     | 27              | 0.0299            | 0.184          | -                  | -              | -               |
| Lu et al. 2015⁶²         | 40              | -                 | 1.776          | 8.708              | 2.001          | -               |
| Zojaji et al. 2014⁶⁶     | 12              | -                 | -              | 5.949              | -              | -               |
| Asgari and Cornelis 2015⁵⁶| 96              | 0.669             | -              | 2.837              | 53.762         | 5.415           |
| Liu et al. 2005⁵⁷        | 24              | 0.12              | 3.238          | 7.46               | 75.02          | 39.663          |
| Afolayan and Hassan 2017⁵⁸| 17              | 39.879            | 38.114         | -                  | -              | -               |

**Table 13 — Concentrations of Cadmium, Lead, Chromium, Zinc, and Copper in Zea mays**
### Table 14 — One Sample t-Test for Concentration of Cadmium in Maize

| N  | Mean  | Standard deviation | Standard error mean |
|----|-------|--------------------|---------------------|
| Cd | 18    | 4.31260            | 10.184505           | 2.400511            |

#### One-Sample Test

| t  | df  | Sig. (2-tailed) | Mean difference | 95% Confidence interval of the difference |
|----|-----|----------------|-----------------|------------------------------------------|
| Cd | 1.755 | 17 | 0.097 | 4.212600 | -0.85204 | 9.27724 |

Abbreviations: N, sample size; t, test statistic; df, degrees of freedom; sig. (2-tailed), two-tailed p-value corresponding to the test statistic (Supplemental Material 1).

### Table 15 — One Sample t-Test for Concentration of Lead in Maize

| N  | Mean  | Standard deviation | Standard error mean |
|----|-------|--------------------|---------------------|
| Pb | 19    | 14.62436           | 27.249976           | 6.251573            |

#### One-Sample Test

| t  | df  | Sig. (2-tailed) | Mean difference | 95% Confidence interval of the difference |
|----|-----|----------------|-----------------|------------------------------------------|
| Pb | 2.307 | 18 | 0.033 | 14.424361 | 1.29029 | 27.55843 |

Abbreviations: N, sample size; df, degrees of freedom; sig. (2-tailed), two-tailed p-value corresponding to the test statistic (Supplemental Material 2).

### Table 16 — One Sample t-Test for Concentration of Chromium in Maize

| N  | Mean  | Standard deviation | Standard error mean |
|----|-------|--------------------|---------------------|
| Cr | 15    | 4.61925            | 7.688129            | 1.985066            |

#### One-Sample Test

| t  | df  | Sig. (2-tailed) | Mean difference | 95% Confidence interval of the difference |
|----|-----|----------------|-----------------|------------------------------------------|
| Cr | 1.823 | 14 | 0.090 | 3.619253 | -0.63829 | 7.87680 |

Abbreviations: N, sample size; df, degrees of freedom; sig. (2-tailed), two-tailed p-value corresponding to the test statistic (Supplemental Material 3).
interval contains zero indicates that the test would not be rejected at the \( \alpha = .05 \) level, and there is not significant evidence that the mean concentration of Cr is different from 1 mg/kg.

A one-sample Student's t-test (Table 17) was performed to test the hypothesis that the mean concentration of Cu in *Zea mays* is not significantly different from the permissible limit set by WHO for Cu in food. The permissible limit for Cu in all foods is set at 10 mg/kg.

| N | Mean | Standard deviation | Standard error mean |
|---|------|-------------------|--------------------|
| Cu | 13   | 13.37346          | 11.325714          | 3.141188          |

**Table 17 — One Sample t-Test for Concentration of Copper in Maize**

The mean concentrations of Cu in *Zea mays* (mean = 13.37, standard deviation = 11.33, number = 13) were not significantly different from the hypothesized value of 10 mg/kg, \( t(12) = 1.07, p=0.30 \). The confidence interval above is given as \( -3.47060, 10.21752 \). Thus, the fact that this interval contains zero indicates that the test would not be rejected at the \( \alpha = .05 \) level, and there is not significant evidence that the mean concentration of Cu is different from 10 mg/kg.

Copper is an essential element in mammalian nutrition as a component of metallo-enzymes in which it acts as an electron donor or acceptor. Conversely, exposure to high levels of Cu can result in a number of adverse health effects.79

**Discussion**

Maize is capable of bioaccumulating heavy metals from contaminated soils by translocating them from roots to shoots. Certain metals (e.g. Cd and Pb) have been reportedly accumulated by maize above the level used to define metal hyperaccumulation. Based on its capability of heavy metal uptake and sensitivity to high levels of metal pollution, maize is considered to be an accumulator and a metal tolerant plant, especially for Cd and Zn.78

One of the key aspects of the acceptance of phytoextraction pertains to its performance, ultimate utilization of by products and its overall economic viability.

However, the transfer and accumulation of heavy metals from soil to plants is an extremely complex process affected by multiple factors, which exert different influences on the process by means of various mechanisms. Some of the major influencing factors include the chemical forms of the heavy metals, pH of the soil, the soil organic matter content, plant species, climatic conditions, and irrigation with polluted water.76-77 As soils in different areas differ greatly in physical and chemical properties, the mechanisms of heavy metal transfer and accumulation in soil-plant systems is complex, and may be the cause for variations in *Zea mays* accumulation of heavy metals in the literature.78 There are a number of factors which influence uptake. Organic acid exudation by plants is a major factor governing the transfer and accumulation of heavy metals as they affect the uptake of heavy metals by altering the rhizosphere processes responsible for nutrient uptake. Flavonoid exudation can influence nutrient cycles by interacting with proteins and making protein nitrogen more resistant to microbial degradation and could indirectly affect soil pH, thus influencing heavy metals activity. Clay minerals and other soil colloids may also influence the bioavailability of heavy metals (a study by Zhou and Li (1996) suggested that for a given soil pH, increasing the proportion of particles with a size smaller than 0.002 mm can increase the soil capacity for Zn adsorption, thereby limiting the transfer of Zn to plants). Microbes are another factor affecting heavy metals uptake by

