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Heavy metals seasonal variation and uptake pattern in rice grown in Kano State, Nigeria

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ABSTRACT

The contamination of rice by heavy metals (HMs) has been assessed and investigations have uncovered that the concentrations of heavy metals such as lead, chromium, manganese, and cadmium in rice samples have exceeded the permissible thresholds in many locations across the world including Nigeria. This study aimed to determine the pattern of Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg accumulation in the roots and grains of rice samples collected from 10 different locations across the Kano River Irrigation Project during wet and dry season production and compare the metal concentrations with the permissible limits recommended by FAO/WHO. Also, to use Translocation Factors and study Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg uptake patterns in rice during wet and dry growing seasons. Rice grain and root samples were collected from 10 different locations across the irrigation scheme during the 2022 wet season and 2023 dry season. Samples were prepared using standard laboratory methods and subjected to metal analysis using an atomic absorption spectrophotometer. The results show that the accumulation of HMs in rice grain samples follows this order Zn>Cu>Pb>Ni>Cr>Co>Cd for both wet and dry seasons with higher accumulation reported in dry season production. It was only the mean concentration of Zn that exceeded the permissible limit during the wet season. The concentrations of Pb and Cd were also observed to exceed permissible limits in addition to Zn during dry season production. Hg was not detected in all the samples. Wet season production provides a safer rice grains with lesser heavy metals contamination.

Keywords: Rice**;** food contamination; heavy metals; toxicity

INTRODUCTION

Heavy metal contamination of rice has been examined in many places. Studies have found that rice samples from Indonesia, the United States, Bangladesh, and Nigeria have exceeded acceptable limits for heavy metals such as lead, chromium, manganese, and

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cadmium (Al-Huqail *et al*., 2022; Anthony *et al*., 2023; Shahriar *et al*., 2023; Wahyuningsih *et al*., 2023). However, the levels of heavy metals in rice grown in Abakiliki, Ebonyi State, Nigeria were found to be within safe limits (Usman *et al*., 2022). The contamination of heavy metals in rice is mainly attributed to industrial wastewater used for irrigation, especially in developing countries like India. The accumulation of heavy metals in rice poses health risks, including carcinogenic and non-carcinogenic effects. It is important to take appropriate measures to identify the sources and causes of heavy metal contamination in rice and implement strategies to mitigate this issue.

The contamination of food crops by heavy metals (HMs) is more prevalent in developing nations that have limited access to both food and clean water (Shakoor *et al*., 2017). Most of these countries lack established guidelines for regulating HMs concentrations in both food and environmental sources (Edogbo *et al*., 2020). Typically, food crops absorb HMs primarily through their roots and absorption through leaves rarely occurs (Edelstein and Ben-Hur, 2018). The bioavailability and mobility of trace elements in soil are influenced by various factors including transpiration rate, plant species, soil conditions (such as pH, organic matter content, temperature, texture, cation exchange capacity), and the presence of microorganisms and other metals (Gupta *et al*., 2019). HMs can accumulate in food crops and subsequently enter the food chain (Rai *et al*., 2019).

Heavy metals have adverse effects on human health and therefore their contamination with the food chain deserves special attention. Some heavy metals are carcinogenic, mutagenic, teratogenic and endocrine disruptors while others cause neurological and behavioural changes, especially in children (Kazantzis, 2007). Metals facilitate damage to tissue and cellular components which lead to inflammation, lipid peroxidation, suppression of cellular antioxidant defences, and impairment of DNA repair (Nordberg, 2007).

The reported levels of HMs in most staple food grains and vegetables produced in Nigeria are alarming. Otitoju *et al*. (2014) reported Pb concentrations above WHO/FAO recommended levels in the different rice samples collected from Northern Nigeria. It is important to ascertain the safety of the local harvest since many Nigerians solely depend on locally produced commodities due to the hike in the price of imported goods.

