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Seasonal Variation and Uptake Pattern of Heavy Metals in Maize

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Abstract
The detrimental impact of heavy metals on human health necessitates a focus on their contamination in the food chain. Heavy metals possess carcinogenic, mutagenic, teratogenic, and endocrine-disrupting properties. The objective of the study was to ascertain how Zn, Pb, Cd, Ni, Co, Cu, Cr, and Hg are accumulated in the roots and grains of maize samples cultivated under the Kano River Irrigation Project during both wet and dry seasons production and subsequently compare the levels of these heavy metals with the recommended permissible limits established by FAO/WHO. Additionally, the research sought to employ Translocation Factors to examine the uptake pattern of heavy metals in maize during the two growing seasons. Maize samples were procured from 10 different locations within the irrigation scheme during 2022 wet season and 2023 dry season harvests. The samples were prepared using standard laboratory protocols and heavy metals were determined using atomic absorption spectrophotometer. The heavy metals accumulation in maize grains was found in the order Zn>Cu>Pb>Ni>Co during wet season production. Cd, Cr, and Hg were not detected in samples collected during the wet season. It is only the concentration of Zn that exceeded the permissible limit in the samples collected during wet season production. The accumulation order during the dry season was Zn>Cu>Cr>Pb>Ni>Co>Cd. Hg was not detected in all the maize grain samples. The concentrations of Zn, Pb, Cd and Cr exceeded permissible limits in maize grains samples collected during dry season production.

Keywords: Toxicity, Contaminants, Cereals, Nigeria, Agrochemicals.

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INTRODUCTION

Heavy metal pollution in farmland soil can contaminate crops, leading to potential risks to the local ecosystem and human health (Jumei *et al.*, 2023). Intense human activities can contaminate surface water with heavy metals and cause detrimental health effects on humans (Liu *et al.*, 2023)

Maize plants are sensitive to heavy metal contamination, particularly chromium, copper, cadmium, nickel and lead. The uptake of heavy metal by maize plants from contaminated soil has been studied in various researches. Different varieties of maize have been tested for their ability to accrue heavy metals in their edible parts. Some varieties exhibited low accumulation capacities for cadmium, lead, chromium and arsenic in their grains, while others had high accumulation capacities for specific heavy metals (Zha *et al.*, 2023). Cadmium has the highest impact on the accumulation of heavy metals in maize plants, causing negative effects on plant mass and height (Petrović *et al.*, 2023). Maize plants cultivated in soils contaminated by mine tailings have shown high concentrations of heavy metals in their harvestable parts (Wei *et al.*, 2020).

Oladele *et al*. (2019) reported that higher concentrations of Pb and Zn in the soil significantly reduce growth in maize plants. Maize plants have been found to adapt to heavy metal pollution by altering their root characteristics, such as root diameter and root length, in response to an increase in metal bioavailability in the soil (Romdhane *et al.*, 2021). Maize plants grown in soils influenced by mine tailings showed depressed development, including small height, slow growth physiology and cob immaturity (Armienta *et al.*, 2020). Moreover, the presence of Pb and Zn in the soil negatively affects soil microorganisms and subsequently affects crop development (Oladele *et al.*, 2019).

Heavy metals cause significant health dangers to humans. Exposure to heavy metals can lead to various health problems, especially in children and the elderly. The presence of heavy metals in food is a major concern, as these contaminants can gather in the body over time and cause adverse effects on human health. Exposure to heavy metals such as lead, cadmium and mercury can induce cardiovascular problems and reduce IQ levels (Mounam, 2023). Heavy metals such as lead, mercury, cadmium, and arsenic have been classified as carcinogenic to humans due to their ability to induce deoxyribonucleic acid (DNA) damage (Gil and Olmedo, 2023). Heavy metals such as lead, mercury, cadmium, arsenic, and nickel, can have damaging effects on the brain, endocrine-metabolic systems, cardiovascular and reproduction systems (Mugume *et al.*, 2023). The consumption of heavy metal-contaminated crops can lead to chronic accumulation of heavy metals in the kidneys and liver, can also disrupt biochemical processes and cause cardiovascular, neural, kidney and bone diseases (Priya *et al.*, 2023).

