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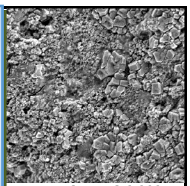

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SEM of *V. Subterranea* leaf

Comparative Study of Zinc Concentration in the Root, Stem, and Leaf of Maize (*Zea mays*) Grown on Soil Collected From Several Dumpsites in Anyigba, Nigeria

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ABSTRACT

Open dumpsites are becoming a major global concern in developing countries, causing heavy metal pollution, and posing a serious threat to human and plant health. This study assessed the zinc (Zn) concentration in the roots, stems, and leaves of maize plants growing on various dumpsite soils in Anyigba (Redeem, Market, and Anokwu). The plant tissues were tested for Zn using an Atomic Absorption Spectrophotometer (AAS). The study found that plants grown on a dumpsite had considerably higher Zn concentrations in their roots, stems, and leaves compared to the control site ($p<0.05$). The concentration of zinc ranges in the following sequence: Control (0.23 mg/kg)>Anokwu (0.62 mg/kg)>Market (0.63 mg/kg)>Redeem (0.80 mg/kg) for Stem; Control (0.34 mg/kg)>Market (0.68 mg/kg)>Anokwu (0.82 mg/kg)>Redeem (1.08 mg/kg) for Leaf; Control (0.66 mg/kg)>Anokwu (0.68 mg/kg)>Market (0.98)>Redeem (1.00 mg/kg). Zinc's bioconcentration factor (BCF) decreased in the following sequence among dumpsites: Anokwu (0.32 mg/kg) > Market (0.25 mg/kg) > Control (0.18 mg/kg) > Redeem (0.14 mg/kg), all of which exceeded WHO permitted levels. Bioaccumulation concentration (BAC) values range between 0.39 and 0.78 mg/kg, suggesting that maize plant is an excluder, while translocation factor (TF) values were all above 1, indicating that the plants translocate heavy metals from roots to shoots. Our study highlights the critical need for monitoring heavy metal contamination in food crops, especially in regions with open dumpsites, to protect public health. Given the potential risks of zinc bioaccumulation, effective measures are required to mitigate exposure, including soil remediation and the use of cleaner, safer agricultural practices. This research contributes to understanding the environmental and health implications of zinc pollution, emphasizing the urgency of addressing the risks associated with open dumpsites.

INTRODUCTION

A significant amount of solid waste is disposed off in either controlled landfills or open dumps. Open dumpsites are increasingly becoming a significant global concern in developing countries [1,2]. These dumpsites can be found everywhere in developing countries and are used to dispose off waste. They have grown from small dumps to large, unmanaged waste sites over time [3]. Recent studies, such as [4–7], highlight the ecological risks of heavy metals, including zinc toxicity, soil degradation, and water contamination. These issues are of great importance as they pose significant risks to both human health and the environment even at low concentration [8,9]. Improper disposal leads to the release of harmful heavy metals into water, soil, and plants, which in turn have negative impacts on the surrounding ecosystems, agricultural produce, animals, and ultimately human well-being [10,11].

There is a widespread issue of illegal waste disposal in all states of Nigeria, as highlighted by [12]. This problem has resulted in the existence of open dumps within densely populated areas, where millions of people reside, as pointed out by [13]. As a result, these waste dumps contribute to soil pollution**.** The solid waste composition includes a variety of materials like household waste, wood, microplastics, organic waste, industrial waste, medical waste, rubber, plastic bags, nylon plastics, papers, glass, discarded vehicles, and inorganic pollutants like heavy metals [14–17]. The presence of heavy metals in soil is a matter of great concern for the environment. This is because the accumulation of these metals can have negative impacts on soil ecology, agricultural productivity, and the health of animals and humans. Additionally, it can also affect the quality of groundwater [18,19]. Metals can enter the environment through various sources, including both natural processes and human actions. Once introduced, they have the potential to be taken up by plants and subsequently enter the food chain, which can have implications for human health. Although certain metals are necessary in small amounts, they can become harmful when present in higher concentrations than what is allowed in the environment [20,21].