The study aimed to determine the pattern of Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg accumulation in the roots and grains of rice samples collected from (10) different locations across the Kano River Irrigation Project during wet and dry season production and compare the metal concentrations with the permissible limits recommended by FAO/WHO. Also, to use Translocation Factors and study Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg uptake patterns in rice during wet and dry growing seasons.

METHODOLOGY

Study Area

The Kano River Irrigation Project (KRIP) is situated in Kano, a northern Nigeria city. The irrigation scheme covers a vast area of approximately 62,000 hectares. KRIP is located between latitude 11°32’N to 11°51’N and longitude 8°20’E to 8°40’E. The primary water source for irrigation in the area is obtained from the Tiga Dam and Ruwan Kanya Reservoir. This irrigation project is located approximately 30 kilometres south of Kano City, spanning across both sides of the Kano-Zaria expressway.

Sampling

Samples were harvested at their optimal maturity. Rice grain and root samples for 2022 wet season production were collected between September and October 2022. Samples (grains and roots) were collected from 10 different locations across the irrigation scheme. These include Waire 'Yantomo, Kadawa Farm Centre, Gafan I, Gafan II, Kwalele, Raje, Kura (Ruga), Kura (Dalili) Imawa I and Imawa II. Rice grain and root samples for the dry season were collected between July and August 2023. Samples were collected from 10 different locations, viz Waire 'Yantomo, Kadawa Farm Centre, Gafan I, Gafan II, Kwalele, Raje, Kura (K/Kudu), Kura (K/Gabas) Imawa I and Imawa II.

Sample Preparation and HMs Determination

Harvested crops were separated into roots and edible grains. Grain samples were properly dried, trashed 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 (Grade 1) 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

HMs content of the roots were compared with that of edible parts to study Zn, Pb, Cd, Ni, Co, Cu, Cr and Hg uptake patterns of rice 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).

$$TF = \frac{R_{conc.}}{G_{conc.}} \quad \text{Equation 1}$$

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

RESULTS AND DISCUSSION

Heavy Metals Content of Rice (2022 Wet Season)

The results for HM contents of the rice grain samples collected during this production season are presented in Table 1. The concentrations of the HMs in the rice grain range between 4.760-10.713, 0.530-1.693, 0.380-1.196, 0.380-1.173, ND-0.400, 2.320-5.660 and ND-1.307 mg/kg for Zn, Pb, Ni, Co, Cu and Cr respectively. Cd and Hg were not detected in all the grain samples collected during this production period and Cr was not detected in the rice grain samples collected from Gafan I and Kura (Dalili). The total means of the HM detected in the samples collected from the 10 locations during this production period are 6.493, 1.196, 0.717, 0.230, 3.991 and 0.694 mg/kg for Zn, Pb, Ni, Co, Cu and Cr respectively. The Mean concentrations for Zn and Cr exceeded the permissible limits recommended by WHO (Ogundele *et al*., 2015).

The results for HM content (mg/kg) of rice root samples are presented in Table 2. Cd and Hg were not detected in all the rice root samples collected during 2022 wet season production and Cr was only detected in the rice root samples collected from Gafan I and Kura (Ruga) The range values for the concentration of Zn, Pb, Ni, Co, Cu and Cr are 1.180-5.133, ND-1.740, 0.200-0.787, 0.100-0.560, 0.100-5.140 and ND-0.500 mg/kg respectively. The total means for the HM concentrations in the rice root are 3.023, 1.003, 0.436, 0.394, 2.380 and 0.068 mg/kg for Zn, Pb, Ni, Co, Cu and Cr respectively.

During this production period, the mean concentration of Co is higher in the root sample while that of Zn, Pb, Ni, Cu and Cr are higher in the grain samples. The higher concentration of metal contaminants in the grain samples is an indication of contamination from agrochemicals applied during crop production. While they have a significant impact on contemporary agriculture, agrochemicals have the potential to pose hazards to both human well-being and the ecological system. Upon interacting with the surroundings, agrochemicals undergo various processes, including sorption (absorption and desorption), transformation (both chemical and biological degradation), and transport (volatilization, leaching, and surface transport) (Lorenzetti *et al*., 2019). Traces of Cd, Pb and Ni were found in most of the agrochemicals sold in Sabon Gari Market (Ibrahim *et al*., 2023). The market is the main source of agrochemicals for most of the farmers working under KRIP, other parts of Kano and neighbouring states.