The study aimed to determine the concentrations of Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg in the roots and grains of maize samples obtained from 10 different locations across the Kano River Irrigation Project during the wet and dry season production. The research also sought to compare the metal concentrations with the permissible limits endorsed by FAO/WHO. Furthermore, the study aimed to employ Translocation Factors determination and investigate the Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg absorption patterns in maize during the wet and dry growing seasons.

METHODOLOGY

Sampling Location

The Kano River Irrigation Project (KRIP) encompasses an expansive area of approximately 62,000 hectares, this irrigation scheme relies on the Tiga Dam and Ruwan Kanya Reservoir as its main sources of irrigation water. The irrigation project is close to Kano City, with a distance of approximately 30 kilometres and spreads across both sides of the Kano-Zaria expressway. Samples were harvested at their optimal maturity. Wet season samples for maize grain and root were collected between September and October 2022. Sampling locations for this season were 'Yantomo, Gafan, Rigada, Makuntiri, Yadakwari, Dakasoye, Kura (Tsauni), Kura (Gorubawa), Imawa I and Imawa II. Dry season samples were collected between May and June 2023. Grains and roots samples were collected from Gafan Bunkure, Gafan I, Gafan II, Kukoki, Kwalele, Bulan Wanzamai, Kura (Babbar Gada), Kura (Fegin Malu), Imawa (Gada Mailotso) and Imawa (Rimin Kwarya).

Sample Preparation and Heavy Metals Determination

Harvested samples were separated into roots and cobs. Maize cob samples were appropriately dried, shelled and thoroughly washed with deionised water. Root samples were soaked in deionised water before thoroughly washed with excess deionised water. Samples were oven-dried to constant weight and crushed into powder before being burnt to ash using a muffle furnace at 550 ºC for 5 hours. The ash was mixed with concentrated HNO_3 and $HClO_4$ (3:1, v/v) in a heating digester. Each 1 g of the sample was mixed with 20 ml of the acid mixture. Then the acid digest was allowed to cool and filtered into 100 mL bottles, using Whatman filter paper and made up to mark with deionised water (Akinyele and Shokunbi, 2015). The concentrations of Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg in the plant tissues were determined in triplicates using an atomic absorption spectrophotometer machine (PerkinElmer PinAAcle 900H) and results were reported as Mean±SD.

Computation of Translocation Factor

Heavy metal contents of the roots were compared with that of edible parts to study Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg uptake patterns of maize during wet and dry seasons. Translocation Factor (TF) is used to study the ability of a plant to translocate the accumulated metals in the roots to shoot and other parts above the roots (Ladislas *et al*., 2012). This was used to study the ability of the crops to translocate accumulated metals in the roots to the edible portion. TF was calculated according to the modified method of Zhuang *et al*. (2007).

$$\mathbf{TF} = \frac{R_{conc.}}{G_{conc.}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 1}$$

Where: $R_{conc.}$ is the metal concentration in the root, and
G_{conc} is the metal concentration in the grain.

RESULTS AND DISCUSSION

Wet Season Harvest

The results for heavy metal concentrations in maize grain samples collected during this production season are presented in Table 1. The concentrations of the heavy metals in the maize grain range between 6.620-12.447, 1.260-2.673, 0.180-0.620, 0.080-0.287 and 1.613-3.673 mg/kg for Zn, Pb, Ni, Co and Cu respectively. Cd, Cr and Hg were not detected in maize grain samples collected during this production season. The overall means for the concentrations of Zn, Pb, Ni, Co and Cu were found to be 9.204, 1.967, 0.366, 0.181 and 2.628 mg/kg respectively. The overall means for Pb, Ni, Co and Cu were found to be below WHO permissible limits while that of Zn exceeded the permitted limit set by WHO.