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The number of microbes around the roots is higher than that in other parts of the soil. Bacteria and fungi surrounding plant roots can promote plant uptake of heavy metals by changing heavy metals activity. For example, some bacteria can reduce As, mercury, and selenium, while others can oxidize iron and As. Among the various mechanisms of plant absorption, passive uptake via micro pores in the cell walls of root cells is the main method by which heavy metals access plants; chemical species with a high redox activity and chelating agents in soil may affect heavy metal uptake and accumulation in plants by changing their chemical form and thus their availability for plants. Nitrogen in soil represents another important factor influencing the transfer of heavy metals in soil-plant systems. It affects the bioavailability of heavy metals mainly by altering soil acidity. Soil pH is another factor influencing uptake of heavy metals from the soil. Among heavy metals, Cd is the most sensitive to soil pH. In addition, ammonium ions can displace trace metals in exchangeable forms or facilitate their release from soil colloids. The changes in concentration of soil-free bases and pH resulting from the dissolution and diffusion of ammonia nitrogen in soil in turn may change the solubility of heavy metals in soil. The mobility of heavy metals in soil-plant systems is also affected by the way heavy metals enter the plants. Chemical elements are primarily uptaken by roots from the soil or by leaves from the atmosphere. Apart from differences among various plant species and cultivars, the overall combination of soil physical and chemical properties controls both the rate and extent of metal uptake. For instance, a small decrease in biomass yield was observed in the case of maize plants grown on sandy soil, whereas in plants grown on loamy soil a significant increase in plant yields and decrease in Cu concentrations in shoot biomass were observed. The ideal soil types for maize plants are loam or silt loam surface soil and brown silt clay loam with a fairly permeable sub soil. The time period of growth can significantly affect the biomass yield of maize.

The degradation and depletion of the soil environment are a consequence of human activities such as deposition and discharge of agricultural residues on lands and water bodies and increased use of fertilizers and pesticides. The WHO reported that normal concentrations of Pb in soil range from 15–30 mg/kg, although from most of the reviewed literature, Pb values were much higher than this value. The allowed amount of Cd and Pb in fertilizer ranges from Cd = 8–300 mg kg⁻¹ and Pb = 20–200 mg kg⁻¹. These values vary among countries, and thus there is no specific fertilizer law. Clear guidelines or permissible limits for heavy metals have not been published by any regulatory body such as the United States Environmental Protection Agency (USEPA), the WHO or the Food and Agriculture Organization, probably due to variation in soil types, especially soil pH which affects bioavailability of heavy metals, and varying plant types. However, there are specific permissible limits based on soil type in different regions of the world. In 2005, the Ministry of Environmental Protection of the People's Republic of China (now the Ministry of Ecology and Environment) set permissible limits of 0.6 mg/kg, 100 mg/kg, 350 mg/kg, 300 mg/kg, 250 mg/kg for Cd, Cu, Pb, Zn and Cr, respectively. A group of Dutch ecologists set limits of 0.76 mg/kg for Cd, 3.6 mg/kg for Cr, 3.5 mg/kg for Cu, 16 mg/kg for Zn, and 55 mg/kg for Pb. The European Commission also set 1.5 mg/kg, 100 mg/kg, 100 mg/kg, and 200 mg/kg for Cd, Cu, Pb and Zn, respectively. The concentration of heavy metals in soils of reviewed studies was higher than the maximum tolerable levels proposed for agricultural soils.

Statistical analysis of the available data shows that there is a significant difference between mean concentrations of Pb and the maximum level set by the Food and Agriculture Organization of the World Health Organization (FAO/WHO). There was no significant difference between the mean concentrations of Cd, Cr, and Cu from the analyzed data and the standard set by WHO. However, the presence of these heavy metals in food is of great health risk concern. Zinc was evaluated by the Joint FAO/WHO Expert Committee on Food Additives in 1966 and 1982 based on clinical studies in which up to 600 mg of Zn sulfate (equivalent to 200 mg elemental Zn) was administered daily in divided doses for a period of several months, without any reported adverse effects, including effects on blood counts and serum biochemistry. There is a wide margin between nutritionally required amounts of Zn and toxic levels. Taking into account recent studies on humans, the WHO proposed in 2003 that the derivation of a guideline value was not required at the time; it was stated however, that drinking water containing Zn at levels above 3 mg/liter may not be acceptable to consumers based on taste considerations.

Tables 6–10 show previously published research on Zea mays planted on heavy metal polluted sites. Cadmium and Cr concentrations in soil were the highest in a tin-mining area, where long-term mining, transportation, mineral processing, and other production activities caused heavy metal pollution in the soil of local plants.
The soil at a battery waste dumpsite exhibited the highest Pb concentration, while the soil at a Zn smelting site presented the highest level of Zn. The heavy metals contained in wastes at these dumps can enter and contaminate the soil via long-term leaching and infiltration. The highest soil Cu concentration was found in mining and smelting facility. Awokunmi et al. and Oladejo et al. reported high levels of heavy metal accumulation in dumpsites in Nigeria. They revealed that dumpsites are sinks for elevated levels of heavy metals. Their work showed accumulation of Pb, Cd, Cr, Cu and Zn in Zea mays planted on these heavy metal concentrated soils. They also found that all of the heavy metals studied were found to accumulate mainly in the roots of the maize plant. Zea mays proves to be heavy metal tolerant and has high metal accumulating ability in the foliar parts with moderate BAF.

The bioconcentration factors (BCF) of Cd, Zn, Pb, Cr, and Cu in Zea mays generally increased with increasing heavy metal concentrations in the soil. The BCF of Cd, Zn, and Cu were high, while Cu and Cd easily accumulate in maize plants. These findings suggest that crops with high capacities for accumulating Cd, Cu, and Zn should be avoided during crop selection in order to reduce the risks to human health posed by the presence of heavy metals in crops. An analysis of the available data on Zea mays revealed that the concentrations of Cd, Cr, Pb, Cu, and Zn are high in Zea mays, but the statistical analysis identified many factors affecting the uptake of heavy metals from the soil, beyond the concentration of heavy metal in the soil. Studies have indicated that Pb concentration in exposed plants increased as the concentration in the soil increased. The results of the present study affirmed maize as a significant accumulator of Pb and Cd.