Table 1: Heavy metal contents (mg/kg) of rice grain (wet season, 2022)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Waire Yantomo	10.713±0.01	0.530±0.03	ND	0.820±0.12	0.400±0.06	4.733±0.02	0.540±0.16	ND
Kadawa Farm Centre	4.873±0.04	1.580±0.37	ND	0.720±0.07	0.180±0.13	3.613±0.04	1.093±0.55	ND
Gafan I	6.507±0.04	1.480±0.53	ND	0.773±0.10	ND	3.347±0.01	ND	ND
Gafan II	4.893±0.04	1.500±0.14	ND	0.800±0.16	0.273±0.14	3.887±0.10	0.580±0.41	ND
Kwalele	4.907±0.01	1.280±0.36	ND	0.667±0.08	0.113±0.10	3.640±0.11	1.307±0.21	ND
Raje	8.273±0.08	1.327±0.75	ND	0.660±0.05	0.320±0.13	3.973±0.05	0.873±0.15	ND
Kura (Ruga)	4.760±0.02	0.727±0.62	ND	0.733±0.06	0.290±0.03	2.320±0.02	0.687±0.38	ND
Kura (Dalili)	5.247±0.04	1.067±0.74	ND	0.440±0.15	0.230±0.07	3.753±0.06	ND	ND
Imawa I	8.347±0.03	0.780±0.64	ND	0.380±0.09	0.313±0.09	4.980±0.07	0.613±0.26	ND
Imawa II	6.407±0.03	1.693±0.48	ND	1.173±0.15	0.180±0.14	5.660±0.11	1.247±0.41	ND
Range	4.760-10.713	0.530-1.693	ND	0.380-1.173	0.000-0.400	2.320-5.660	0.000-1.307	ND
Mean	6.493	1.196	ND	0.717	0.230	3.991	0.694	ND
PL	0.6*	2.0*	0.02*	10*	50**	10*	1.3*	

Key: PL: Permissible limits for heavy metals in food; adopted from *Ogundele *et al*. (2015) and **Chiroma *et al.* (2014)

Table 2: Heavy metal contents (mg/kg) of rice root (wet season, 2022)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Waire Yantomo	2.160±0.05	ND	ND	0.207±0.06	0.560±0.02	1.633±0.10	ND	ND
Kadawa Farm Centre	2.580±0.02	0.773±0.33	ND	0.620±0.15	0.320±0.10	0.253±0.05	ND	ND
Gafan I	5.107±0.03	1.740±0.30	ND	0.787±0.10	0.353±0.05	3.907±0.04	0.180±0.00	ND
Gafan II	5.133±0.04	1.507±0.70	ND	0.520±0.16	0.393±0.13	5.140±0.04	ND	ND
Kwalele	1.507±0.01	0.493±0.17	ND	0.220±0.05	0.333±0.09	2.407±0.03	ND	ND
Raje	1.180±0.02	1.090±0.43	ND	0.210±0.05	0.447±0.10	0.100±0.00	ND	ND
Kura (Ruga)	1.960±0.05	0.667±0.23	ND	0.560±0.05	0.413±0.03	1.547±0.01	0.500±0.00	ND
Kura (Dalili)	2.293±0.02	1.127±0.24	ND	0.200±0.18	0.200±0.10	3.167±0.08	ND	ND
Imawa I	4.913±0.06	1.553±0.42	ND	0.780±0.03	0.560±0.08	3.673±0.03	ND	ND
Imawa II	3.400±0.04	1.080±0.56	ND	0.260±0.11	0.360±0.12	1.973±0.02	ND	ND
Range	1.180-5.133	0.000-1.740	0.000-0.000	0.200-0.787	0.200-0.560	0.100-5.140	ND-0.500	ND
Mean	3.023	1.003	0.000	0.436	0.394	2.380	0.068	ND

