Heavy metals uptake pattern and accumulation in wheat

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Abstract

The study aimed to determine the pattern of heavy metals (HMs) uptake and accumulation in wheat and compare the concentrations of the studied HMs in the wheat grain produced under the Kano River Irrigation Project with the permissible limits recommended by FAO/WHO. Wheat samples were collected from 10 different locations within the irrigation scheme between February and March 2023. The samples were prepared using standard laboratory procedures and HMs were determined using atomic absorption spectrophotometer. The accumulation of HMs in wheat grains is in the order of Cu>Zn>Ni>Cr>Co>Cd. Pb and Hg were not detected in wheat grains. The concentrations of Zn, Cd and Cr in the wheat grain samples exceeded the recommended permissible limits.

Keywords: Food contamination, Heavy metals toxicity, Nigeria, wheat contamination

INTRODUCTION

Wheat is a major staple crop, providing a significant portion of calories and protein to the world's population. It is the most widely cultivated crop, grown on millions of hectares annually (Erenstein *et al.*, 2022). it is a highly nutritious grain that provides essential nutrients for human health. It is a rich source of carbohydrates, proteins, dietary fibre, lipids, vitamins, minerals, and phytochemicals (Wieser *et al.*, 2020). Global wheat production exceeded 750 million metric tonnes (Mt)/annum, this accounts for about 20% of the calories in the human diet (Gooding, 2023). Nigeria's wheat consumption has been increasing over the years, driven by factors such as convenience, affordability, urbanization, and industrialization (Sadiq *et al.*, 2020). Wheat is used for various purposes, including the production of bread, noodles, cookies, cakes, and breakfast cereals (Erenstein *et al.*, 2022).

Heavy metals (HMs) infiltrate soil and water either through the natural process of rock weathering or as a result of human activities such as mining and the disposal of industrial waste (Bhagwat, 2019; Edelstein and Ben-Hur, 2018; Islam *et al.*, 2019; Maqbool *et al.*, 2019; Stefanović, *et al.*, 2023a), abuse of agrochemicals and atmospheric deposit (Abdullahi *et al.*, 2021). The presence of HMs in water and soil escalates the risk of food chain contamination (Taghipour and Jalali, 2019; Saadati *et al.*, 2020). The continuous release of hazardous HMs by various forms of human activities in quantities significantly surpassing those emitted by natural processes has created mounting concern regarding human health and environmental safety (Hu *et al.*, 2018; Samiee *et al.*, 2019; Vareda *et al.*, 2019; Yuan *et al.*, 2019). Excess HMs in the soil can directly alter its physical and chemical properties, decrease biological activity and diminish nutrient bioavailability (Kahkha *et al.*, 2017). Production season is another important factor affecting soil HM behaviour and bioavailability (Salem *et al.*, 2020).

Heavy metal contamination in wheat is of significant concern due to its potential impact on food safety, human health and crop quality. Their presence in food can cause complicated health issues that can lead to lead to death (Rai *et al.*, 2019). Wheat plants are susceptible to accumulating high levels of toxic heavy metals such as cadmium lead and chromium (Zhou and Zheng, 2022). Various studies have highlighted the toxic effects of heavy metals on wheat, including impaired growth, yield losses, and biochemical responses (Zhou and Zheng, 2022). The presence of these metals in the soil can affect the density, composition, and physiological activities of microbiota, leading to a reduction in wheat production and posing risks to human and animal health (Rizvi *et al.*, 2020; Zhou and Zheng, 2022). Additionally, the use of wastewater for irrigation has been associated with an increased risk of heavy metal accumulation in wheat grains (Mussarat *et al.*, 2021). Various agrochemicals used for crop protection have also been reported to contaminate wheat with HMs and subsequently affect yield and nutritional qualities (Wołejko *et al.*, 2017).

Various approaches have been studied to mitigate heavy metal uptake and phytotoxicity in wheat, including agronomic and biological methods (Dong *et al.*, 2023), the use of plant growth-promoting rhizobacteria with heavy metal tolerance and plant growth-promoting potentials (Rizvi *et al.*, 2020). The use of low-metal-accumulating or metal-toxicity-tolerant wheat varieties is considered the most efficient and eco-friendly approach to ensure food safety and protect human health (Saeed *et al.*, 2023). However, the selection of the appropriate method depends on factors such as soil properties, type of metal, contamination level, and environmental conditions (Stefanović *et al.*, 2023b). Understanding wheat's response to heavy metal stress and implementing management strategies to decrease metal uptake and accumulation is crucial for improving growth and grain quality (Rizvi *et al.*, 2020).

