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Evaluation of Some Selected Metals in Rice Cultivated in Four Local Government Areas in Enugu State, Nigeria

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Abstract

In this study, we investigated the presence of Zn, Fe, Cu, and Ca in rice cultivated in four local government areas (Nkanu East, Aninri, Uzo Uwani, Isi Uzo) within Enugu state, Nigeria. We employed an Atomic Absorption Spectrometer with an air acetylene flame to analyze these metals after digesting the rice samples. Risk assessment studies were carried out to determine any potential health risk to consumers by evaluating the estimated daily intake (EDI), the target hazard quotient (THQ) and hazard index (HI). The average concentration (mg/kg) of trace metals in the rice samples was within the acceptable limits established by FAO/WHO. Specifically, Zn ranged from 0.265 to 0.632 mg/kg, Fe from 2.73 to 4.131 mg/kg, Cu from 0.205 to 4.131 mg/kg, and Ca from 9.718 to 12.150 mg/kg. There were no statistically significant differences in metal concentrations among the various locations. Consequently, the rice analyzed in this study can be considered safe for consumption. The calculated EDI (mg/kg-day) values were below the maximum tolerable daily intake thresholds. THQ values also fell within safe levels, and the HI values were less than 1, signifying no potential health risks associated with consuming rice from these locations. In conclusion, there is no significant non-carcinogenic health risk associated with exposure to trace metals through the consumption of rice from these areas.

Keywords

Trace Metals, Rice, Risk Assessment, Target Hazard Quotient, Hazard Index, Enugu

1. Introduction

Rice is a staple food in several African countries, including Nigeria (Ojo et al., 2020). It is the most widely consumed staple food in Nigeria, with Nigerians consuming several tonnes of rice daily (Ugwuja & Chukwukere, 2021). Approximately 85% of households regularly include rice in their diets, and the per capita rice consumption is estimated at 35 kg per annum, indicating a high demand for rice in the country (Obayelu et al., 2022). Rice constitutes the largest share of total food expenditure for households in both rural and urban areas (Ojogho et al., 2013; Chiaka et al., 2022). Nigeria ranks as the second-largest importer of rice globally and holds the top position as the highest producer and consumer of rice in West Africa. The country spends $1.56 - 2.2 billion annually on rice imports, highlighting the significant volume of imports (Nasrin et al., 2015). Rice is one of the most valuable cereal crops cultivated and consumed in Nigeria (Ojo et al., 2020), with its cultivation being widespread across states in Nigeria, including Enugu, Cross River, Ebonyi, Benue, Kaduna, Niger, Kebbi, and Taraba. Rice production and consumption have been on the rise in Nigeria (Obayelu et al., 2022).

The contamination of rice grains by trace metals has raised concerns about the safety of rice consumption. Trace metals, including elements such as copper (Cu), zinc (Zn), iron (Fe), and calcium (Ca), are naturally occurring and can be found in varying concentrations in rice-growing soils and water bodies (Ali et al., 2020). While trace metals are necessary for human health in small amounts, high levels of certain metals can be hazardous (Islam et al., 2015).

The presence of harmful trace metals in rice, such as lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As), is a growing cause for concern. These metals can accumulate in rice grains during growth and cultivation, raising significant health concerns for consumers (Rahman et al., 2019). To emphasize the presence of toxic metals in rice samples, previous investigations have demonstrated varying degrees of metal contamination, occasionally surpassing the established threshold for safe human consumption. In a study conducted by Ogbodo et al. (2022) in Ebonyi State, South-East Nigeria, they examined the levels of toxic metals in both paddy soils and rice (Oryza Sativa (L)) at the Ikwo region. The metals investigated included Hg, Cu, As, Pb, Cr, Fe, Cd, Zn, Mn, and Ni. The findings indicated that these metals in polished rice generally fell within the permissible levels for human consumption (<0.01). However, that the concentration of Hg in the polished grains of Landrace, FARO44, FARO52, and Fadama rice varieties exceeded the limits set by the WHO. Ezeofor et al. (2019) conducted a study on the trace metals in paddy soils and grains in Ugbawka farm in Nkanu East, Enugu State Nigeria. The study reported that the concentration of cadmium in soil as well as cadmium and chromium in the rice grains exceeded the limit of listed international organization.