Table 3: Heavy metal contents (mg/kg) of rice grain (dry season, 2023)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Waire 'Yantomo	10.753±0.24	2.113±0.12	0.160±0.00	1.920±0.03	0.753±0.04	6.987±0.03	2.033±0.19	ND
Kadawa Farm Cence	11.087±0.01	2.607±0.14	0.167±0.02	1.980±0.12	0.773±0.01	6.740±0.02	1.240±0.20	ND
Gafan I	7.960±0.00	2.100±0.11	0.147±0.01	1.507±0.14	0.753±0.03	4.507±0.09	1.073±0.06	ND
Gafan II	10.540±0.03	2.460±0.12	0.167±0.01	1.847±0.13	0.813±0.07	3.873±0.05	1.480±0.14	ND
Kwalele	9.233±0.01	1.767±0.17	0.153±0.01	1.607±0.09	0.720±0.06	9.167±0.03	1.347±0.09	ND
Raje	7.147±0.05	1.953±0.27	0.153±0.01	2.093±0.09	0.747±0.08	5.787±0.03	1.067±0.78	ND
Kura K/Kudu	7.547±0.03	1.780±0.19	0.140±0.00	1.580±0.03	0.827±0.05	4.300±0.07	1.133±0.56	ND
Kura K/Gabas	10.547±0.03	2.187±0.20	0.140±0.02	1.640±0.05	0.740±0.02	5.287±0.05	0.993±0.13	ND
Imawa I	7.267±0.02	2.107±0.53	0.140±0.00	1.833±0.06	0.820±0.02	3.380±0.03	1.120±0.46	ND
Imawa II	6.967±0.02	2.013±0.07	0.160±0.00	1.660±0.12	0.853±0.01	4.860±0.00	0.440±0.22	ND
Range	6.967-11.087	1.767-2.607	0.140-0.167	1.507-2.093	0.720-0.853	3.380-9.167	0.440-2.033	
Mean	8.905	2.109	0.153	1.767	0.780	5.489	1.193	
PL	0.6*	2.0*	0.02*	10*	50**	10*	1.3*	

Key: PL: Permissible limits for heavy metals in food; adopted from *Ogundele *et al.* (2015) and **Chiroma *et al.* (2014)

Table 4: Heavy metal contents (mg/kg) of rice root (dry season, 2023)

Location	Zn	Pb	Cd	Ni	Co	Cu	Cr	Hg
Waire 'Yantomo	1.540±0.00	1.987±0.19	0.107±0.01	1.093±0.02	0.520±0.03	0.740±0.02	1.260±0.37	ND
Kadawa Farm Cence	1.200±0.00	1.533±0.16	0.113±0.01	1.047±0.02	0.553±0.08	0.687±0.05	1.033±0.16	ND
Gafan I	1.267±0.01	1.713±0.01	0.100±0.00	0.980±0.03	0.540±0.02	0.660±0.03	1.120±0.39	ND
Gafan II	1.287±0.01	1.833±0.14	0.140±0.00	1.107±0.06	0.693±0.01	0.847±0.04	1.247±0.13	ND
Kwalele	1.593±0.02	2.113±0.27	0.140±0.00	1.153±0.06	0.560±0.02	1.300±0.03	1.253±0.14	ND
Raje	1.513±0.01	2.013±0.12	0.147±0.01	1.340±0.07	0.753±0.07	0.893±0.02	1.513±0.26	ND
Kura K/Kudu	1.100±0.00	1.793±0.15	0.100±0.00	0.973±0.04	0.513±0.01	0.680±0.06	0.927±0.14	ND
Kura K/Gabas	1.407±0.01	2.160±0.12	0.127±0.01	1.167±0.02	0.733±0.02	0.800±0.02	1.140±0.27	ND
Imawa I	1.173±0.01	1.600±0.22	0.100±0.00	1.027±0.06	0.647±0.03	0.720±0.02	1.020±0.15	ND
Imawa II	1.047±0.01	1.893±0.21	0.093±0.01	0.993±0.10	0.527±0.03	0.733±0.06	0.993±0.43	ND
Range	1.047-1.593	1.533-2.160	0.093-0.147	0.973-1.340	0.513-0.753	0.660-1.300	0.927-1.513	
Mean	1.313	1.864	0.117	1.088	0.604	0.806	1.151	