The results for the heavy metal content of the maize root samples collected during the 2022 wet season are presented in Table 2. The concentrations of Zn, Pb, Ni, Co and Cu in the root samples range between 0.347-5.000, 0.640-2.220, 0.247-1.020, 0.067-0.373 and 0.307-2.653 mg/kg respectively. Similar to the grain samples, Cd, Cr and Hg were also not detected. The overall means observed are 2.873, 1.284, 0.557, 0.220 and 1.427 for Zn, Pb, Ni, Co and Cu respectively. Higher concentrations of Zn, Pb and Cu were observed in the grain samples and concentrations of Ni, Co were found to be higher in the root samples.

Dry Season Harvest

The results for heavy metal contents of the maize grain samples collected during this production season are presented in Table 3. The mean concentrations of Zn, Pb, Cd, Ni, Co, Cu and Cr range between 11.540-20.927, 1.540-2.347, 0.160-0.200, 1.147-1.613, 0.567-0.773, 3.093-5.867 and 1.747-4.627 mg/kg respectively. Hg is the only heavy metal that was not detected among the selected metals. The overall mean concentrations are 15.852, 2.092, 0.179, 1.387, 0.686, 4.145 and 2.529 mg/kg for Zn, Pb, Cd, Ni, Co, Cu and Cr respectively.

The overall mean values for Zn, Pb, Cd, and Cr in samples collected during dry season harvest exceeded permissible limits recommended by WHO (Ogundele *et al*., 2015) while those of Ni, Co and Cu fell below the permissible limits. Findings similar to this were also reported by many researchers in other parts of Nigeria. The Ni and Pb values observed in maize produced in Ogun State, Nigeria exceeded WHO permissible limits (Olu *et al*., 2013). The concentrations of Zn, Cu and Pb in maize produced in Port Harcourt, Nigeria are within FAO/WHO permissible limits (Sagbara *et al*., 2020). The values of Pb, Cd and Cr detected by Ifie *et al*. (2022) in maize produced in Delta State, Nigeria exceeded permissible limits. Simon *et al*. (2014) observed Pb above the WHO permissible limit in maize samples collected from Minna, Nigeria.

The results for the heavy metal contents of the maize root samples collected during dry season production are presented in Table 4. Mean values for the concentrations of Zn, Pb, Cd, Ni, Co, Cu and Cr range between 1.833-7.053, 0.993-1.793, 0.127-0.187, 0.827-1.293, 0.480-0.820, 0.593-3.253 and 2.380-8.373 mg/kg respectively. Similarly, Hg was also not detected in root samples collected during this production season. The mean of means of the sampling locations for Zn, Pb, Cd, Ni, Co, Cu and Cr in the maize roots are 3.765, 1.367, 0.155, 1.042, 0.601, 1.205 and 3.695 mg/kg respectively.

The concentrations of Zn, Pb, Cd, Ni, Co and Cu were found to be higher in the grains than in the roots while that of Cr was found to be higher in the roots than in the grains. Observing higher concentration of Ni and Co in the grains contradict the wet season production accumulation pattern where these two metals were found to accumulate more in the roots.

Comparison between wet and dry season results shows that maize accumulates more heavy metals during the dry season as Cd and Cr were not detected during wet season production. Also, the pattern of metal deposits between the roots and the grains varies with the production season. The results of a systemic review conducted by Aladesanmi *et al*. (2019) shows that maize is capable of accumulating high amount of Cd, Cr, Pb, Cu, and Zn, though, the accumulation depends on many factors including soil texture, cation exchange capacity, root exudation and especially soil pH and chemical forms of the heavy metals. The concentrations of toxic heavy metals observed by Afolayan (2018) in maize were high and capable of causing numerous hostile health conditions. The concentrations of Cu, Ni and Pb reported in maize produced in Ogun State, Nigeria (Olu *et al*., 2013) surpassed the concentrations observed here. Also, Cd, Cr, Pb, Ni, Cu and Co were reported by Awokunmi *et al*. (2015) in maize produced in dumpsites in Ekiti. The Pb value reported by Simon *et al*. (2014) in maize samples collected from Minna, Nigeria agreed with what was observed in this research.