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The study aimed to determine the pattern of heavy metals (HMs) uptake and accumulation in wheat and compare the concentrations of the studied HMs in the wheat grain produced under the Kano River Irrigation Project with the permissible limits recommended by FAO/WHO.

METHODOLOGY

Sampling Location

The Kano River Irrigation Project (KRIP) covers approximately 62,000 hectares of land and only relies on the Tiga Dam and Ruwan Kanya Reservoir as its primary sources of irrigation water. This irrigation scheme is close to Kano City and extends across both sides of the Kano-Zaria expressway. Wheat samples were harvested at their optimal maturity and samples were collected between February and March 2023. Wheat grain and root samples were collected from 10 different locations across the irrigation scheme. The sampling locations are Gaiyare, Waire, Kadawa, Gafan, Makuntir, Kwalele Kura (K/Kudu), Kura (K/Gabas), Imawa I (Gada Mailotso) and Imawa II (Gonar Hajia).

Sample Preparation and HMs Determination

Harvested samples were separated into roots and grains. The grain samples were properly dried, trashed and adequately cleansed with deionised water. The root samples were soaked in deionised water before being extensively washed with an excess amount of water. The samples were then subjected to oven-drying until a constant weight was achieved. Then pulverized into a fine powder and subsequently incinerated to ash using a muffle furnace at a temperature of 550 °C 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 (Perkin Elmer PinAAcle 900H) and results were reported as Mean±SD.

Computation of Translocation Factor

A comparative analysis was conducted between the contents of heavy metals in the roots and those in the wheat grains to investigate the uptake patterns of Zn, Pb, Cd, Ni, Co, Cu, Cr, and Hg. The Translocation Factor (equation 1) was employed to examine the plant's capacity to transport the accumulated metals from the roots to the grains. TF was computed using the modified approach outlined by Zhuang *et al.* (2007).

$$TF = R_{conc.}/G_{conc.} \qquad \textbf{Equation 1}$$

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

RESULTS AND DISCUSSION

The results for HM contents of wheat grain are presented in Table 1. Mean concentrations for Zn, Cd, Ni, Co, Cu and Cr range between 1.640-6.713, 0.460-0.547, 2.012-4.053, ND-1.733, 3.873-5.353 and ND-11.127 mg/kg respectively. Pb and Hg were not detected in all the samples and Cr was only detected in samples collected from Gaiyare, Gafan, Makuntiri and Kwalele. The overall means for the sampling locations are 4.582, 0.509, 3.181, 0.623, 4.599 and 2.125 mg/kg for Zn, Cd, Ni, Co, Cu and Cr respectively. The overall mean concentration for Zn, Cd and Cr exceeded WHO-approved permissible limits.

The concentrations of Pb, Cd, Cr and Co reported by Madhi *et al.* (2020) are far beyond what was observed in this research. Also that of Zn in samples collected from Tianjin, China (Yu *et al.*, 2016), Cr and Pb in pot experiment conducted in China (Fang *et al.*, 2019), Zn and Pb in German wheat samples (Gramss, 2020), Zn and Pb in various samples collected from Pakistan (Al-Othman *et al.*, 2016), Cr, Cu, Ni, Pb and Zn in samples produced at Shandong Province, China (Wan *et al.*, 2022), Zn, Pb, Cr and Cu produced at Pancevo, Serbia (Stefanović *et al.*, 2023b) Pb, Cu and Zn samples obtained from Xuzhou, China (Maqbool *et al.*, 2019). Cu, Zn, Ni and Cd concentrations below what was observed in this study were also reported by Alemu *et al.* (2022) in wheat flour samples obtained from Amhara and Oromia, Ethiopia.