The impact of these harmful substances on both the environment and human's health is becoming more evident. They have the ability to enter and build up in the food chain, posing a threat to the ecosystem's stability and our well-being [4]. People are often exposed to these harmful substances by breathing them in, swallowing them, or having them come into contact with their skin through contaminated soil and water. They can also be exposed by consuming contaminated food [22]. Excessive levels of zinc, a common heavy metal in soil, can negatively affect crop quality and yield. Additionally, the accumulation of zinc through absorption or deposition can pose a health risk to humans if consumed. It is important to be aware of these potential issues and take steps to mitigate them. Human activity releases heavy metals into the environment, which primarily end up in soils. Vehicle exhausts are also a significant contributor. Unfortunately, the accumulation of these metals in soils can have detrimental effects on soil function, raising concerns about the environment, human health, and ensuring productivity.

Maize, also known as *Zea mays L*., plays a crucial role as a cereal and versatile crop within the Poaceae family. It finds applications in human food, animal feeds, and poultry feed, as well as in various industrial processes. These include maize starch, dextrose, maize syrup, and maize flakes [23]. A significant amount of maize produced globally is utilized for animal consumption, providing essential proteins and calories for billions of individuals in developing regions, notably in Africa, Mesoamerica, and Asia [24,25]. Maize plays a crucial role in food security, providing a significant portion of daily calorie intake in several countries, especially in developing regions[24,26]**.** Current predictions suggest that by 2050, the demand for maize in developing countries will double due to the growing population, expansion of the poultry industry**,** which is the primary catalyst for increased maize production [26,27]**.**

In the past three decades, the global population has increased by over 30%, resulting in a current population of over 7 billion individuals on Earth [28]. Experts predict that this growth will continue, reaching 11.2 billion by the year 2100. The rapid growth of the world population and its ever-increasing demands for a higher quality of life have led to a significant rise in agricultural activities, as well as the need for higher crop yields to meet global food demands [29]. In order to increase agricultural yield, farmers frequently utilize different methods to improve the availability of soil nutrients for plants to absorb. One method involves cultivating plants using soil collected from dumpsites, which is rich in organic nutrients. However, inorganic pollutants such as heavy metals can taint these soils, despite their potential to promote agricultural productivity. Cultivated plants in these soils, particularly maize, can absorb heavy metals through a process known as phytoextraction [30]**.** As these metals make their way into the food chain, they have the potential to build up and become more concentrated as they move up along the chain and potentially, causing a negative effect on the health of both humans and animals who consume them. This study aims to analyze the levels of zinc in various parts of maize plants grown in soil from different dumpsites in Anyigba. Furthermore, it seeks to determine these plants' biological concentration factor (BCF), biological accumulation concentration (BAC), and translocation factor (TF). Through this research, valuable insights can be gained regarding the potential effects of these dumpsites on the plant, the environment, and the safety of consuming their produce.

MATERIALS AND METHODS

Experimental Design

The experimental design was a randomized complete block design with 12 replicates for each soil. The three different soils gotten from the various dump site was placed in polythene bags with 12 replicates each for each treatment. The Maize seeds were planted into the various soil, watered at two days interval throughout the period of the study. The dumpsites were selected considering the volume and nature of waste, proximity to agricultural settlements and their age.

Sample collection and Zn analysis

Control samples were also taken 500 m away from each dumpsite sample. After Four weeks of planting, 12 whole plants of Maize were randomly harvested from each bed within and across treatments. Composite plant part samples (leaves, stems, and roots) were made for each treatment. Each sample was washed with a jet of tap water and then with distilled water. The samples were then spread on a clean plastic tray and air dried at room temperature for 3 weeks until no trace of water was found in it. This was done to prevent any disruptions during analysis and minimize the amount of water present. Plant tissues were separately put in open polypropylene bags, labeled, and sent to the laboratory.