Translocation factor

Calculated values for translocation factors of wet season 2022 and dry season 2023 are presented in Table 5. A Root:Grain metal concentration value >1 signifies higher accumulation in the roots while values <1 indicate accumulation in the grains.

The translocation results for the wet season 2022 show that Ni and Co accumulate more in the roots than in the grains while Zn, Pb and Cu accumulate more in the grains than in the roots. Results for dry season 2023 show that Cr accumulates more in the root while Zn, Pb, Cd, Ni, Co and Cu accumulate more in the grains.

Table 1: Heavy Metal Contents (mg/kg) of Maize Grain (Wet Season, 2022)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Yantomo	9.287±0.05	2.013±0.29	ND	0.247±0.05	0.153±0.08	2.493±0.02	ND	ND
Gafan	10.553±0.05	1.593±0.01	ND	0.620±0.09	0.213±0.13	3.167±0.05	ND	ND
Rigada	12.447±0.07	1.807±0.26	ND	0.600±0.16	0.233±0.08	3.353±0.12	ND	ND
Makuntiri	6.620±0.06	1.420±0.31	ND	0.213±0.13	0.167±0.04	1.627±0.06	ND	ND
Yadakwari	7.200±0.03	1.260±0.58	ND	0.347±0.08	0.280±0.02	3.013±0.09	ND	ND
Dakasoye	10.147±0.05	2.500±0.45	ND	0.333±0.15	0.120±0.06	2.013±0.01	ND	ND
Kura (Tsauni)	7.533±0.03	2.660±0.43	ND	0.180±0.13	0.187±0.13	3.673±0.06	ND	ND
Kura (Gorubawa)	7.567±0.01	1.920±0.59	ND	0.220±0.12	0.080±0.06	2.020±0.05	ND	ND
Imawa I	10.053±0.05	1.827±0.45	ND	0.447±0.07	0.087±0.03	3.307±0.10	ND	ND
Imawa II	10.633±0.01	2.673±0.33	ND	0.453±0.11	0.287±0.13	1.613±0.08	ND	ND
Range	**6.620-12.447**	**1.260-2.673**	**ND**	**0.180-0.620**	**0.080-0.287**	**1.613-3.673**	**ND**	**ND**
Mean	**9.204**	**1.967**	**ND**	**0.366**	**0.181**	**2.628**	**ND**	**ND**
WHO Permissible Limits	**0.6***	**2.0***	**0.02***	**10***	**50****	**10***	**1.3***	

ND = Not detected
*(Ogundele *et al*., 2015)
**(Chiroma *et al*., 2014)

Table 2: Heavy Metal Contents (mg/kg) of Maize Root (Wet Season, 2022)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Yantomo	0.987±0.03	1.500±0.22	ND	0.247±0.08	0.213±0.15	0.720±0.05	ND	ND
Gafan	4.827±0.01	1.673±0.24	ND	1.020±0.05	0.313±0.05	2.213±0.11	ND	ND
Rigada	0.953±0.71	1.233±0.33	ND	0.313±0.06	0.287±0.13	0.500±0.02	ND	ND
Makuntiri	2.447±0.06	0.740±0.28	ND	0.700±0.09	0.220±0.07	2.653±0.09	ND	ND
Yadakwari	0.347±0.01	1.340±0.16	ND	0.700±0.11	0.067±0.08	0.307±0.07	ND	ND
Dakasoye	5.000±0.03	2.220±0.09	ND	0.707±0.15	0.373±0.09	2.533±0.06	ND	ND
Kura (Tsauni)	3.873±0.01	1.740±0.37	ND	0.580±0.09	0.187±0.02	1.620±0.07	ND	ND
Kura (Gorubawa)	3.727±0.03	0.940±0.07	ND	0.407±0.14	0.080±0.02	1.093±0.03	ND	ND
Imawa I	3.360±0.04	0.640±0.21	ND	0.467±0.05	0.293±0.11	1.240±0.02	ND	ND
Imawa II	3.207±0.03	0.813±0.42	ND	0.433±0.05	0.167±0.05	1.393±0.01	ND	ND
Range	**0.347-5.000**	**0.640-2.220**	**ND**	**0.247-1.020**	**0.067-0.373**	**0.307-2.653**	**ND**	**ND**
Mean	**2.873**	**1.284**	**ND**	**0.557**	**0.220**	**1.427**	**ND**	**ND**