In general, Pb bioaccumulation was higher in the root tissues compared with the shoot tissues. This trend was also observed in grass species (Agropyron elongatum) and monocotyledon salt marsh plants. Plants are considered to be hyperaccumulators when they actively take up exceedingly large amounts of one or more heavy metals from the soil. Hyperaccumulators accumulate heavy metals in their shoot 100–1000 times higher than nonaccumulators. Reports have also shown that Cd-hyperaccumulating plant species in general accumulate more than 1 mg/kg of Cd, whereas regular plants accumulate only about 0.001–0.05 mg/kg of Cd. Zea mays has been observed to accumulate Cd in excess of this level. In the literature review, Zea mays accumulated above normal levels on many occasions, but on some occasions did not accumulate above normal levels. This may be due to various factors including soil heavy metal concentration and other influencing factors, such as the chemical forms of the heavy metals, soil pH, the soil organic matter content, plant species, and climatic conditions. It was noted that Pb bioaccumulation of corn in the root tissues at the highest treatment level were comparable with the Pb bioaccumulation values of Brassica juncea, which is a well-known hyperaccumulator species. These results further indicate that the Pb bioaccumulation capability of Zea mays is on par with other hyperaccumulating plants. The increase in accumulation and uptake of Pb in the root tissues could be attributed to their proximity to the Pb source. This contention was supported by other studies which showed that high concentrations of Pb available near the root system lead to an increase in Pb uptake and accumulation. Studies have shown that greater bioaccumulations of Pb in the shoot tissue of seedling at treatments of 100, 500, 2000 and 5000 mg/kg correlates with increasing concentration of Pb in soil. Lead taken up by the roots is transported and precipitated throughout the plant corresponding with the presence of Pb in the shoot tissues, and the connection of conducting vascular tissues of corn could be the main pathway of Pb uptake from the root to the shoot area. Likewise, comparing the bioaccumulation in Zea mays with Raphanus sativa revealed that the former accumulated more Pb compared to the latter, indicating that maize has a greater tolerance to Pb or higher tendency to accumulate Pb. This suggests that Zea mays has the ability to accumulate considerable amounts of Pb, and is thus a potential candidate for remediating Pb-contaminated soils.

Some studies showed accumulation of Pb, Cd, Cr, Cu and Zn in Zea mays planted on heavy metal concentrated soils. They also revealed that all of the studied heavy metals were found to accumulate mainly in the roots of the maize plant. Chromium concentration in the roots was reported to be higher than other parts. The present study found that Cr was mainly immobilized in the roots in comparison with other parts of Zea mays. Studies on vegetables also supported this point. This study clearly demonstrated that maize accumulated high amounts of Pb from the soil. These findings show the potential of Zea mays to ameliorate Pb-contaminated soil. Identification of tolerant plant species growing in heavy metal contaminated sites and characterization of their Pb bioaccumulation properties are essential for the proper use and management of contaminated areas. Heavy metals accumulation
decreased in the following order: soil > root > leaves > grains. However, the stalk and stem of plants show higher tendencies of metal accumulation compared to maize silk and grain. Other plant parts such as stem, stalk and silk were also found to contain these metals, indicating that they are unsafe for use as animal feedstock.

The current study revealed that dumpsites are sinks for elevated levels of heavy metals. It is important to note that if peasant farmers continue to cultivate maize and other arable crops on abandoned dumpsites, this will increase the levels of heavy metals which may eventually enter the food chain and present possible adverse human health effects. Heavy metal accumulation in soils and plants is of increasing concern due to the potential human health risks. Heavy metal contaminants not only represent a threat to agricultural product safety, but also harm to immune, reproductive, and nervous systems of organisms after entering their bodies through ingestion. This eventually leads to food chain contamination, which is an important pathway for entry of toxic pollutants into the human body. Heavy metals uptake by plants from soil reduces crop productivity by inhibiting physiological metabolism. Accumulation of heavy metals in plants and biomagnification presents a threat to human and environmental health. Excessive accumulation of heavy metals in agricultural soils often leads to elevated heavy metal uptake by crops, and thus affects food quality and safety. Food chain contamination is an important pathway for the entry of toxic pollutants into the human body. Heavy metals have been proven to be toxic to both humans and the environment. Therefore, regular environmental monitoring and restoration is imperative to determine that soils used for maize farming are not contaminated with heavy metals.

Owing to their toxicity and possible bioaccumulation, these compounds should be subject to mandatory monitoring. Governments should promote harmonized data collection, research, legislation and regulations, and consider the use of indicators. Assessments determining the chemical concentration scenario and the use of biomarkers should provide useful data to set standards and guideline values designed to protect human and environmental health from heavy metal contaminants. Exposure measurements are essential for the protection of high-risk populations and subgroups. Furthermore, governments should, when setting acceptable levels or criteria related to chemicals, take into consideration the potential enhanced exposures and/or vulnerabilities of children.

The ability of Zea mays to accumulate heavy metals from soil is significantly affected by a number of factors aside from the concentration of heavy metals in soil. However, based on the outcomes of the present study, it was concluded that Zea mays is capable of accumulating all selected heavy metals from soil over a wide range of environmental conditions.

**References**

1. Nagajyoti PC, Lee KD, Seekanth T V. Heavy metals, occurrence and toxicity for plants: a review. Environ Chem Lett [Internet]. 2010 Sep [cited 2019 Sep 26];8(3):199-216. Available from: https://doi.org/10.1007/s10311-010-0297-8 Subscription required to view.

2. Ma LQ, Rao GN. Chemical fractionation of cadmium, copper, nickel, and zinc in contaminated soils. J Environ Qual. 1997 Jan-Feb;26(1):259-64.

3. Li X, Thornton I. Chemical partitioning of trace and major elements in soils contaminated by mining and smelting activities. Appl Geochem [Internet]. 2001 Dec [cited 2019 Sep 26];16(15):1693-706. Available from: https://doi.org/10.1016/S0883-2927(01)00065-8 Subscription required to view.

4. Yang Y, Zhang FS, Li HF, Jiang RF. Accumulation of cadmium in the edible parts of six vegetable species grown in Cd-contaminated soils. J Environ Manage [Internet]. 2009 Feb [cited 2019 Sep 26];90(2):1117-22. Available from: https://doi.org/10.1016/j. jenvman.2008.05.004 Subscription required to view.