The Biological concentration factor (BCF) was calculated by determining the ratio of metal concentration in plant roots to soil, as shown in Equation 1. The Translocation factor (TF) was defined as the ratio of heavy metals in plant shoots to those in plant roots, as described in Equation 2. Lastly, the biological accumulation coefficient (BAC) was determined by calculating the ratio of heavy metal in shoots to that in soil, as given in Equation 3 [31].

$$BCF = \frac{Zn\ Concentration_{root}}{Zn\ Concentration_{soil}} \quad \text{(Eqn 1)}$$

$$TF = \frac{Zn\ Concentration_{shoot}}{Zn\ Concentration_{root}} \quad \text{(Eqn 2)}$$

$$BAC = \frac{Zn\ Concentration_{shoot}}{Zn\ Concentration_{soil}} \quad \text{(Eqn 3)}$$

Digestion and Analysis of Plant Sample

The plant species were dried in an oven at 70 ºC until a consistent weight was achieved. Roots and shoots were homogenized using a mortar, sieved through a 2 mm sieve, and stored at room temperature for analysis. Each of the prepared samples (1.0 g) was carefully weighed into 100 cm^3 conical flasks. A precise ratio of HNO_3 and HCL acid (3:1) was added to the mixture (21), which was then heated for 30 minutes on a water bath at 100 ºC. The mixture was left to cool, and an additional 5 cm^3 of HNO_3 was introduced. The heating process was then carried out for duration of 1 hour at a temperature of 100 ºC. The digest was boiled on a water bath to reduce its volume, and then allowed to

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cool. Water was distilled and heated for an additional 30 min. The final digest was allowed to cool and filtered. The final volume of digest was made up to 100 cm^3 with the distilled water and was analyzed for the required heavy metal by Atomic Adsorption Spectrophotometer (AAS) Buck Scientific VG990 Model.

Data Analysis

The Statistical Package for Social Science (SPSS) by IBM (International Business Machine), version 20.0, was used to analyze significant differences in zinc concentrations across the three treatments. One-Way ANOVA was chosen for its effectiveness in comparing means among groups, followed by an LSD post hoc test to assess specific pairwise differences. This statistical approach aligns with best practices recommended for heavy metal data analysis, addressing variance and distribution considerations specific to such datasets (19). All statistical tests were considered significant at $p < 0.05$ with a 95% confidence level.

RESULTS

Significantly elevated zinc concentrations in the roots, stems, and leaves of maize plants grown on soil obtained from the dumpsites were observed when compared to the control, as represented in **Table 1** and **Fig. 1** below. This bioaccumulation can be attributed to zinc hyperaccumulation mechanisms in plants [35]. The roots of maize from Redeem dumpsite had the highest concentration (0.80 ± 0.01 mg/kg), followed by Market dumpsite (0.63 ± 0.01 mg/kg) and Anokum dumpsite (0.62 ± 0.01 mg/kg), which were all significantly higher than the control (0.23 ± 0.01 mg/kg). There was a similar pattern observed in stems, where Redeem dumpsite had the highest concentration (1.08 ± 0.01 mg/kg). The leaf tissue from the Market dumpsite exhibited the highest zinc accumulation (0.98 ± 0.10 mg/kg), with Redeem and the control group following suit. It appears that dumpsite soils may contain higher levels of zinc, which can be absorbed by maize plants.

Table 1. Zinc concentration in different maize organs collected from various dumpsites. Error bars represent mean ± standard deviation (n=3).

Organ	Control	Redeem	Market	Anokum
Root	0.23 ± 0.01^a	0.80 ± 0.01^a	0.63 ± 0.01^a	0.62± 0.01^a
Stem	0.34 ± 0.06 ^{b}	1.08 ± 0.01^c	0.68 ± 0.01^b	0.82 ± 0.01^c
Leaf	0.66 ± 0.06^c	1.00 ± 0.10^b	0.98 ± 0.10^c	0.68 ± 0.07^b

Values are means ± standard deviation of triplicate determinations. Means with different superscripts within the same group are significantly different (p<0.05). All parameters were calculated in mg/kg.