ND = Not detected

Table 3: Heavy Metal Contents (mg/kg) of Maize Grain (Dry Season, 2023)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Gafan Bunkure	11.540±0.04	1.540±0.22	0.160±0.00	1.320±0.08	0.567±0.06	3.093±0.02	2.693±0.05	ND
Gafan II	13.633±0.03	2.067±0.19	0.187±0.01	1.400±0.11	0.620±0.05	3.820±0.00	4.627±0.31	ND
Gafan	13.860±0.02	2.053±0.32	0.173±0.01	1.300±0.02	0.633±0.08	3.340±0.03	3.100±0.30	ND
Kukoki	20.927±0.07	2.347±0.18	0.180±0.00	1.600±0.04	0.740±0.02	4.200±0.04	2.467±0.10	ND
Kwalele	19.307±0.04	2.173±0.12	0.167±0.01	1.387±0.02	0.687±0.01	3.880±0.00	1.747±0.47	ND
Bulan Wanzamai	18.100±0.04	2.187±0.11	0.187±0.01	1.353±0.05	0.647±0.07	3.740±0.07	2.100±0.14	ND
Kura (Babbar Gada)	11.887±0.03	2.007±0.18	0.167±0.01	1.147±0.08	0.687±0.08	3.533±0.04	1.913±0.54	ND
Kura (Fegin Malu)	16.907±0.02	2.333±0.15	0.200±0.00	1.393±0.08	0.747±0.03	5.867±0.06	1.800±0.32	ND
Imawa (Gada Mailotso)	16.067±0.05	2.033±0.08	0.187±0.01	1.613±0.09	0.773±0.12	5.767±0.04	2.487±0.55	ND
Imawa (Rimin Kwarya)	16.293±0.02	2.180±0.23	0.180±0.02	1.353±0.08	0.760±0.05	4.213±0.04	2.360±0.28	ND
Range	**11.540-20.927**	**1.540-2.347**	**0.160-0.200**	**1.147-1.613**	**0.567-0.773**	**3.093-5.867**	**1.747-4.627**	
Mean	**15.852**	**2.092**	**0.179**	**1.387**	**0.686**	**4.145**	**2.529**	
PL	**0.6***	**2.0***	**0.02***	**10***	**50****	**10***	**1.3***	

ND = Not detected
*(Ogundele *et al.*, 2015)
**(Chiroma *et al.*, 2014)