5. Lu A, Zhang S, Shan XQ. Time effect on the fractionation of heavy metals in soils. Geoderma
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[Internet]. 2005 Apr [cited 2019 Sep 26];125(3-4):225-34. Available from: https://doi.org/10.1016/j.geoderma.2004.08.002 Subscription required to view.

6. Liu J, Qian M, Cai G, Yang J, Zhu Q. Uptake and translocation of Cd in different rice cultivars and the relationship with Cd accumulation in rice grain. J Hazard Mater [Internet]. 2007 May 8 [cited 2019 Sep 26];143(1-2):443-7. Available from: https://doi.org/10.1016/j.jhazmat.2006.09.057 Subscription required to view.

7. Guo GL, Zhou QX. Speciation distribution and bioavailability of heavy metals in contaminated phaozem. Environ Chem. 2005;24:383-8.

8. Wu YG, Xu YN, Zhang JH, Hu SH. Evaluation of ecological risk and primary empirical research on heavy metals in polluted soil near Xiaoqinling gold mining region, Shaanxi, China. Trans Nonferrous Metals Society China [Internet]. 2010 Apr [cited 2019 Sep 26];20(4):688-94. Available from: https://doi.org/10.1016/S1003-6326(09)60199-0 Subscription required to view.

9. Chen JQ, Wang ZX, Wu X, Zhu JJ, Zhou WB. Source and hazard identification of heavy metals in soils of Changsha based on TIN model and direct exposure method. Trans Nonferrous Metals Society China [Internet]. 2011 Mar [cited 2019 Sep 25];21(3):642-51. Available from: https://doi.org/10.1016/S1003-6326(11)60761-9 Subscription required to view.

10. Wang Y, Qiao M, Liu Y, Zhu Y. Health risk assessment of heavy metals in soils and vegetables from wastewater irrigated area, Beijing-Tianjin city cluster, China. J Environ Sci (China) [Internet]. 2012 Apr [cited 2019 Sep 26];24(4):690-8. Available from: https://doi.org/10.1016/S1001-0742(11)60833-4 Subscription required to view.

11. Guo GH, Wu FC, Xie F, Zhang R. Spatial distribution and pollution assessment of heavy metals in urban soils from southwest China. J Environ Sci [Internet]. 2012 Mar [cited 2019 Sep 26];24(3):410-8. Available from: https://doi.org/10.1016/S1001-0742(11)60762-6 Subscription required to view.

12. Osakwe SA, Akpoveta OV, Okoh BE, Ize-Iyamu OK. Chemical forms of heavy metals in soils around municipal waste dumpsites in Asaba Metropolis, Delta State, Nigeria. Chem Speciat Bioavail [Internet]. 2012 [cited 2019 Sep 26];24(1):23-30. Available from: https://doi.org/10.3184/095422912X13255245250543

13. Shao X, Cheng H, Duan X, Lin C. Concentrations and chemical forms of heavy metals in agricultural soil near the world’s largest and oldest tungsten mine located in China. Chem Speciat Bioavail [Internet]. 2013 [cited 2019 Sep 26];25(2):125-32. Available from: https://doi.org/10.3184/095422913X13707909633728

14. Xu L, Wang T, Luo W, Ni K, Liu S, Wang L, Li Q, Lu Y. Factors influencing the contents of metals and as in soils around the watershed of Guanting Reservoir, China. J Environ Sci (China) [Internet]. 2013 Mar 1 [cited 2019 Sep 26];25(3):561-8. Available from: https://doi.org/10.1016/S1001-0742(12)60095-3 Subscription required to view.

15. Nedelkoska TV, Doran PM. Characteristics of heavy metal uptake by plant species with potential for phytoremediation and phytomining. Miner Eng [Internet]. 2000 May [cited 2019 Sep 26];13(5):549-61. Available from: https://doi.org/10.1016/S0892-6875(00)00035-2 Subscription required to view.

16. Wang J, Chen C. Biosorbsents for heavy metals removal and their future. Biotechnol Adv [Internet]. 2009 Mar-Apr [cited 2019 Sep 26];27(2):195-226. Available from: https://doi.org/10.1016/j.biotechadv.2008.11.002 Subscription required to view.

17. Havrot M, Nowak A. Monitoring of bioremediation of soil polluted with diesel fuel applying bioassays. Electron J Pol Agric Univ [Internet]. 2005 [cited 2019 Sep 26];8(2):Article 15 [2 p.]. Available from: http://www.ejpau.media.pl/volume8/issue2/art-17.html

18. Bell FG, Bullock SE, Halbich TF, Lindsay P. Environmental impacts associated with an abandoned mine in the Witbank Coalfield, South Africa. Int J Coal Geol [Internet]. 2001 Jan [cited 2019 Sep 26];45(2-3):195-216. Available from: https://doi.org/10.1016/S0166-5162(00)00033-1 Subscription required to view.

19. Schwartz G, Gerard E, Perronnet K, Morel JL. Measurement of in situ phytoextraction of zinc by spontaneous metallophytes growing on a former smelter site Sci Total Environ [Internet]. 2001 Nov 12 [cited 2019 Sep 26];279(1-3):215-21. Available from: https://doi.org/10.1016/S0048-9697(01)00784-7 Subscription required to view.

20. Passariello B, Giuliano V, Quaresima S, Barbaro M, Caroli S, Forte G, Garelli G, Iavicoli I. Evaluation of the environmental contamination at a abandoned mining site. Microchem J [Internet]. 2002 Oct [cited 2019 Sep 25];73(1-2):245-50. Available from: https://doi.org/10.1016/S0026-265X(02)00069-3 Subscription required to view.

21. Wojtaszek P. Oxidative burst: an early plant response to pathogen infection. Biochem J [Internet]. 1997 Mar 15 [cited 2019 Sep 26];322(3):681-92. Available from: https://doi.org/10.1042/bj3220681 Subscription required to view.