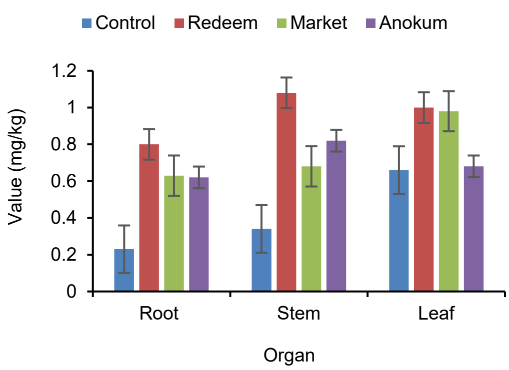

Fig. 1. Zinc concentration in different maize organs collected from various dumpsites. Error bars represent mean ± standard deviation (n=3).

Table 2 and **Fig. 2** show the bioconcentration factor, translocation factor, and bioaccumulation coefficient of maize plants grown at three dumpsites (Redeem, Market, and Anokum) as well as a control site. Market (0.25) and Anokum (0.32) dumpsites had the highest bioconcentration factor (BCF), indicating that zinc was absorbed more effectively from the soil than at the Control (0.18) and Redeem sites (0.14). Interestingly, the largest zinc translocation from roots to shoots, as evaluated by the Translocation Factor (TF), was reported in the control group (4.22 mg/kg), while the lowest was found in Anokum.

When analyzing both BCF and TF, it was observed that the control and Anokum dumpsites exhibited the highest biological accumulation coefficient (BAC) values (control: 0.77 mg/kg, Anokum: 0.78 mg/kg). This suggests a significant accumulation of zinc in the maize plants at these locations. Zinc concentrations in maize from these dumpsites exceed the permissible limits set by the World Health Organization (WHO, 1996) for heavy metals in crops, which raises serious concerns for human health. This highlights the need for further research into the environmental and health implications of consuming maize from contaminated sites. Additional studies are needed to assess the long-term health risks associated with the consumption of maize grown at these dumpsites, as well as to inform policies on food safety and environmental management.

Table 2. BCF, TF and BAC for Zn in different dumpsites and control in Anyigba.

	Control	Redeem	Market	Anokum
BCF	0.18	0.14	0.25	0.32
TF	4.22	2.60	2.64	2.43
BAC	0.77	0.39	0.6	0.78

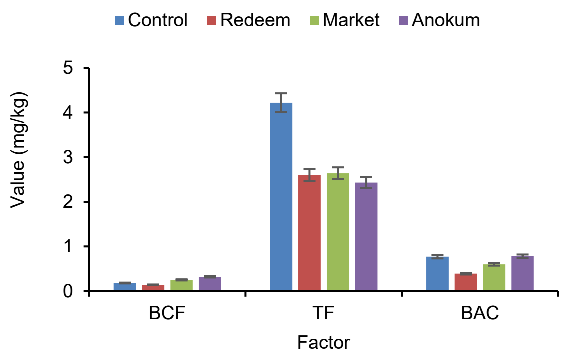

Fig. 2. BCF, TF, and BAC for Zn in different dumpsites and control in Anyigba. Error bars represent mean ± standard deviation (n=3).

DISCUSSION

Heavy Metals in Maize Plants Grown on Different Dumpsites.

While certain trace elements are necessary for the well-being of plants, those that grow in polluted surroundings can accumulate these elements to dangerous levels in their various organs, presenting a health risk to those who consume them [8]. This study revealed that the concentration of heavy metal (Zn) in maize plants was higher in areas near dumpsites compared to control sites. It is possible that the contamination occurred due to the disposal of certain substances at each location, as well as the maize plant's ability to accumulate high levels of these substances in the soil. The current findings align with the reports of [18] and Queirolo [34], who examined heavy metal translocation in other plants. **Table 1** consistently showed a lower zinc content in the roots of the maize plants compared to the stem and leaf. This finding aligns with the research conducted by Awokunmi and others [32].

