



Chemical Safety of Unpolished Nigerian Rice

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ABSTRACT

Levels of arsenic (As), lead (Pb), cadmium (Cd), calcium (Ca), chromium (Cr), potassium (K), sodium (Na), and zinc (Zn) in locally cultivated rice consumed in Ondo and Ekiti States of Nigeria were investigated. The rice samples were obtained from six different rice-producing towns; Akure, Ondo, Ado, Igbemo, Ikole and Erinjiyan. The estimated dietary intake (EDI) of these elements were determined and compared with the provisional tolerable daily intake (PTDI) and dietary reference intake (DRI) values for toxic and essential elements respectively. The measured mean levels of Pb, As, Cr, Cd, Zn, Na, Ca and K were 0.047 ± 0.007 , 0.041 ± 0.004 , 0.570 ± 0.032 , 0.026 ± 0.003 , 7.856 ± 0.659 , 42.15 ± 0.191 , 337.11 ± 0.315 , and 2650.09 ± 0.337 $\mu\text{g/g}$ respectively while the average EDI were 00.101 ± 0.042 $\mu\text{g/day}$, 0.088 ± 0.14 $\mu\text{g/day}$, 1.234 ± 0.045 $\mu\text{g/day}$, 0.057 ± 0.002 $\mu\text{g/day}$, 0.017 ± 0.071 mg/day , 0.091 ± 0.013 mg/day , 0.73 ± 0.018 mg/day and 5.742 ± 0.337 mg/day respectively. The EDIs were not significantly higher than the reference values for the elements except Cr. Also the rice samples were not rich enough in sodium, calcium and potassium compared to the dietary reference intakes for these elements. It is recommended that rice diets should be supplemented with other food items such as meat, fruits and vegetables.

Introduction

Rice is a staple cereal grain that is widely consumed all over the world, especially in Asia where it accounts for 35 to 60% of the calories consumed per day (Khush, 1997). Globally, rice consumption supplies 2,400 calories per person per day (FAO, 2000). In Nigeria, there have been great improvement in local rice production; from 207,200 tonnes/ha in 1961-1965 to 3,000,000 tonnes/ha in 1996-2000 (Ajijola et al., 2012). This is in response to increase in rice consumption in Nigeria and other African nations (Bamidele et al., 2010). Two types of rice are mainly cultivated in Nigeria: the African rice (*Oryza glaberrima*) and the Asian rice (*Oryza sativa*). Recently, new varieties of rice have been introduced e.g. NERICA (New Rice for Africa), which is an interspecific hybrid between the African and Asian rice.

The pollution of environment by heavy metals is of significant concern due to the reported adverse effects of metal pollution on human and other living organisms (Yoon, 2003). The dietary exposure of humans to toxic metals has elicited various adverse effects such as developmental retardation, several types of diseases such as cancer, kidney damage, endocrine disruption, immunological, neurological effects and other metabolic and physiological disorders (Mudgal et al., 2010). There have been reports that crops grown on soils contaminated with heavy metals have the potential to bioaccumulate

those metals, and could be harmful to humans when such crops are consumed (Satpathy et al., 2014; Balkhair and Ashraf, 2016). Also, incidences of toxic elements in food items have been widely reported certain (Arsian and Arikian, 2013; Kurnaz et al., 2016; Ossai et al., 2016; Yilmaz et al., 2016).

The specific objectives of the study are two folds: firstly to determine the levels of some toxic and essential elements in locally cultivated rice samples consumed in different towns in both Ondo and Ekiti states of Nigeria, and secondly to estimate the dietary daily intake of the elements and compared to recommended daily intakes.

Materials and Methods

Study Location and Sample Collection

This study was carried out in Ondo and Ekiti states of Nigeria comprising different towns from each state. In Ondo state, the towns chosen were Akure and Ondo while Ado-Ekiti, Igbemo, Ikole-Ekiti, and Erinjiyan were chosen in Ekiti state. Both Ondo ($7^{\circ}10'N$, $5^{\circ}05'E$) and Ekiti ($7^{\circ}40'N$, $5^{\circ}15'E$) states are located in the South-Western part of Nigeria. The States are geographically within the rainforest zone of Nigeria and have marked wet and dry seasons (Iloje, 2001).

Rice samples were obtained at different points from the major markets (in the sampled towns), and were stored in polythene bags with proper identification. In the laboratory, the samples were sorted to eliminate stones, chaff, sticks and other unwanted materials. The samples were then pulverized in a mortar into fine, powdery forms. The pulverized samples were sieved to obtain very fine particles using a sieve of 0.5 mm mesh size.