22. Mithofer A, Schulze B, Boland W. Biotic and heavy metal stress response in plants: evidence for common signals. FEBS Lett [Internet]. 2004 May 21 [cited 2019 Sep 26];566(1-3):1-5. Available from: https://doi.org/10.1016/j.flelt.2004.04.011

23. Srivastava S, Tripathi RD, Dwivedi UN. Synthesis of phytochelatins and modulation of antioxidants in response to cadmium stress in Cuscuta reflexa – an angiospermic parasite. J Plant Physiol [Internet]. 2004 Jun [cited 2019 Sep 26];161(6):665-74. Available from: https://doi.org/10.1016/j.jplphysiol.2004.01.030 Subscription required to view.

24. Qadir S, Qureshi MI, Javed S, Abdin MZ. Genotypic variation in phytoremediation potential of Brassica juncea cultivars exposed to Cd stress. Plant Sci [Internet]. 2004 Nov [cited 2019 Sep 26];167(5):1711-81. Available from: https://doi.org/10.1016/j.plantsci.2004.06.018 Subscription required to view.

25. Dong J, Wu F, Zhang G. Influence of cadmium on antioxidant capacity and four microelement concentrations in tomato seedlings (Lycopersicon esculentum). Chemosphere [Internet]. 2006 Sep [cited 2019 Sep 26];64(10):1659-66. Available from: https://doi.org/10.1016/j.chemosphere.2006.01.030 Subscription required to view.

26. Demiral T, Turkan I. Comparative lipid peroxidation, antioxidant defense systems and proline content in roots of two rice cultivars differing in salt tolerance. Environ Exp Bot [Internet]. 2005 Jun [cited 2019 Sep 26];53(3):247-57. Available from: https://doi.org/10.1016/j.envexpbot.2004.03.017 Subscription required to view.

27. Hugar HY, Pallad YB. Studies on maize-vegetable intercropping systems. Karnataka J Agric Sci. 2008;21(2):162-4.

28. Tagne A, Feujo TP, Sonna C. Essential oil and plant extracts as potential substitutes to synthetic fungicides in the control of fungi. International Conference: Diversifying Crop Protection; 2008 Oct 12-15; La Grande-Motte, France. European Union: Endure; 2008. 3 p.

29. Prasanna BM, Vasal SK, Kassahun B, Singh NN. Quality protein maize. Curr Sci. 2001;81(10):1308-19.

30. Yaouba A, Tatsadjieu N, Jazet DP, Mbofung CM. Inhibition of fungal development in maize grains under storage condition by essential oils. Int J Biosci. 2012;2(6):41-8.

31. Golob P, Kutukwa N, Deveraeu A, Bartosik RE, Rodriguez JC. Maize. In: Hodgins R, Farrell G, editors. Crop post-harvest: science and technology. Vol. 2, Durables [Internet]. Ames, IA: Blackwell Science
of heavy metals in soil and maize plant (Zea Mays) in the vicinity of two government approved dumpsites in Benin City, Nigeria. Asian J Chem Sci. 2017;3(3):1-9.

42. Stanislawskas-Glibukih E, Korzeniowska J, Kocan A. Effect of peat on the accumulation and translocation of heavy metals by maize grown in contaminated soils. Environ Sci Pollut Res Int. 2015 Mar [cited 2019 Sep 26];22(6):4706-14. Available from: https://doi.org/10.1007/s11356-014-3706-x Subscription required to view.

43. Prabhaj S, Chaeremtenaryarak L, Sirit B, Moore MR, Noller BN. Effects of residues from municipal solid waste landfill on corn yield and heavy metal content. Waste Manag [Internet]. 2009 Aug [cited 2019 Sep 27];29(8):2316-20. Available from: https://doi.org/10.1016/j.wasman.2009.02.009 Subscription required to view.

44. Yang H, Li Z, Lu L, Long J, Liang Y. Cross-species extrapolation of prediction models for cadmium transfer from soil to corn grain. PLoS One [Internet]. 2013 Dec 6 [cited 2019 Sep 27];8(12):Article e80855 [about 24 screens]. Available from: https://doi.org/10.1371/journal.pone.0080855

45. Cai BX, Huang Y, Wang Y, Li HX, Chai JL. An analysis of differences in accumulation of heavy metals in main crops in a tin mining area of Yunnan Province. Geol Bull China. 2014;33(8):1175-81.

46. Li MH, Li X, Song RS. Cadmium accumulation in crops grown in polluted farmland. Chin J Eco-Agric. 2008;16(3):675-9.

47. Jin Q, Zeng QH, Zhu B, Wang ML, Mou QS. Investigation and risk assessment for the risk of Pb and Cd in soil and vegetables of Zhoushui Bridge District. Agric Sci (China). 2014;42(3):199-202.

48. Zhu PL. Distribution of heavy metals in food crops and soil in some areas of Beijing [dissertation]. [Xi’an, China]: Xi’an University of Technology; 2013.

49. Kang SJ, Liu SJ, Zou GY, Sun H. Effects of sludge fertilizer and domestic waste fertilizer on heavy metal accumulation and yield of wheat-corn. China J Soil Sci. 2011;42(3):752-7.

50. Wang Y, Li YD, Cao GJ, Wang YJ. Content of heavy metals in soil and accumulation rule on maize grain in Changchun Area. J Maize Sci. 2008;16(2):80-7.

51. Yu R, Wang Y, Wang C, Yu Y, Cui Z, Liu J. Health risk assessment of heavy metals in soils and maize (Zea mays L.) from Yushu, northeast China. Hum Ecol Risk Assess [Internet]. 2017 [cited 2019 Sep 27];23(6):1493-504. Available from: https://doi.org/10.1080/10807039.2017.1327800 Subscription required to view.

52. Nan Z, Li J, Zhang J, Cheng G. Cadmium and zinc interactions and their transfer in soil-crop system under actual field conditions. Sci Total Environ [Internet]. 2002 Feb 21 [cited 2019 Sep 27];285(1-3):187-95. Available from: https://doi.org/10.1016/S0048-9697(01)00919-6 Subscription required to view.

53. Bi X, Feng X, Yang Y, Qiu G, Li G, Li F, Liu T, Fu Z, Jin Z. Environmental contamination of heavy metals from zinc smelting areas in Hezhang County, western Guizhou, China. Environ Int [Internet]. 2006 Sep [cited 2019 Sep 27];32(7):883-90. Available from: https://doi.org/10.1016/j.envint.2006.05.010 Subscription required to view.