Plant roots play a significant role in the entry of heavy metals into the food chain, as highlighted by recent studies [4,33]. According to Quierolo and others [34], a higher concentration of heavy metals in the shoots suggests that the metals absorbed by the roots are not undergoing processes that would inactivate or precipitate them in the root tissues. This allows the metals to be transported to the tissues above. The zinc concentration in the leaf varied across the different dumpsites, ranging from 0.68900 ± 0.66 ± 0.06 to 1.01 ± 0.01. Notably, samples from S3 had the lowest concentration, whereas samples from S1 had the highest concentration. The reported range of 0.4–0.6 mg/kg in the leaves of spinach grown on dumpsite soil, as found by Opaoluwa and others [27], is lower than the value mentioned here. Upon comparing the results from **Table 1** regarding Zinc concentration in various dumpsites to the World Health Organization (WHO) permissible limit of 0.60 mg/kg [28], it becomes evident that all of them exceeded the limit. This could potentially pose a health risk to consumers.

Excessive zinc concentrations in plants can result in stunted growth and yellowing of new leaves, potentially leading to cellular demise [35]. As they move up each level of the food chain, these elevated levels of zinc, like the ones mentioned here, become more concentrated. According to a study by [36], excessive zinc intake can lead to a range of health issues, including vomiting, diarrhea, bloody urine, icterus (yellow mucus membrane), liver failure, elevated cancer risk, kidney failure, and anemia.

BCF, TF and BAC of Maize Plants Grown on Dumpsite

The zinc BCF values in the different dumpsites showed a decrease in the following order: Anwoku (0.32) > Market (0.25) > Control (0.18) > Redeem (0.14). The BCF range found in this study aligns with the lower values (0.23–0.27 mg/kg) reported by [30], in their investigation of Zinc (Zn) BCF in the Root and Stem of Rhizophora sp. BAC falls into three categories based on its concentration: those with less than 1 are considered excluders, those with a concentration between 1 and 10 are accumulators, and those with a concentration greater than 10 are hyperaccumulators [35].

Based on the findings presented in **Table 2**, it appears that the maize plant has the ability to exclude the heavy metal (Zn) that was analyzed in various dumpsites and their corresponding control sites. This conclusion is drawn from the fact that all the BAC values were < 1. This discovery supports the findings of [18] in their research on maize plants in Benin. A translocation factor (TF) value greater than 1 indicates that the plant efficiently moves heavy metals from the roots to the shoots. Therefore, it is evident from **Table 2** that the maize plant efficiently transports zinc from the roots to the shoot.

Soil pH and texture also play a significant role in heavy metal bioavailability, affecting how readily plants can absorb these metals. Acidic soils increase the solubility of many heavy metals, including zinc, enhancing their availability for plant uptake, whereas basic soils reduce this bioavailability. According to Kibria et al. [15], acidic pH values can elevate bioavailable zinc concentrations, and this is compounded by soil texture, which influences nutrient retention and drainage properties. Future research on these soil factors could help explain why zinc levels vary in maize grown in contaminated soils.

CONCLUSION

This study investigated the concentration of heavy metals (specifically zinc) in maize samples grown on soil collected from various dumpsites in Anyigba. Recent research indicates that maize plants could potentially absorb elevated zinc levels from the soils found in dumpsites. The soil at the dumpsite contains high levels of zinc, exceeding the permissible limits set by the WHO. This is a consequence of improper disposal of waste containing heavy metals. According to the analysis of maize plants, there is a notable buildup of zinc in these specific locations. This analysis also indicates that the maize plant has the ability to exclude certain substances, but it has a high translocation factor, meaning it can transfer heavy metals to other parts of the plant, such as the leaves and stem. As a result, it puts crop consumers at risk and contributes to higher levels of environmental pollution. The toxic effects of zinc, as highlighted by Plum and others (36), emphasize the importance of evaluating health risks linked to consuming zinc-contaminated maize. Future studies should focus on understanding zinc bioavailability and absorption rates in humans who consume contaminated maize, investigate the potential interactions between zinc and other heavy metals. Additionally, analyzing other commonly cultivated plants on dumpsites, such as vegetables, is recommended.