Sample Preparation and Metal Analyses

Sample preparation and metal analyses followed standard procedures (APHA and WCPF, 1998; AOAC, 2003). Briefly, five (5) g each of the samples were transferred into digestion flasks after which 4 ml of perchloric acid and 8 ml of nitric acid were added. The digestion flasks were placed on a hot plate set at 120°C (gradually increased) until the samples were digested. The digested samples were diluted with distilled water appropriately in the range of standards which were prepared from stock standard solution of the metals. The determination of levels of Cd, Cr, Pb, As and Zn in digested samples were performed using atomic absorption spectrophotometry (Model 210 VGP) while the levels of Na, K and Ca were determined using flame photometry.

Estimation of Elemental Dietary Intake through Rice Consumption

The daily intake of elements depends on both the concentration in food and the daily food consumption. The EDIs of toxic and essential elements (Pb, As, Cd, Cr, Zn, Na, Ca and K) were calculated as reported by Batista et al. (2011) and Adedire et al. (2015) as follows:

$$EDI = C_m \times M_g$$

where EDI is the estimated daily intake (mg/day/individual or $\mu\text{g/day/individual}$), C_m is the mean concentration of metals in the rice samples ($\mu\text{g/g}$ or mg/kg) and M_g is the mass of rice consumed daily by an individual. The daily consumption of rice was taken as 70 g/day based on the report of The African Rice Center (2005) regarding rice consumption in Nigeria. The EDIs of the essential elements were compared to the dietary reference intakes (DRIs) obtained from the Food and Nutrition Board of the Institute of Medicine (2004). The EDI of the lead was compared with the European Food Safety Authority (EFSA, 2010) benchmark dose lower confidence limit, while the EDI of cadmium was compared to the provisional tolerable daily intake (PTDI) value obtained from provisional tolerable weekly intake (PTWI) values based on WHO guidelines.

Data Analyses

Data were reported as mean \pm standard deviation. The data on levels of metals were analyzed using a one-way analysis of variance. This was followed by Tukey's comparison tests whenever significant difference existed. All statistics were performed using SPSS 21.0 software (SPSS, Inc. 2013) and statistical significance was assumed at $P \leq 0.05$.

Results and Discussion

Levels and Dietary Intakes of Toxic Elements in Rice Samples

The mean levels of toxic elements (arsenic, cadmium and lead) in rice samples from each location are shown in Table 1. The mean levels of the toxic elements differed significantly ($P < 0.05$) in samples collected from different locations. The mean level of arsenic was highest in samples collected from Igbemo ($0.059 \pm 0.006 \mu\text{g/g}$) and lowest in samples obtained from Akure ($0.026 \pm 0.002 \mu\text{g/g}$). The detected mean level of arsenic in rice samples was just 8.2% of the upper limit of $0.5 \mu\text{g/g}$ allowed in food, and much lower than the reported levels of arsenic in rice samples from Brazil, Taiwan and Thailand which were found to be $0.223 \mu\text{g/g}$, $0.383 \mu\text{g/g}$ and $0.11 \mu\text{g/g}$ respectively (Williams et al., 2005; Batista et al., 2011). The mean level of cadmium was highest in samples collected from Ikole-Ekiti ($0.038 \pm 0.005 \mu\text{g/g}$) and lowest in samples obtained from Ado-Ekiti ($0.015 \pm 0.003 \mu\text{g/g}$). The detected mean level of cadmium in rice samples was 6.5% of the upper limit of $0.4 \mu\text{g/g}$ allowed in food. The mean value of cadmium in these samples was higher than the value detected in Brazilian rice samples ($0.0127 \mu\text{g/g}$) but quite similar to the levels detected in South Korean and Swedish samples where cadmium levels were found to be 0.021 and $0.024 \mu\text{g/g}$ respectively (Fu et al., 2008; Jorhem et al., 2008; Batista et al., 2010). The mean level of lead in rice samples ranged from $0.051 \pm 0.007 \mu\text{g/g}$ in samples collected from Erinjiyan to $0.041 \pm 0.007 \mu\text{g/g}$ in samples obtained from Ado-Ekiti. The detected mean level of lead in rice samples was 23.5% of the upper limit of $0.2 \mu\text{g/g}$ permitted in food. The mean detected lead levels in this study were higher than the levels found in Chinese rice ($0.028 \pm 5.6 \mu\text{g/g}$; Fu et al., 2012) but similar to the detected level in Brazilian rice with a mean level of $0.057 \mu\text{g/g}$ (Poletti et al., 2014). The observed high levels of toxic elements (As, Pb, Cd) in this study could be due to heavy soil pollution arising from indiscriminate waste disposal system, vehicular pollution and contamination with petroleum products (Huang et al., 2006).