Consuming rice contaminated with high levels of toxic trace metals can pose serious health risks. Even in small concentrations, metals such as Pb and Cd can lead to chronic health issues, including kidney damage, bone problems, and neurological abnormalities (Rahman & Hasegawa, 2011). The long-term exposure to heavy metals through rice consumption is particularly concerning due to rice's role as a dietary staple for many people. Given the critical importance of food safety and armed with knowledge about various sources of metal contamination in rice, this study aims to quantitatively assess the concentrations of heavy metals in rice grains cultivated in South Eastern Nigeria and evaluate the potential health risks it may pose to consumers.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted in Nkanu East, Aninri, Uzo Uwani, and Isi Uzo Local Government Areas of Enugu State, Nigeria. These areas are situated at Latitude 6.44132 and Longitude 7.49883, with GPS coordinates of 6˚26'28.8"N 7˚29'55.8"E. The region is known for its rich and fertile soils, making it suitable for rice and other agricultural production. The soil texture is loamy, which is considered to be best for agricultural purposes because it can be easily ploughed and has the tendency to retain good moisture and other essential minerals. Additionally, rice processing mills are the only agricultural processing industry present in the community.

2.2. Sampling and Sample Preparation

A total of twelve raw rice samples of about 200 g each were obtained from local habitants in four local government areas (Nkanu east, Aninri, Uzo Uwani and Isi Uzo) in Enugu state, Nigeria. The samples were sent in good condition to the laboratory for analysis. The raw rice samples were thoroughly washed with distilled water, dried in the oven at 105˚C for 24 hours, finely ground with pestle and mortar, and then stored in polythene bags. Approximately 5.0 g of the ground rice sample was transferred into 50 mL beaker, and 20 mL of concentrated HNO_3 was added. The samples were digested on hot plate at 70˚C for 1 hour and shaken at 20-minute intervals. After cooling, the digested samples were filtered through 125 mm size filter paper into 25 mL standard flask. The filtrates were diluted to the marks with distilled water and stored in polyethylene bottles prior to instrumental analysis. The digested samples were analyzed for heavy metals using Agilent AA55 Atomic Absorption Spectrometer with air-acetylene flame. Blank determination was also carried out without the rice sample.

2.3. Health Risk Assessment

Risk assessments of trace metals in plants were used to quantify the non-carcinogenic risks to humans (Chonokhuu et al., 2019).

2.3.1. Estimated Daily Intake (EDI)

The estimated daily intake (EDI) of the trace metals was determined based on their mean concentration in the rice and the estimated daily consumption of the rice in gram. It was calculated using the formula by Guadie et al. (2022), with slight modification as presented in Equation (1).

$$\text{EDI} = \left(\left(C_{\text{metal}} \times \text{IR}\right)/\text{BW}\right) * 10^{-3} \quad (1)$$

where, C_{metal} (mg/kg) is the concentration of metal in rice, IR is the rice consumption rate per day in the local area (g/person/day), BW is the body weight, and 10^{-3} is unit conversion factor. The daily consumption of rice in Nigeria is 70 g/person/day (Ezeofor et al., 2019). The average adult body weight used in this study was 60 kg.

2.3.2. Target Hazardous Quotient (THQ)

Target hazardous quotient (THQ) was used to estimate the non-carcinogenic risk to human health from consumption of trace-metals-contaminated rice. This was calculated using the Equation (2), which is expressed as the ratio of EDI to the chronic reference dose (R*f*D) of a specific metal, as described by Guadie et al. (2022); Getaneh et al. (2021); Gebeyehu & Bayissa (2020), and Ezeofor et al. (2019).

$$\text{THQ} = \text{EDI}/\text{RfD} \quad (2)$$

where, EDI is the estimated daily intake of the metals in mg/day/kg body weight and RfD is the reference dose (mg/kg/day). The reference dose reported for Zn, Fe, and Cu were 0.3, 0.7, and 0.04, respectively (US EPA, 2000). If THQ value is ≥1, there may be adverse health effects for human due to metals exposure. However, if THQ < 1, then it is safe for health risk of non-carcinogenic elements (Kortei et al., 2020).

2.3.3. Hazard Index (HI)

Hazard index (HI) is used to evaluate the potential human health risk through consumption of more than one heavy metal. HI was calculated as the sum of the THQ as shown in the Equation (3) below (Gebeyehu & Bayissa, 2020);

$$\text{HI} = \sum_{n=1}^{i} \text{THQ}; \, i = 1, 2, 3, \cdots, n \quad (3)$$

If the value of HI ≥ 1, there is a possibility of health effect. However, if HI < 1, there is insignificant risk of non-carcinogenic effects (Chonokhuu et al., 2019).

2.4. Statistical Analysis

The results were expressed as mean ± standard deviation (SD). Conformity to the linear model assumptions was assessed using the global test (global validation of linear model assumptions). A one-way analysis of variance (ANOVA) was used to determine whether or not there is a statistically significant difference between the mean concentrations of the selected trace metals in rice samples from the different locations. Significance was determined at 5% probability level ($p < 0.05$). Pearson's correlation analysis was used to compare the relationship between the different metals in the rice samples. Statistical analysis was done with R (R Core Team, 2014).