54. Bi X, Feng X, Yang Y, Li X, Shin GP, Li F, Qiu G, Li G, Liu T, Fu Z. Allocation and source attribution of lead and cadmium in maize (Zea mays L.) impacted by smelting emissions. Environ Pollut [Internet]. 2009 Mar [cited 2019 Sep 27];157(3):834-9. Available from: https://doi.org/10.1016/j.envpol.2008.11.013 Subscription required to view.

55. Nwite JN, Alu MO. Effect of different levels of spent engine oil on soil properties, grain yield of maize and its heavy metal uptake in Abakaliki, Southeastern Nigeria. J Soil Sci Environ Manag. 2015 Jul;5(4):44-51.

56. Asgari K, Cornelis WM. Heavy metal accumulation in soils and grains, and health risks associated with use of treated municipal wastewater in subsurface drip irrigation. Environ Monit Assess [Internet]. 2015 Jul [cited 2019 Sep 27];187(7):410. Available from: https://doi.org/10.1007/s10661-015-4565-8 Subscription required to view.

57. Liu WH, Zhao JZ, Ouyang ZY, Soederlund L, Liu GH. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. Environ Int [Internet]. 2005 Aug [cited 2019 Sep 27];31(6):805-12. Available from: https://doi.org/10.1016/j.envint.2005.04.042 Subscription required to view.

58. Afelayan AO, Hassan AT. Lead, cadmium and iron concentrations in Zea mays grown within the vicinity of Ori Ile Battery Waste Dumpsite, Olobo, Ibadan, Nigeria. Am J Biosci Bioeng [Internet]. 2017 Oct [cited 2019 Sep 27];5(5):92-103. Available from: https://doi.org/10.11648/j.biosci.20170505.11

59. Ibrahim KN, Yet ZR, Som A, Razali N, Rohaizah NA, Othman EN, Burok NA, Yunus Y, Othman R, Yahya TF. Theoretical heavy metal concentration (Pb, Cu, Fe, Zn, Ni) in plant parts of Zea mays L. cultivated in agricultural area near Alor Gajah, Melaka, Malaysia. Am J Environ Eng. 2015;5(3A):8-12.

60. Mantovì P, Baldoni G, Toderi G. Reuse of
liquid, dewatered, and composted sewage sludge on agricultural land: effects of long-term application on soil and crop. Water Res. [Internet]. 2005 Jan-Feb [cited 2019 Sep 27];39(2-3):289-96. Available from: https://doi.org/10.1016/j.watres.2004.10.003 Subscription required to view.

61. Malomo O, Olufoye OE, Adekoyeni OO, Jimoh MO. Evaluation of heavy metal concentration in maize grown in selected industrial areas of Ogun State and its effects on urban food security. Int J Sci Technol Soc. 2013;(2):48-56.

62. Lu Y, Yao H, Shan D, Jiang Y, Zhang S, Yang J. Heavy metal residues in soil and accumulation in maize at long-term wastewater irrigation area in Tongliao, China. J Chem [Internet]. 2015 [cited 2019 Sep 27];2015:Article 682880 [9 p.]. Available from: http://dx.doi.org/10.1155/2015/682880

63. Mu SY, Liu BL, Ma XW, Dai XP, Huang DJ, Zhang YM. The effect research on heavy metal accumulation in soils, wheat and corn grain in agriculture wastewater irrigation areas at Gansu. Bajin Acad Essays Chin Environ Sci Assoc. 2013;256-61.

64. Alushllari M, Civici N, Deda A. The bioaccumulation factor of essential metals in maize plant. Sci Agric. 2016;5(2):76-9.

65. Rattan RK, Datta SP, Chhonkar PK, Suribabu K, Singh AK. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. Agric Ecosyst Environ [Internet]. 2005 [cited 2019 Sep 17];109(3-4):310-22. Available from: https://doi.org/10.1016/j.agee.2005.02.025 Subscription required to view.

66. Zojaji F, Hassani AH, Sayadi MH. Bioaccumulation of chromium by Zea mays in wastewater-irrigated soil: an experimental study. Bioaccumulation of metals; 2011 Mar 21-25; The Hague, Netherlands. Contaminants in foods; 2011 Mar 21-25; The Hague, Netherlands. Heavy metal residues in soil and accumulation, atmospheric distribution and the uptake of heavy metal by plants. Acta Biol Szeged. 2005;49(1):69-70.

72. Yang XE, Jin XF, Feng Y, Islam E. Molecular mechanisms and genetic basis of heavy metal tolerance/hyperaccumulation in plants. J Integr Plant Biol [Internet]. 2005 Sep [cited 2019 Sep 27];47(9):1025-35. Available from: https://doi.org/10.1046/j.1744-7909.2005.00144.x Subscription required to view.

73. Bali R, Siegle R, Harris AT. Phytoextraction of Au: uptake, accumulation and cellular distribution in Medicago sativa and Brassica juncea. Chem Eng J [Internet]. 2010 Jan 15 [cited 2019 Sep 27];156(2):286-97. Available from: https://doi.org/10.1016/j.cej.2009.10.019 Subscription required to view.

74. Chen GC. Molecular mechanisms of heavy metals tolerance and accumulation in unsaturated pseudomonas putida C21 biofilm [dissertation]. Hangzhou, China: Zhejiang University; 2011. Chinese.

75. Bennedsen LR, Krischker A, Jorgensen TH, Sogaard EG. Mobilization of metals during treatment of contaminated soils by modified Fenton’s reagent using different chelating agents. J Hazard Mater [Internet]. 2012 Jan 15 [cited 2019 Sep 27];219-200:128-34. Available from: https://doi.org/10.1016/j.jhazmat.2011.10.068 Subscription required to view.

76. Gall JE, Rajakaruna N. The physiology, functional genomics, and applied ecology of heavy metal-tolerant Brassicaceae. In: Lang M, editor. Brassicaceae: characterization, functional genomics and health benefits. Hauppauge, NY: Nova Biomed; 2013 Sep p. 121-48.