Arsenic, cadmium and lead are extremely toxic to vertebrates including man. Arsenic is a human carcinogen; chronic exposure to arsenic has been shown to result in increased incidences of cancer in various body parts including buccal cavity, pharynx, lung etc. (Enterline et al., 1995). Human acute exposure to lead has been shown to cause encephalopathy, nausea and vomiting, and long term exposure resulted in nephropathy (kidney disease) and disruption of haem biosynthesis (Vavas-Acien et al., 2007). Cadmium has been reported to be nephrotoxic to human, causing renal dysfunction (Rastogi, 2008). The results of this study did not indicate any potential health hazard by toxic elements from consumption of local rice. The mean estimated daily intakes of arsenic, cadmium and lead were 2.87, 1.82 and $3.29 \mu\text{g/day}$ for arsenic, cadmium and lead respectively, which are just 1.91, 2.6, and 9.4% of the provisional tolerable daily intake values for arsenic, cadmium and lead respectively (Table 3).

Table 1 The levels of toxic elements in rice samples in Ondo and Ekiti states

Location	Lead ($\mu\text{g/g}$)	Arsenic ($\mu\text{g/g}$)	Cadmium ($\mu\text{g/g}$)
Akure	0.044 ^{ab} ±0.003	0.026 ^a ±0.002	0.02 ^{ab} ±0.006
Ondo	0.048 ^{ab} ±0.05	0.031 ^a ±0.003	0.017 ^a ±0.002
Ado-Ekiti	0.041 ^a ±0.007	0.043 ^{bc} ±0.004	0.015 ^a ±0.003
Igbemo	0.049 ^{ab} ±0.002	0.059 ^d ±0.006	0.026 ^b ±0.003
Ikole	0.047 ^{ab} ±0.002	0.036 ^{ab} ±0.011	0.038 ^c ±0.005
Erinjiyan	0.051 ^b ±0.007	0.048 ^c ±0.003	0.042 ^c ±0.002
Average conc.	0.047±0.007	0.041±0.004	0.026±0.003
UL	0.2*	0.5*	0.4*

Each value is the mean \pm standard deviation of the six replicates. Means within the same column followed by the same letter (in superscript) are not significantly different but means with different letters are significantly different from others at $P>0.05$ using Tukey's test, *= Tolerable Upper Intake Levels (UL) according to Food and Nutrition Board, Institute of Medicine, National Academies, 2004.

Table 2 The levels of essential elements in rice samples in Ondo and Ekiti states

Location	Sodium ($\mu\text{g/g}$)	Calcium ($\mu\text{g/g}$)	Chromium ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)	Potassium ($\mu\text{g/g}$)
Akure	39.37 ^{ab} ±0.198	330.58 ^a ±0.699	0.227 ^a ±0.022	6.833 ^{ab} ±0.619	2610.8 ^a ±0.375
Ondo	48.13 ^d ±0.053	343.6 ^c ±0.270	0.308 ^b ±0.033	6.067 ^a ±0.628	2625.8 ^b ±0.145
Ado-Ekiti	38.03 ^d ±0.068	337.73 ^{bc} ±0.182	0.648 ^c ±0.028	6.883 ^{ab} ±0.578	2642.7 ^c ±0.595
Igbemo	43.0 ^{bc} ±0.391	329.92 ^a ±0.043	0.823 ^e ±0.033	8.9 ^e ±0.754	2662.5 ^d ±0.588
Ikole-Ekiti	44.82 ^{cd} ±0.408	344.17 ^c ±0.227	0.715 ^d ±0.035	9.933 ^c ±1.663	2686.8 ^f ±0.068
Erinjiyan	39.52 ^{ab} ±0.026	336.65 ^{ab} ±0.473	0.697 ^{cd} ±0.043	8.517 ^{bc} ±1.102	2671.9 ^e ±0.255
Average conc.	42.15±0.191	337.11±0.315	0.570±0.032	7.856±0.659	2650.1±0.337
UL	2300*	2500*	ND**	40**	ND*

Each value is the mean \pm standard deviation of the six replicates. Means within the same column followed by the same letter (in superscript) are not significantly different but means with different letters are significantly different from others at $P>0.05$ using Tukey's test, UL= Tolerable Upper Intake Levels, ND= Not Determinable, *= Tolerable Upper Intake Levels (UL) according to Food and Nutrition Board, Institute of Medicine, National Academies, 2004.