Table 4: Heavy Metal Contents (mg/kg) of Maize Root (Dry Season, 2023)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Gafan Bunkure	1.833±0.04	1.380±0.02	0.173±0.01	0.893±0.09	0.480±0.02	0.653±0.02	2.573±0.66	ND
Gafan II	2.647±0.01	0.993±0.02	0.153±0.01	0.827±0.04	0.527±0.09	0.593±0.05	2.793±0.64	ND
Gafan	5.153±0.02	1.267±0.13	0.160±0.00	0.960±0.04	0.627±0.03	1.153±0.02	3.253±0.50	ND
Kukoki	5.500±0.02	1.173±0.10	0.147±0.01	0.973±0.06	0.593±0.05	0.660±0.04	2.733±0.48	ND
Kwalele	4.787±0.01	1.793±0.08	0.187±0.01	1.260±0.02	0.647±0.04	1.013±0.04	8.373±0.60	ND
Bulan Wanzamai	2.553±0.02	1.533±0.28	0.133±0.01	0.953±0.01	0.587±0.04	0.927±0.04	3.673±0.09	ND
Kura (Babbar Gada)	3.153±0.01	1.653±0.16	0.173±0.01	1.293±0.01	0.820±0.02	3.253±0.03	3.300±0.47	ND
Kura (Fegin Malu)	7.053±0.01	1.553±0.08	0.153±0.01	1.100±0.08	0.600±0.02	0.633±0.03	5.400±0.18	ND
Imawa (Gada Mailotso)	2.000±0.00	1.213±0.20	0.127±0.01	1.027±0.07	0.527±0.04	1.547±0.01	2.467±0.28	ND
Imawa (Rimin Kwarya)	2.967±0.01	1.113±0.32	0.147±0.01	1.133±0.06	0.607±0.09	1.613±0.05	2.380±0.11	ND
Range	**1.833-7.053**	**0.993-1.793**	**0.127-0.187**	**0.827-1.293**	**0.480-0.820**	**0.593-3.253**	**2.380-8.373**	
Mean	**3.765**	**1.367**	**0.155**	**1.042**	**0.601**	**1.205**	**3.695**	

ND = Not detected

Table 5: Effects of Growing Season on Translocation (Root to Grains) of Heavy Metals in Maize

	Wet Season						Dry Season						
LOCATION	**Zn**	**Pb**	**Ni**	**Co**	**Cu**	**LOCATION**	**Zn**	**Pb**	**Cd**	**Ni**	**Co**	**Cu**	**Cr**
Yantomo	0.11	0.75	1.00	1.39	0.29	Gafan Bunkure	0.16	0.90	1.08	0.68	0.85	0.21	0.96
Gafan	0.46	1.05	1.65	1.47	0.70	Gafan II	0.19	0.48	0.82	0.59	0.85	0.16	0.60
Rigada	0.08	0.68	0.52	1.23	0.15	Gafan	0.37	0.62	0.92	0.74	0.99	0.35	1.05
Makuntiri	0.37	0.52	3.28	1.32	1.63	Kukoki	0.26	0.50	0.81	0.61	0.80	0.16	1.11
Yadakwari	0.05	1.06	2.02	0.24	0.10	Kwalele	0.25	0.83	1.12	0.91	0.94	0.26	4.79
Dakasoye	0.49	0.89	2.12	3.11	1.26	Bulan Wanzamai	0.14	0.70	0.71	0.70	0.91	0.25	1.75
Kura (Tsauni)	0.51	0.65	3.22	1.00	0.44	Kura (Babbar Gada)	0.27	0.82	1.04	1.13	1.19	0.92	1.72
Kura (Gorubawa)	0.49	0.49	1.85	1.00	0.54	Kura (Fegin Malu)	0.42	0.67	0.77	0.79	0.80	0.11	3.00
Imawa I	0.33	0.35	1.04	3.38	0.38	Imawa (Gada Mailotso)	0.12	0.60	0.68	0.64	0.68	0.27	0.99
Imawa II	0.30	0.30	0.96	0.58	0.86	Imawa (Rimin Kwarya)	0.18	0.51	0.81	0.84	0.80	0.38	1.01
MEAN	0.32	0.67	1.77	1.47	0.63	**MEAN**	0.24	0.66	0.88	0.76	0.88	0.31	1.70

Accumulation in the Root: $\frac{R_{conc.}}{G_{conc.}} > 1$

Accumulation in the Grains: $\frac{R_{conc.}}{G_{conc.}} < 1$

CONCLUSION

The accumulation of heavy metals in maize grains was observed to follow the order of Zn>Cu>Pb>Ni>Co in the samples collected during wet season harvest. Results from the samples collected during this period did not reveal the presence of Cd, Cr, and Hg. It was also observed that only the concentration of Zn exceeded the allowable limit in the samples collected during the wet season production. On the other hand, the order of accumulation during the dry season follows the order of Zn>Cu>Cr>Pb>Ni>Co>Cd. While Hg was not detected in any of the maize grain samples. In the samples collected during the production period of the dry season, the concentrations of Zn, Pb, Cd, and Cr exceeded the permissible limits recommended by FAO/WHO.