77. Neilsen S, Rajakaruna N. Phytoaccumulation of heavy metals in soils: use-potential to clean metal-contaminated arable lands. In: Ansari A., Gill S., Gill R., Lanza G., Newman L, editors. Phytoremediation: the role of plants in the mobilization of major and trace elements from soil. Basel, Switzerland: Springer; 2015. p. 159-68.

78. Wuana RA, Okieimen FE. Metal Heavy Metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. ISRN Environ Sci [Internet]. 2011 [cited 2019 Sep 27];2011:Article 402647 [20 p.]. Available from: http://dx.doi.org/10.5402/2011/402647

79. Badawy SH, Helal MI, Chaudri AM, Lawlor K, McGrath SP. Soil solid-phase controls lead activity in soil solution. J Environ Qual. 2002 Jan-Feb;31(1):162-7.

80. Zeng F, Ali S, Zhang H, Ouyang Y, Qiuby B, Wu F, Zhang G. The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Environ Pollut [Internet]. 2011 Jan [cited 2019 Sep 27];159(1):84-91. Available from: https://doi.org/10.1016/j.envpol.2010.09.019 Subscription required to view.

81. Terzano R, Cuccovillo G, Gattullo CE, Medici L, Tomasi N, Pinton R, Mimmoto T, Cesco S. Combined effect of organic acids and flavonoids on the mobilization of major and trace elements from soil. Biol Fertil Soils [Internet]. 2015 Aug [cited 2019 Sep 27];51(6):685-95. Available from: https://doi.org/10.1007/s00374-015-1009-0 Subscription required to view.

82. Kuiters AT. Role of phenolic substances from decomposing forest litter in plant-soil interactions. Acta Bot Neerlandica [Internet]. 1990 Dec [cited 2019 Sep 27];39(4):329-48. Available from: https://doi.org/10.1111/j.1438-8677.1990.tb01412.x Subscription required to view.

83. Garg N, Geetanjali A. Symbiotic nitrogen fixation in legume nodules: process and signaling - a review. Agron Sustain Dev [Internet]. 2007 Mar [cited 2019 Sep 27];27(1):59-68. Available from: https://doi.org/10.1051/agro:2006030 Subscription required to view.

84. Hattenschwiler S, Vitousek PM. The role of polyphenols in terrestrial ecosystem nutrient cycling. Trends Ecol Evol [Internet]. 2000 Jun 1 [cited 2019 Sep 27];15(6):238-43. Available from: https://doi.org/10.1016/S0169-5347(00)01861-9 Subscription required to view.

85. Cai Z, Wang B, Xu M, Zhang H, He X, Zhang L, Gao S. Intensified soil acidification from chemical N fertilization and prevention by manure in an 18-year field experiment in the red soil of southern China. J Soils Sediments [Internet]. 2015 Feb [cited 2019 Sep 27];15(2):260-70. Available from: https://doi.org/10.1007/s11368-014-0989-y Subscription required to view.