Table 1: Heavy Metal Contents (mg/kg) of wheat grain

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Gaiyare	6.713±0.01	ND	0.513±0.01	4.053±0.01	1.733±0.05	5.353±0.31	11.127±0.41	ND
Waire	4.887±0.02	ND	0.520±0.02	3.353±0.06	0.533±0.09	4.607±0.31	ND	ND
Kadawa	4.500±0.02	ND	0.500±0.02	3.140±0.16	0.460±0.07	4.540±0.05	ND	ND
Gafan	6.573±0.03	ND	0.547±0.01	4.053±0.11	0.813±0.03	4.573±0.24	1.880±0.06	ND
Makuntiri	5.740±0.04	ND	0.513±0.03	3.433±0.06	0.760±0.04	5.020±0.15	5.507±0.87	ND
Kwalele	5.560±0.04	ND	0.527±0.03	3.613±0.13	1.187±0.08	5.087±0.14	2.740±0.33	ND
Kura K/Kudu	1.640±0.02	ND	0.460±0.04	2.013±0.03	0.000	3.873±0.03	ND	ND
Kura K/Gabas	2.713±0.02	ND	0.507±0.01	2.673±0.15	0.293±0.08	4.347±0.12	ND	ND
Imawa I (Gada Mai Lotso)	3.860±0.00	ND	0.487±0.01	2.693±0.10	0.190±0.05	4.240±0.13	ND	ND
Imawa II (Gonar Hajia)	3.633±0.03	ND	0.520±0.02	2.787±0.05	0.260±0.06	4.353±0.11	ND	ND
Range	1.640-6.713	ND	0.460-0.547	2.013-4.053	0.000-1.733	3.873-5.353	0.000-11.127	ND
Mean	4.582	ND	0.509	3.181	0.623	4.599	2.125	ND
PL	0.6*	2.0*	0.02*	10*	50**	10*	1.3*	

*(Ogundele et al., 2015), **(Chiroma et al., 2014)

Concentrations below what was observed in this research were also reported by many researchers in wheat grains. These include the concentrations of Cd, Ni, Co, Cu and Cr in samples collected from various locations in Iran (Ghanati *et al.*, 2019), Cd, Cu and Cr in samples collected from Tianjin, China (Yu *et al.*, 2016), Cd, Zn and Cr in samples collected from Kosovo (Dreshaj *et al.*, 2022), Ni, Zn and Cu in samples produced at Sistan, Iran (Kahkha *et al.*, 2017), Zn in pot experiment conducted in China (Fang *et al.*, 2019), Ni, Cd and Cr in German wheat samples (Gramss, 2020), Cd, Ni, Cu and Cr in various samples collected from Pakistan (Al-Othman et al., 2016), Cd in samples produced at Shandong Province, China (Wan et al., 2022), Cd and Cr in wheat produced at Xuzhou, China (Maqbool *et al.*, 2019) and Cd produced at Pancevo, Serbia (Stefanović *et al.*, 2023a). The variation in the concentrations of HM may be attributed to production location, cultural practices, wheat breed, soil properties, soil health, irrigation water quality and environmental safety.

The overall mean concentrations for Zn, Cd and Cr exceeded WHO-approved permissible limits. Madhi *et al.* (2020) reported Pb, Cd, Cr and Co concentrations above permissible limits in wheat samples collected from Basrah and Maysan. Hassan *et al.* (2013) also reported Cr and Ni concentrations above permissible limits in wheat samples collected from Abbottabad district, Pakistan. Wheat produced in Tianjin, China possessed Cd content above the permissible limit (Yu *et al.*, 2016). On the other hand, Corguinha *et al.* (2015) reported As Cd and Pb concentrations below permissible limits in wheat grain produced in the states of Mato Grosso and Minas Gerais, Brazil.

Pb and Hg were not detected in all the samples. In the same way, Cd, Hg, and Pb were not detected in the wheat and barley grains imported to Egypt from some EU countries (Thabit *et al.*, 2021). In contrast, Ghanati *et al.* (2019) detected both Pb and Hg in wheat and various wheat products. Similarly, Dreshaj *et al.* (2022) and Kahkha *et al.* (2017) detected Pb in wheat grains.

The results for the HM concentrations in the wheat root are presented in Table 2. Mean values for the concentrations of Zn, Cd, Ni, Co, Cu and Cr range between 2.787-6.460, 0.500-0.600, 2.720-3.987, 0.153-1.413, 3.747-5.260 and ND-5.647 mg/kg respectively. Similar to grain samples, Pb and Hg were also not detected in all the root samples. Cr was only detected in samples collected from Gaiyare, Kadawa, Makuntiri, Kwalele and Imawa I (Gada Mailotso). Contrary to what was observed in the grains, Cr was detected in the root samples collected from Kadawa and Imawa I. The overall means for the concentrations of Zn, Cd, Ni, Co, Cu and Cr are 4.985, 0.528, 3.359, 0.675, 4.414 and 2.288 mg/kg respectively. Higher mean values for Zn, Cd, Ni and Co were found in root samples while higher mean values for Cu and Cr were found in the grain samples. Yu *et al.* (2016) reported Cu, Pb, Zn and Ni concentrations above what was observed in this study in the root of wheat produced at Tianjin. Also, the con-