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REFERENCES

Afolayan, A. O. (2018). Accumulation of Heavy Metals from Battery Waste in Topsoil, Surface Water, and Garden Grown Maize at Omilende Area, Olodo, Nigeria. *Global Challenges*, *2*(3), 1700090. https://doi.org/10.1002/gch2.201700090

Akinyele, I. O., and Shokunbi, O. S. (2015). Comparative analysis of dry ashing and wet digestion methods for the determination of trace and heavy metals in food samples. *Food Chemistry*, *173*, 682–684. https://doi.org/10.1016/j.foodchem.2014.10.097

Aladesanmi, O. T., Oroboade, J. G., Osisiogu, C. P., and Osewole, A. O. (2019). Bioaccumulation factor of selected heavy metals in Zea mays. *Journal of Health and Pollution*, *9*(24). https://doi.org/10.5696/2156-9614-9.24.191207

Armienta, M. A., Beltrán, M., and Martínez, S. (2020). Heavy metal assimilation in maize (Zea mays L.) plants growing near mine tailings. *Environmental Geochemical and Health*, *42*, 2361–2375.

Awokunmi, E., Adefemi, O., and Asaolu, S. (2015). Tissues Accumulation of Heavy Metals by Maize (Zea maize L.) Cultivated on Soil Collected from Selected Dumpsites in Ekiti State, Nigeria. In *American Chemical Science Journal* (Vol. 5, Issue 2, pp. 156–162). https://doi.org/10.9734/acsj/2015/9262

Chiroma, T. M., Ebewele, R. O., and Hymore, F. . (2014). Comparative Assesseement Of Heavy Metal Levels In Soil, Vegetables And Urban Grey Waste Water Used For Irrigation In Yola And Kano. *International Refereed Journal of Engineering and Science*, *3*(2), 1–09. www.irjes.com

Gil, F., and Olmedo, P. (2023). Food safety heavy metals and metalloids. In B. Caballero (Ed.), *Encyclopedia of Human Nutrition* (4th ed., pp. 351–361). Academic Press. http://www.nber.org/papers/w16019

Ifie, I., Igwebuike, C. G., Imasuen, P., Akalamudo, W., Oghenebrorhie, O., Akpodiete, J. O., and Eze, U. A. (2022). Assessment of aflatoxin and heavy metals levels in maize and poultry feeds from Delta State, Nigeria. *International Journal of Environmental Science and Technology*, *19*(12), 12551–12560. https://doi.org/10.1007/s13762-022-03996-1

Jumei, L., Si, W., Xiao, Z., Tang, R., Niu, P., Fu, Y., and Shen, W. (2023). Risks to Human Health of Exposure to Heavy Metals through Wheat Consumption near a Tailings Dam in North China. *Polish Journal of Environmental Studies*, *32*(4), 3195–3207. https://doi.org/10.15244/pjoes/163442

Ladislas, S., El-Mufleh, A., Gérente, C., Chazarenc, F., Andrès, Y., and Béchet, B. (2012). Potential of aquatic macrophytes as bioindicators of heavy metal pollution in urban stormwater runoff. *Water, Air, and Soil Pollution*, *223*(2), 877–888. https://doi.org/10.1007/s11270-011-0909-3

Liu, Q., Cheng, Y., and Fan, C. (2023). Pollution Characteristics and Health Exposure Risks of Heavy Metals in River Water Affected by Human Activities. *Sustainability (Switzerland)*, *15*(10), 1–14. https://doi.org/10.3390/su15108389

Mounam, M. A. W. A. (2023). Review : The Health risks caused by heavy metals contamination of milk products. *Diyala Journal of Medicine*, *24*(2), 141–154. https://doi.org/10.26505/djm.24027530504