3. Results and Discussions

3.1. Comparison of the Trace Metal Concentrations in the Rice Samples from the Different Locations

The mean concentrations of the trace metals in the rice samples varied among the different locations. In Aninri samples, the mean concentration ranged from 0.22 mg/kg to 11.22 mg/kg in an ascending order of Cu < Zn < Fe < Ca. The mean concentrations of the trace metals in the rice samples from Isi Uzo ranged from 0.35 mg/kg to 12.15 mg/kg in an ascending order of Cu < Zn < Fe < Ca. The mean concentrations of the trace metals in the rice samples from Nkanu East ranged from 0.24 mg/kg to 10.87 mg/kg in an ascending order of Cu < Zn < Fe < Ca. The mean concentrations of the trace metals in the rice samples from Uzo Uwani ranged from 0.21 mg/kg to 9.72 mg/kg in an ascending order of Cu < Zn < Fe < Ca. The order of the trace metals remained the same across all locations.

Analysis of the specific concentrations of the individual trace metals showed that the mean concentration of Zn ranged from 0.27 ± 0.16 mg/kg in Uzo Uwani to 0.63 ± 0.21 mg/kg in Aninri. However, the observed difference in the concentration of Zn in the rice samples from the different locations was not statistically significant ($F(3, 8) = [3.603]$, $p = 0.065$). Similarly, the level of Fe ranged from 2.73 ± 0.49 mg/kg in Uzo Uwani to 4.13 ± 0.48 mg/kg in Isi Uzo. The observed difference in the Fe concentration in the rice samples from the study sites was not a statistically significant ($F(3, 8) = [3.326]$, $p = 0.077$). The highest concentration was observed in rice samples from Isi Uzo (0.35 ± 0.11 mg/kg), while the least was observed in samples from Uzo Uwani (0.21 ± 0.10 mg/kg). However, the observed difference in the concentration of Cu in the rice samples was not statistically significant for the different locations ($F(3, 8) = [1.691]$, $p = 0.245$). The highest concentration of Ca was also observed in rice samples from Isi Uzo (12.15 ± 1.03 mg/kg), while the least was observed in rice samples from Uzo Uwani (9.71 ± 1.87 mg/kg). Again, the observed difference in the concentration of Ca in the rice samples was not statistically significant for the different locations ($F(3, 8) = [1.670]$, $p = 0.250$).

These findings are consistent with previous studies on heavy metal contamination in rice samples. In a study on heavy metal contamination in rice samples from selected rice fields in Nigeria, Ezeofor et al. (2019) reported that trace metal concentrations differed between areas. Similar studies in other nations, such Ghana (Rivera-Rivera et al., 2020) and China (Zhao et al., 2015; Lv et al., 2015), have also reported variability in heavy metal concentrations in rice samples from different locations. It is important to note that the observed differences in trace metal concentrations among the locations in this study were not statistically significant. Importantly, all the identified metals fell within the recommended maximum tolerance values in mg/kg (Zn: 60, Fe: 450, Cu: 40) (Hassan et al., 2022). This implies that trace metal levels in rice samples from the different locations do not pose substantial health concern to the consumers. However, heavy metal contamination in rice must still be monitored and regulated to ensure food safety and human health (Chamannejadian et al., 2013).

3.2. Correlation Matrix

The relationships between various trace metal contents in the rice samples were assessed using Pearson's correlation, and the findings are displayed in **Table 1**. A very strong positive correlation was observed between the concentrations of Cu and Ca (0.824). This suggests that as the concentration of Cu increases, the concentration of Ca also tends to increase, and vice versa. This correlation coefficient indicates a strong linear relationship between these two trace metals. Statistically significant strong positive correlations were also observed between Fe and Ca (0.750), as well as between Fe and Cu (0.679). These findings suggest that there is a strong linear relationship between the concentrations of Fe and Ca, as well as between the concentrations of Fe and Cu. Additionally, statistically significant moderate positive correlations were observed between Zn and Fe (0.595) and Zn and Ca (0.584). These correlations shed light on the interactions between these trace elements and can help us better understand the factors that influence their presence in rice. Further investigation into the underlying mechanisms and potential ramifications of these correlations in the context of food safety and human health is required.

3.3. Health Risk Assessment

The Estimated Daily Intake (EDI) of metals found in rice samples from diverse locations is of utmost importance in assessing the potential health implications associated with the consumption of rice from these regions. EDI serves as a metric for estimating the daily exposure of individuals to these metal substances through their dietary intake. In this study, the daily intake of trace metals was determined by considering the average concentration of each metal in the rice samples and the dietary habits of adults (US EPA, 2000).