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DECELERATION OF COMPETING INTEREST

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

AUTHORS CONTRIBUTION STATEMENTS

Edogbanya Paul Ramadan Ocholi: Supervision and final review. Victor Okpanachi: Sampling, study design, and resource. Victoria Ijaja: Conceptualization, and writing. Victoria Unekwuojo Obochi: writing and review. Christiana Ojochogwu Bello: Formatting, editing and review.

REFERENCES

1. Joseph OA, Hammed AL, Mohammed SN. Investigation of groundwater vulnerability to open dumpsites and its potential risk using electrical resistivity and water analysis. Heliyon. 2023;9(2):e13265.
2. Abubakar IR, Maniruzzaman KM, Dano UL, AlShihri FS, AlShammari MS, Ahmed SMS, et al. Environmental sustainability impacts of solid waste management practices in the Global South. Int J Environ Res Public Health. 2022;19(19):12717.
3. Siddiqua A, Hahladakis JN, Al-Attiya WAKA. An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environ Sci Pollut Res. 2022;29(39):58514-36.
4. Alengebawy A, Abdelkhalek ST, Qureshi SR, Wang MQ. Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. Toxics. 2021;9(3):42.
5. Giarikos DG, White L, Daniels AM, Santos RG, Baldauf PE, Hirons AC. Assessing the ecological risk of heavy metal sediment contamination from Port Everglades, Florida, USA. PeerJ. 2023;11:e16152.