Mugume, H. K., Byamugisha, D., Omara, T., and Ntambi, E. (2023). Deposition, Dietary Exposure and Human Health Risks of Heavy Metals in Mechanically Milled Maize Flours in Mbarara City, Uganda. *Journal of Xenobiotics*, *13*(3), 298–311. https://doi.org/10.3390/jox13030022

Ogundele, D., Adio, A., and Oludele, O. (2015). Heavy Metal Concentrations in Plants and Soil along Heavy Traffic Roads in North Central Nigeria. *Journal of Environmental* and *Analytical Toxicology*, *5*(6), 6–10. https://doi.org/10.4172/2161-0525.1000334

Oladele, E. O., Yahaya, T., and Adewumi, O. O. (2019). Growth Response of Maize (Zea Mays L.) to Metal Toxicity. *Journal of Natural Science, Engineering and Technology*, *17*(1), 75–82. https://doi.org/10.51406/jnset.v17i1.1899

Olu, M., Olufade, O. I., Adekoyeni, O. O., and Jimoh, M. O. (2013). Evaluation of Heavy Metal Concentration in Maize Grown in Selected Industrial Areas of Ogun State and its Effects on Urban Food Security. *International Journal of Science, Technology and Society*, *1*(2), 48–56. https://doi.org/10.11648/j.ijsts.20130102.12

Petrović, S., Mitov, D., Mrmošanin, J., Arsić, B., Pavlović, A., and Tošić, S. (2023). The national maize hybrid as a potential mediator in the contamination of the food chain with heavy metals. *International Journal of Environmental Analytical Chemistry*, *103*(19), 1–14. https://doi.org/10.1080/03067319.2023.2230145

Priya, A. K., Muruganandam, M., Ali, S. S., and Kornaros, M. (2023). Clean-Up of Heavy Metals from Contaminated Soil by Phytoremediation: A Multidisciplinary and Eco-Friendly Approach. *Toxics*, *11*(5), 1–24. https://doi.org/10.3390/toxics11050422

Romdhane, L., Panozzo, A., Radhouane, L., Dal Cortivo, C., Barion, G., and Vamerali, T. (2021). Root characteristics and metal uptake of maize (Zea mays L.) under extreme soil contamination. *Agronomy*, *11*(1), 1–14. https://doi.org/10.3390/agronomy11010178

Sagbara, G., Zabbey, N., Sam, K., and Nwipie, G. N. (2020). Heavy metal concentration in soil and maize (Zea mays L.) in partially reclaimed refuse dumpsite 'borrow-pit' in Port Harcourt, Nigeria. *Environmental Technology and Innovation*, *18*(100745), 1–12. https://doi.org/10.1016/j.eti.2020.100745

Simon, O. S., John, O. J., Matthew, T. K., Bukola, J. O., and John, E. (2014). Heavy metals in some fruits and cereals in Minna markets, Nigeria. *Parkistan Journal of Nutrition*, *13*(12), 722–727.

Wei, X., Zhou, Y., Jiang, Y., Tsang, D. C. W., Zhang, C., Liu, J., Zhou, Y., Yin, M., Wang, J., Shen, N., Xiao, T., and Chen, Y. (2020). Health risks of metal(loid)s in maize (Zea mays L.) in an artisanal zinc smelting zone and source fingerprinting by lead isotope. *Science of The Total Environment*, *742*(140321), 1–23. https://doi.org/10.1016/j.scitotenv.2020.140321

Zha, Y., Zhao, L., Niu, T., Yue, E., Wang, X., and Shi, J. (2023). Multi-Target Element-Based Screening of Maize Varieties with Low Accumulation of Heavy Metals (HMs) and Metalloids: Uptake, Transport, and Health Risks. *Agriculture (Switzerland)*, *13*(6), 1–15. https://doi.org/10.3390/agriculture13061123

Zhuang, P., Yang, Q. W., Wang, H. B., and Shu, W. S. (2007). Phytoextraction of heavy metals by eight plant species in the field. *Water, Air, and Soil Pollution*, *184*(1), 235–242. https://doi.org/10.1007/s11270-007-9412-2