The Estimated Daily Intake (EDI) values for Zn, Fe, Cu, and Ca (measured in mg/kg-day) exhibited similarities across most of the sampled locations, falling within the following ranges: 0.00026 to 0.01309 for Aninri, 0.00041 to 0.01418

Table 1. Pearson's correlations matrix for trace metals in the rice samples.

	Zn	Fe	Cu	Ca
Zn	1.000			
Fe	0.595*	1.000		
Cu	0.494	0.679*	1.000	
Ca	0.584*	0.750**	0.824***	1.000

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed), ***Correlation is significant at the 0.001 level (2-tailed).

Table 2. Estimated daily intake (EDI), target hazardous quotient (THQ) and hazard index (HI) values of trace metals in adults through the consumption of rice.

Sampling location	Zn		Fe		Cu		Ca		HI
	EDI	THQ	EDI	THQ	EDI	THQ	EDI	THQ	
Aninri	0.00049	0.00164	0.00223	0.00319	0.00026	0.00653	0.01309	-	0.01136
Isi Uzo	0.00054	0.00180	0.00482	0.00689	0.00041	0.01030	0.01418	-	0.01898
Nkanu East	0.00060	0.00200	0.00333	0.00476	0.00028	0.0070	0.01268	-	0.01376
Uzo Uwani	0.00022	0.00075	0.00213	0.00304	0.00024	0.00598	0.01134	-	0.00976
MTDI	60.0		0.8		0.2		-		

MTDI: maximum tolerable daily intake.

for Isi Uzo, 0.00028 to 0.01268 for Nkanu East, and 0.00022 to 0.01134 for Uzo Uwani. Notably, rice samples from Aninri (0.00026 mg/kg-day), Nkanu East (0.00028 mg/kg-day), and Uzo Uwani (0.00024 mg/kg-day) exhibited similar EDIs for Cu. Similarly, rice samples from Aninri (0.01309 mg/kg-day), Isi Uzo (0.01418 mg/kg-day), Nkanu East (0.01268 mg/kg-day), and Uzo Uwani (0.01134 mg/kg-day) displayed comparable EDIs for Ca. The resulting EDI values (measured in mg/kg-day) for the metals followed an ascending order: Cu < Zn < Fe < Ca. These EDI values for the metals were determined to be within safe limits when compared to the Maximum Tolerable Daily Intake (MTDI) values of 0.2 for Cu, 0.8 for Fe, and 60.0 for Zn (Kacholi & Sahu, 2018; Guadie et al., 2022). Thus, the data from all the samples from the fourlocal areas suggest that the order of metal concentrations in the rice samples remained the same and below the exposure limits.

The results of the Target Hazard Quotient (THQ) values presented in **Table 2** are all less than 1 and followed the order Zn < Fe < Cu < Ca. This suggests that the consumption of rice contaminated with these metals from these locations is unlikely to pose significant health risks. Similarly, the Hazard Index (HI) values for metals in rice samples from different locations followed the ascending order: Uzo Uwani < Aninri < Nkanu East < Isi Uzo. The HI values in each of the locations were all less than 1. These results suggest that the consumption of rice from these locations does not pose any significant health risks.

The Hazard Index (HI) values for trace metals through the consumption of rice from various locations are presented in **Table 2**. The results reveal that the HI values of metals in rice samples from different locations followed the ascending order: Uzo Uwani < Aninri < Nkanu East < Isi Uzo. The HI values in each of the locations, specifically Aninri (0.01136), Isi Uzo (0.01898), Nkanu East (0.01376), and Uzo Uwani (0.00976), were all less than 1. This suggests that the consumption of rice from these locations does not pose any significant health risks.

4. Conclusion

The study assessed the presence of trace metals (Zn, Fe, Cu, and Ca) in rice samples collected from Aninri, Isi Uzo, Nkanu East, and Uzo Uwani in Enugu state. A comparison of the average concentrations of these trace metals in rice samples from these different locations found no statistically significant differences at a 95% confidence level. Importantly, all the identified metals fell within the permissible limits established by FAO/WHO. Strong correlations were observed among the trace metals in the rice grains. This indicated that the metals were similar in origin. Furthermore, the evaluation of health risks associated with these trace metals, as indicated by the THQ and HI values, showed that they were all below 1. Consequently, there is no substantial health risk to adult consumers of rice from these locations due to prolonged exposure. However, it is important to note that further research with larger sample sizes and standardized sampling methods is needed to provide a more comprehensive understanding of the concentration of trace metals in rice samples from various locations.

Conflicts of Interest

The authors declare no conflict of interest.

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