Table 2: Heavy Metal contents (mg/kg) of wheat root

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Gaiyare	5.113±0.03	ND	0.507±0.02	3.393±0.18	1.220±0.05	4.953±0.20	5.127±0.53	ND
Waire	4.707±0.01	ND	0.500±0.00	3.200±0.13	0.560±0.04	4.247±0.47	ND	ND
Kadawa	6.460±0.04	ND	0.553±0.01	3.613±0.05	0.600±0.11	4.700±0.27	5.627±0.02	ND
Gafan	5.267±0.03	ND	0.527±0.01	3.280±0.04	0.427±0.10	4.053±0.20	ND	ND
Makuntiri	5.500±0.05	ND	0.520±0.02	3.247±0.05	0.727±0.10	4.593±0.19	5.647±0.09	ND
Kwalele	6.253±0.01	ND	0.520±0.00	3.900±0.14	1.413±0.05	5.260±0.21	5.233±0.02	ND
Kura K/Kudu	4.560±0.02	ND	0.500±0.02	3.200±0.04	0.507±0.13	4.280±0.33	ND	ND
Kura K/Gabas	3.553±0.05	ND	0.547±0.01	3.047±0.06	0.400±0.04	4.153±0.33	ND	ND
Imawa I (Gada Mai Lotso)	5.647±0.02	ND	0.600±0.00	3.987±0.07	0.740±0.12	4.153±0.38	1.247±0.27	ND
Imawa II (Gonar Hajia)	2.787±0.01	ND	0.507±0.02	2.720±0.05	0.153±0.04	3.747±0.35	ND	ND
Range	2.787-6.460	ND	0.500-0.600	2.720-3.987	0.153-1.413	3.747-5.260	0.000-5.647	ND
Mean	4.985	ND	0.528	3.359	0.675	4.414	2.288	ND

ND – Not Detected

Table 3: Effects of growing season on translocation (root to grains) of heavy metals in wheat

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Gaiyare	0.76	ND	0.99	0.84	0.70	0.93	0.46	ND
Waire	0.96	ND	0.96	0.95	1.05	0.92	ND	ND
Kadawa	1.44	ND	1.11	1.15	1.30	1.04	ND	ND
Gafan	0.80	ND	0.96	0.81	0.52	0.89	ND	ND
Makuntiri	0.96	ND	1.01	0.95	0.96	0.92	1.03	ND
Kwalele	1.12	ND	0.99	1.08	1.19	1.03	1.91	ND
Kura K/Kudu	2.78	ND	1.09	1.59	0.00	1.10	ND	ND
Kura K/Gabas	1.31	ND	1.08	1.14	1.36	0.96	ND	ND
Imawa I (Gada Mai Lotso)	1.46	ND	1.23	1.48	3.89	0.98	ND	ND
Imawa II (Gonar Hajia)	0.77	ND	0.97	0.98	0.59	0.86	ND	ND
MEAN	1.24	ND	1.04	1.10	1.16	0.96	0.34	ND

ND – Not Detected

centration of Pb in the root of various samples collected from Pakistan (Al-Othman *et al.*, 2016). Concentrations Cd, Ni, Cu, Zn and Cr below what was observed in this research were reported by Al-Othman *et al.* (2016) in the root of wheat produced in Pakistan.

Translocation factor

Calculated values for translocation factors of wheat are presented in Table 3. A Root:Grain metal concentration value >1 signifies higher accumulation in the roots while values <1 indicate accumulation in the grains. The overall mean values for TF show higher accumulations of Zn, Cd, Ni and Co in the root and higher accumulation of Cu and Cr in the grain. Similar to this finding, Al-Othman *et al.* (2016) also reported higher concentrations of HMs in the wheat root than in the grain.

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

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

CONCLUSION

The accumulation of HMs in wheat grains is in the order of Cu>Zn>Ni>Cr>Co>Cd. Pb and Hg were not detected in wheat grains. The concentrations of Zn, Cd and Cr in the wheat grain samples exceeded the recommended permissible limits. Controlling HMs contamination in wheat requires production on good quality soil and the use of only good quality water for irrigation. The use of low-metal-accumulating or metal-toxicity-tolerant wheat varieties is considered the most efficient and eco-friendly approach. Microbiological remediation strategies, such as the use of metal-tolerant plant growth-promoting rhizobacteria, have shown promise in enhancing wheat production in metal-stressed soil.

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