https://doi.org/10.54987/jebat.v7i2.1007

6. Morimura H, Ishigami K, Kanie S, Sato Y, Kikuchi Y. Antioxidant cysteine and methionine derivatives show trachea disruption in insects. Oliveira PL, editor. PLoS One. 2024;19(10):e0310919.
7. Altıkulaç A, Turhan Ş. Evaluation of some potentially toxic elements and associated ecological and health risks in topsoil samples adjacent to an industrial zone in Turkey. ACS Omega. 2024;9(42):42668-78.
8. Hlihor RM, Roșca M, Hagiu-Zaleschi L, Simion IM, Daraban GM, Stoleru V. Medicinal plant growth in heavy metals contaminated soils: Responses to metal stress and induced risks to human health. Toxics. 2022;10(9):499.
9. Opaluwa OD, Aremu MO, Ogbo LO, Abiola KA, Odiba IE, Abubakar MM, Nweze NO. Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia Metropolis, Nasarawa State, Nigeria. Adv Appl Sci Res. 2012;3(2):780-4.
10. Nyiramigisha P, Komariah, Sajidan. Harmful impacts of heavy metal contamination in the soil and crops grown around dumpsites. Rural Agric Syst. 2021;9(0):271-82.
11. Ferronato N, Torretta V. Waste mismanagement in developing countries: A review of global issues. Int J Environ Res Public Health. 2019;16(6):1060.
12. Ichipi EB, Senekane MF. An evaluation of the impact of illegal dumping of solid waste on public health in Nigeria: A case study of Lagos State. Int J Environ Res Public Health. 2023;20(22):7069.
13. Akobundu NA, Nwodo HO. Evaluation of heavy metal in soils from Enyimba dumpsite in Aba, Southeastern Nigeria using contamination factor and geo-accumulation index. Environ Earth Sci. 2013;3(1):p125.
14. Awasthi P, Chataut G, Khatri R. Solid waste composition and its management: A case study of Kirtipur Municipality-10. Heliyon. 2023;9(11):e21360.
15. Kibria MdG, Masuk NI, Safayet R, Nguyen HQ, Mourshed M. Plastic waste: Challenges and opportunities to mitigate pollution and effective management. Int J Environ Res. 2023;17(1):20.
16. Ayilara M, Olanrewaju O, Babalola O, Odeyemi O. Waste management through composting: Challenges and potentials. Sustainability. 2020;12(11):4456.
17. Abah MA, Olawale O, Timothy M, Timothy NC, Oyibo ON, Okpanachi V, et al. Effect of temperature on microplastic degradation in soil environment. Asian J Sci Technol Eng Art. 2024;2(5):677-91.
18. Oladejo N, Anegbe B, Adeniyi O. Accumulation of heavy metals in soil and maize plant (Zea mays) in the vicinity of two government approved dumpsites in Benin City, Nigeria. Afr J Chem Soc. 2017;3(3):1-9.
19. Rashid A, Schutte BJ, Ulery A, Deyholos MK, Sanogo S, Lehnhoff EA, et al. Heavy metal contamination in agricultural soil: Environmental pollutants affecting crop health. Agronomy. 2023;13(6):1521.
20. Anegbe B, Okuo J, Ewekay E, Ogbeifun D. Fractionation of lead-acid battery soil amended with biochar. Bayero J Pure Appl Sci. 2015;7(2):36.
21. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol. 2014;7(2):60-72.
22. Hussain S, Khan M, Sheikh TMM, Mumtaz MZ, Chohan TA, Shamim S, et al. Zinc essentiality, toxicity, and its bacterial bioremediation: A comprehensive insight. Front Microbiol. 2022;13:900740.
23. Gheith EMS, El-Badry OZ, Lamlom SF, Ali HM, Siddiqui MH, Ghareeb RY, et al. Maize (Zea mays L.) productivity and nitrogen use efficiency in response to nitrogen application levels and time. Front Plant Sci. 2022;13:941343.
24. Shiferaw B, Prasanna BM, Hellin J, Bänziger M. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. Food Sec. 2011;3(3):307-27.
25. Erenstein O, Jaleta M, Sonder K, Mottaleb K, Prasanna BM. Global maize production, consumption and trade: trends and R&D implications. Food Sec. 2022;14(5):1295-319.
26. Grote U, Fasse A, Nguyen TT, Erenstein O. Food security and the dynamics of wheat and maize value chains in Africa and Asia. Front Sustain Food Syst. 2021;4:617009.
27. Okpanachi V. Impacts of agricultural activities on the quality of water in Ogane-Aji River, Anyigba, Kogi State, Nigeria. Zenodo; 2022. Available from: https://zenodo.org/doi/10.5281/zenodo.13956147
28. Sadigov R. Rapid growth of the world population and its socioeconomic results. Sci World J. 2022;2022:1-8.
29. Hemathilake DMKS, Gunathilake DMCC. Agricultural productivity and food supply to meet increased demands. In: Future Foods. Elsevier; 2022. p. 539-53.
30. Purwaningdyah AR, Takarina ND. Translocation factor of zinc (Zn) in water and sediment by root and stem of Rhizophora sp. at Blanakan Riparian, West Java. IOP Conf Ser: Earth Environ Sci. 2020;550(1):012006.
31. Mishra T, Pandey VC. Phytoremediation of red mud deposits through natural succession. In: Phytomanagement of Polluted Sites. Elsevier; 2019. p. 409-24.
32. Awokunmi E, Adefemi O, Asaolu S. Tissues accumulation of heavy metals by maize (Zea mays L.) cultivated on soil collected from selected dumpsites in Ekiti State, Nigeria. ACS J. 2015;5(2):156-62.
33. Keyster M, Niekerk LA, Basson G, Carelse M, Bakare O, Ludidi N, et al. Decoding heavy metal stress signalling in plants: Towards improved food security and safety. Plants. 2020;9(12):1781.
34. Queirolo F. Total arsenic, lead, and cadmium levels in vegetables cultivated at the Andean villages of northern Chile. Sci Total Environ. 2000;255(1-3):75-84.
35. Balafrej H, Bogusz D, Triqui ZEA, Guedira A, Bendaou N, Smouni A, et al. Zinc hyperaccumulation in plants: A review. Plants. 2020;9(5):562.
36. Plum LM, Rink L, Haase H. The essential toxin: Impact of zinc on human health. Int J Environ Res Public Health. 2010;7(4):1342-65.