Table 5: Effects of growing season on translocation (root to grains) of heavy metals in rice

LOCATION	WET SEASON 2022						LOCATION	DRY SEASON 2023						
	Zn	Pb	Ni	Co	Cu	Cr		Zn	Pb	Cd	Ni	Co	Cu	Cr
Waire Yantomo	0.20	0.00	0.25	1.40	0.35	0.00	Waire 'Yantomo	0.14	0.94	0.67	0.57	0.69	0.11	0.62
Kadawa Farm Centre	0.53	0.49	0.86	1.78	0.07	0.00	Kadawa Farm Cence	0.11	0.59	0.68	0.53	0.72	0.10	0.83
Gafan I	0.78	1.18	1.02	0.00	1.17	0.00	Gafan I	0.16	0.82	0.68	0.65	0.72	0.15	1.04
Gafan II	1.05	1.00	0.65	1.44	1.32	0.00	Gafan II	0.12	0.75	0.84	0.60	0.85	0.22	0.84
Kwalele	0.31	0.39	0.33	2.94	0.66	0.00	Kwalele	0.17	1.20	0.91	0.72	0.78	0.14	0.93
Raje	0.14	0.82	0.32	1.40	0.03	0.00	Raje	0.21	1.03	0.96	0.64	1.01	0.15	1.42
Kura (Ruga)	0.41	0.92	0.76	1.43	0.67	0.73	Kura K/Kudu	0.15	1.01	0.71	0.62	0.62	0.16	0.82
Kura (Dalili)	0.44	1.06	0.45	0.87	0.84	0.00	Kura K/Gabas	0.13	0.99	0.90	0.71	0.99	0.15	1.15
Imawa I	0.59	1.99	2.05	1.79	0.74	0.00	Imawa I	0.16	0.76	0.71	0.56	0.79	0.21	0.91
Imawa II	0.53	0.64	0.22	2.00	0.35	0.00	Imawa II	0.15	0.94	0.58	0.60	0.62	0.15	2.26
MEAN	0.50	0.85	0.69	1.50	0.62	0.07	MEAN	0.15	0.90	0.77	0.62	0.78	0.15	1.08

Note: Values >1 indicating higher accumulation in the Root; Values <1 indicating higher accumulation in the Grain

Heavy Metals Content of Rice (2023 Dry Season)

The concentrations of the HMs in the rice grains samples collected during the 2023 dry season are presented in Table 3. The Mean concentrations for Zn, Pb, Cd, Ni, Co, Cu and Cr range between 6.967-11.087, 1.767-2.607, 0.140-0.167, 1.507-2.093, 0.720-0.853, 3.380-9.167 and 0.440-2.033 mg/kg respectively. Hg was not detected in all the samples. This coincides with the finding of David *et al*. (2019) who reported the absence of Hg in both local and imported rice samples. Contrary to the wet season, Cd was detected during the dry season in all the sampling locations. The Mean of Means values for Zn, Pb, Cd, Ni, Co, Cu and Cr are 8.905, 2.109, 0.153, 1.767, 0.780, 5.489 and 1.193 mg/kg respectively.

The results for the HM mean concentrations (mg/kg) of the rice root samples collected during the dry season 2023 are presented in Table 4. Mean concentration ranges are 1.047-1.593, 1.533-2.160, 0.093-0.147, 0.973-1.340, 0.513-0.753, 0.660-1.300 and 0.927-1.513 mg/kg for Zn, Pb, Cd, Ni, Co, Cu and Cr respectively. Hg was not detected in all the samples. The total means for Zn, Pb, Cd, Ni, Co, Cu and Cr were found to be 1.313, 1.864, 0.117, 1.088, 0.604, 0.806 and 1.151 mg/kg respectively.