86. Zhou S, Liu J, Xu M, Lv J, Sun N. Accumulation, availability, and uptake of heavy metals in a red soil after 22-year fertilization and cropping. Environ Sci Pollut Res Int [Internet]. 2015 Oct [cited 2019 Sep 27];22(19):15154-63. Available from: https://doi.org/10.1007/s11356-015-4745-7 Subscription required to view.
87. Zhou W, Li JY. The adsorption of zinc on several typical soils in Beijing area of research. Environ Sci. 1996;17(6):43-5.
88. Cetin SC, Karaca A, Kizikaya R, Turgay OC. Role of plant growth promoting bacteria and fungi in heavy metal detoxification. In: Sherameti I, Varma A, editors. Detoxification of heavy metals. Berlin: Springer-Verlag; 2010. p. 369-88. [Soil biology 30].
89. Zhang C, Xiao JI. Bioremediation technology of contaminated soil. Beijing, China: China Environmental Science Press; 2000.
90. Mclaughlin MJ, Smolders E, Degryse F, Rietra R. Uptake of metals from soil into vegetables. In: Swartjes FA, editor. Dealing with contaminated sites: from theory towards practical application. Berlin: Springer; 2011. p. 325-67.
91. Zhao W, Cai ZC, Xu ZH. Does ammonium-based addition influence nitrification and acidification in humid subtropical soils of China. Plant Soil [Internet]. 2007 Aug [cited 2019 Sep 27];297(1-2):213-21. Available from: https://doi.org/10.1007/s11104-007-9334-1 Subscription required to view.
92. Perilli P, Mitchell LG, Grant CA, Pisante M. Cadmium concentration in durum wheat grain (Triticum turgidum) as influenced by nitrogen rate, seeding date and soil type. J Sci Food Agric. 2002;75: [56 p.].
93. Cazzato E, Laudadio V, Tufarelli V. Effects of harvest period, nitrogen fertilization and mycorrhizal fungus inoculation on triticale (×Triticosecale Wittmack) forage yield and quality. Renew Agric Food Syst [Internet]. 2012 Dec [cited 2019 Sep 27];27(4):278-86. Available from: https://doi.org/10.1017/S1742170511000482 Subscription required to view.
94. Zhou J, Xia F, Liu X, He Y, Xu J, Brookes PC. Effects of nitrogen fertilizer on the acidification of two typical acid soils in South China. J Soils Sediments [Internet]. 2014 [cited 2019 Sep 27];14(2):415-22. Available from: https://doi.org/10.1007/s11368-013-0695-1 Subscription required to view.
95. Singh BR, Myhr K. Cadmium uptake by barley as affected by Cd sources and pH levels. Geoderma [Internet]. 1998 Jun [cited 2019 Sep 27];84(1-3):185-94. Available from: https://doi.org/10.1016/S0016-7061(97)00128-6 Subscription required to view.
96. Blake L, Goulding KW. Effects of atmospheric deposition, soil pH and acidification on heavy metal contents in soils and vegetation of semi-natural ecosystems at Rothamsted Experimental Station, UK. Plant Soil [Internet]. 2002 Mar [cited 2019 Sep 27];240(2):235-51. Available from: https://doi.org/10.1023/A:1015731530498 Subscription required to view.
97. Lorenz SE, Hamon RE, Mcgrath SP, Holm PE, Christensen TH. Applications of fertilizer cations affect cadmium and zinc concentrations in soil solutions and uptake by plants. Eur J Soil Sci [Internet]. 1994 Jun [cited 2019 Sep 27];45(2):159-65. Available from: https://doi.org/10.1111/j.1365-8389.1994.tb00497.x Subscription required to view.
98. Yang ZL, Shen XL, Li S. Effects of heavy metals on wheat root weight and amino nitrogen with different fertilizer conditions. Chin Agric Sci Bull. 2007;23(8):453-7.
99. Kamnev AA, van der Lelie D. Chemical and biological parameters as tools to evaluate and improve heavy metal phytoremediation. Biosci Rep [Internet]. 2000 Aug [cited 2019 Sep 27];20(4):239-58. Available from: https://doi.org/10.1023/A:1026436802265 Subscription required to view.
100. Karczewska A, Galka B, Kabala C, Szopka K, Kocan K, Dziamba K. Effects of various chelators on the uptake of Cu, Pb, Zn and Fe by maize and Indian mustard from silty loam soil polluted by the emissions from copper smelter. Fresenius Environ Bull. 2009;18(10):1967-74.
101. Maize: climate and soils [Internet]. Hydrozabud, India: IKISAN; [2009?] [cited 2019 Sep 27]. [about 4 screens]. Available from: http://www.ikisan.com/tg-maize-climate-and-soils.html
102. Heavy metals-environmental aspects. Environment Health Criteria. No. 85. Geneva, Switzerland: World Health Organization; 1989.
103. Roberts TL. Cadmium and phosphorous fertilizers: the issues and the science. Procedia Eng [Internet]. 2014 [cited 2019 Sep 27];83:52-9. Available from: https://doi.org/10.1016/j.proeng.2014.09.012
104. The limit of pollutant in food. Beijing, China: State Environmental Protection Administration; 2005. GB 2762.
105. Vodyanitskii, YN. (2016) Standards for the contents of heavy metals in soils of some states. Annals of Agrarian Science. 14, 3: 257-263.
106. Council Directive 66/278/EEC on the protection of environment, and in particular of soil, when sewage sludge is used in agriculture. Luxembourg: European Commission, Office for Official publications of the European Communities; 1986.
107. Jesus BJ, Yllano OB. Bioaccumulation and bioconcentration of Pb in the tissues of Zea mays L. Philipp J Sci. 2005 Jun;134(1):21-9.
108. Aiyu HG, Adannu HM. The potential of maize as phytoremediation tool of heavy metals. Eur Sci J. 2014 Feb;10(6):30-7.
109. Yang H, Wong JW, Yang ZM, Zhou LX. Ability of Agrocyron elongatum to accumulate the single metal of cadmium, copper, nickel and lead and root exudation of organic acids. J Environ Sci (China). 2001 Jul;13(3):368-75.
110. Fitzgerald EJ, Caffrey JM, Nesaratnam ST, McLoughlin P. Copper and lead concentrations in salt marsh plants on the Suir Estuary, Ireland. Environ Pollut [Internet]. 2003 May [cited 2019 Sep 27];123(1):67-74. Available from: https://doi.org/10.1016/S0929-1440(02)00366-4 Subscription required to view.
111. Keeran NS, Balasundaram U, Govindan G, Parida, AK. Prosopis juliflora: a potential plant for mining of genes for genetic engineering to enhance phytoremediation of metals. In: Prasad NV, editor. Transgenic plant technology for remediation of toxic metals and metalloids. Cambridge, MA: Academic Press; 2019. p. 381-92.
112. Mcgrath SP, Zhao FJ, Lombi E. Phytoremediation of metals, metalloids, and radionuclides. Adv Agron. 2002;75: [56 p.].
113. Chaney RL, Malik M, Li YM, Brown SL, Brewer EP, Angle JS, Baker AJ. Phytoremediation of soil metals. Curr Opin Biotechnol. 1997 [cited 2019 Sep 27];8:279-84. Available from: https://doi.org/10.1016/S0958-1669(97)80004-3 Subscription required to view.
114. Xiong ZT. Bioaccumulation and physiological effects of excess lead in a roadside pioneer species Sonchus oleraceus L. Environ Pollut [Internet]. 1997 [cited 2019 Sep 27];97(3):275-9. Available from: https://doi.org/10.1016/S0269-7491(97)00086-9 Subscription required to view.
115. Tung G, Temple PJ. Uptake and localization of lead in corn (Zea mays L) seedlings, a study by histochemical and electron microscopy. Sci Total Environ [Internet]. 1996 Oct 11 [cited 2019 Sep 27];188(2-3):71-85. Available from: https://doi.org/10.1016/0048-9697(96)01516-X Subscription required to view.
116. Malone C, Koepple DE, Miller RJ. Localization of lead accumulated by corn plants. Plant Physiol [Internet]. 1974 Mar [cited 2019 Sep 27];53(3):388-94. Available from: https://doi.org/10.1104/pp.53.3.388
117. Han DH, Lee JH. Effects of liming on uptake of lead and cadmium by Raphanus sativa. Arch...
Review

Environ Contam Toxicol [Internet]. 1996 Nov [cited 2019 Sep 29];31(4):488-93. Available from: https://doi.org/10.1007/BF00212432 Subscription required to view.

118. Zoubi MM, Arslan AI, Abdelgawad A, Pejon N, Tabbaa M, Jouzdan O. The effect of sewage sludge on productivity of a crop rotation of wheat, maize and vetch and heavy metals accumulation in soil and plant in Aleppo Governorate. American-Eurasian J Agric Environ Sci. 2008;3(4):618-25.

119. Shahandeh H, Hosner LR. Enhancement of Cr(III) phytoaccumulation. Int J Phytoremediation [Internet]. 2000 [cited 2019 Sep 27];2(3):269-86. Available from: https://doi.org/10.1080/15226510009359037 Subscription required to view.

120. Muchuweti M, Birkett JW, Chinyanga E, Zvauya R, Scrimshaw MD, Lester JN. Heavy metal content of vegetables irrigated with mixtures of wastewater and sewage sludge in Zimbabwe: Implications for human health. Agric Ecosyst Environ [Internet]. 2006 Jan [cited 2019 Sep 29];112(1):41-8. Available from: https://doi.org/10.1016/j.agee.2005.04.028 Subscription required to view.