The mean concentrations of all the detected HMs found to be higher in the grains than in the roots. This pattern of accumulation was also observed in the rice samples collected during the 2022 wet season production. Higher concentration in the grains is an indication of contamination from agrochemicals application.

The mean concentrations for Zn, Pb and Cd exceed WHO permissible limits (Ogundele *et al*., 2015) in dry season samples, while that of Ni, Co, Cu and Cr fall below the permissible limits (Ogundele *et al*., 2015). It was only the Zn concentration that exceeded the WHO permissible limit in samples collected during the wet season harvest. Comparably, Ihedioha (2016) also reported Cd, Pb and Cr above WHO permissible in rice samples collected from Enugu, Nigeria. Ugbede *et al* (2021) reported Pb, Ni, Cd and Cr concentrations below WHO permissible limits in rice grain produced in Ezillo, Ebonyi State, Nigeria. As, Cd, Cu, Pb, Zn, Ni and Cr concentrations reported by Ihedioha *et al*. (2019) and Anthony *et al*. (2023) in rice samples collected from Abakaliki, Nigeria are within the WHO permissible limits. Pb concentration reported by Olaleye *et al* (2022) in samples of different rice varieties collected from Danbatta in Kano exceeded permissible limits set by WHO and EU. David *et al*. (2019) and Ijeoma *et al*. (2020) analysed samples of imported rice and observed Cd, Cr, Ni and Hg concentrations below WHO permissible limits. Pb concentration reported by Otitoju *et al*. (2019) in rice grain samples produced in southwestern Nigeria exceeded WHO permissible limits.

Comparison between wet and dry season results shows that rice produced during the dry season accumulates more HMs than that produced during the wet season. The concentrations of HMs in rice vary with location and agricultural practices. Mundi *et al* (2019) associated higher concentrations of HM in rice with the application of mineral fertiliser and pesticides. The concentrations of Zn, Pb, Cd, Ni and Cr observed in both wet and dry were far below the concentrations reported by Ihedioha (2016) in rice grain samples collected from Enugu, Nigeria. In contrast, Mundi *et al* (2019) reported Zn, Pb, Ni, Cu and Cr below the values observed in this research in rice samples collected from various locations in Nassarawa State. The concentrations of Pb, Ni, Cd and Cr observed in this research are within the range reported by Ugbede *et al* (2021) in rice grain samples collected from Ezillo, Ebonyi State and that reported by Ihedioha *et al* (2019) in rice samples collected from Abakaliki, Nigeria. The concentrations of Pb observed in this research also tallied with that reported by Ezekiel (2015) in rice produced in Oyo State. Olaleye *et al*. (2022) reported Pb and Zn concentrations within the range observed in this research and Zn concentration below what was observed here.

Effects of Growing Season on Translocation of HMs in Rice

The ratio of HM concentration in the root to that in the grain was adopted to understand the relationship of HMs accumulation between root and grain. Calculated values for translocation factors in rice for wet and dry seasons 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 Zn, Pb, Cu and Cr accumulate more in the grains than in the roots while Co accumulate more in the roots than in the grains. 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.

CONCLUSION

The accumulation order of the studied HMs in rice grains adheres to the hierarchy of Zn>Cu>Pb>Ni>Cr>Co>Cd in both dry and wet seasons production. Rice produced during the dry season accumulates more HMs than that produced during the wet season. The concentrations of Zn, Pd and Cd observed in rice samples produced during the dry season surpassed the acceptable thresholds recommended by FAO/WHO. It was only the concentration of Zn observed to exceed the FOA/WHO permissible limit in samples produced during the wet season. Notably, Hg was not detected in all the samples produced during both the wet and dry seasons. Wet season production provides a safer rice grains with lesser heavy metals contamination.

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