Table 3 Estimated Daily Intake (EDI) ($\mu\text{g/day}$ or mg/day) of toxic metals, essential micronutrients and macronutrients compared to provisional tolerable daily intake (PTDI) for toxic elements and the dietary reference intake (DRI) for essential elements.

Location	Lead ($\mu\text{g/day}$)	Arsenic ($\mu\text{g/day}$)	Chromium ($\mu\text{g/day}$)	Cadmium ($\mu\text{g/day}$)	Zinc (mg/day)	Sodium (mg/day)	Calcium (mg/day)	Potassium (mg/day)
Akure	3.08	1.82	15.89	1.40	0.47	2.76	23.14	182.76
Ondo	3.36	2.17	21.56	1.19	0.42	3.37	24.05	183.81
Ado-Ekiti	2.87	3.01	45.36	1.05	0.48	2.66	23.64	184.99
Igbemo	3.43	4.13	57.61	1.82	0.62	3.01	23.09	186.38
Ikole-Ekiti	3.29	2.52	50.05	2.66	0.70	3.14	24.09	188.08
Erinjiyan	3.57	3.36	48.79	2.94	0.60	2.77	23.57	187.03
Average EDI	3.29	2.87	39.90	1.82	0.55	2.95	23.60	185.51
PTDI/DRI	35 ^b	150 ^a	35 ^c	70 ^a	8 ^c	1500 ^c	1200 ^c	4700 ^c

Notes: ^aPTDI, Provisional Tolerable Daily Intake for toxic elements based on PTWI/7 (WHO guidelines), ^bCorresponding benchmark dose lower confidence limit (BMDL) for lead were obtained by multiplying the BMDL value 0.5 $\mu\text{g/kg/day}$ (EFSA, 2010), ^cDietary reference intakes (DRIs) for essential elements are the most recent set of dietary recommendations established by the Food and Nutrition Board of the Institute of Medicine.

Levels and Dietary Intakes of Essential Elements in Rice Samples

The levels of essential elements detected in rice samples varied significantly across the sampling locations for the different elements. The values ranged between $344.17 \pm 0.227 - 330.58 \pm 0.699$, $0.823 \pm 0.033 - 0.227 \pm 0.022$, $2686.83 \pm 0.068 - 2610.82 \pm 0.375$, $44.82 \pm 0.408 - 38.03 \pm 0.068$ and $9.933 \pm 1.663 - 6.067 \pm 0.628$ $\mu\text{g/g}$ for calcium, chromium, potassium, sodium and zinc respectively (Table 2). The detected values for calcium, chromium, potassium and sodium are quite higher than the values reported for polished South Korean rice given as 94.8, 0.57, 2200 and 13.4 mg/kg respectively (Jung et

al., 2005). However, the detected values for zinc are quite low when compared to the values detected in South Korean rice samples reported as 17.0 mg/kg (Jung et al., 2005).

In humans, the essential elements play important roles in various biochemical and physiological activities; calcium is an essential component of bones and cartilage, and also play important role in blood clotting, by stimulating the release of thromboplastin from the blood platelets, enhance the action of insulin (Mertz, 1969), calcium deficiency can lead to rickets and poor blood clotting. Chromium plays significant role in the regulation of sugar levels in the body; its deficiency impairs the

body's ability to utilize glucose to meet its energy needs and raises insulin requirements. Zinc interacts with a wide range of organic ligands and has roles in the metabolism of RNA and DNA. It also regulates apoptosis (Hambidge and Krebs, 2007). Sodium is essential for regulation of blood volume, blood pressure, osmotic equilibrium and pH (Geleijnse et al., 2004). Potassium is necessary for various physiological processes such as hormone secretion and action, vascular tone, systemic blood pressure control, gastrointestinal motility, acid-base balance, glucose and insulin metabolism (Linus and Wingo, 2013; Malnic et al., 2013). The deficiency of potassium in man could result in muscle weakness, paralytic decreased reflex response; and in severe cases, respiratory paralysis, alkalosis and cardiac arrhythmia (Visveswaran, 2009). Despite the usefulness of these elements in human, they are potentially harmful when their allowable levels in the body are exceeded. For example, a high level of chromium in the blood could result in damage to the blood cells through oxidation reactions which cause haemolysis, and subsequently kidney and liver failure (Dayan and Paine, 2001).

The estimated dietary intakes for the essential elements determined in this study are shown in Table 3. The estimated dietary intakes were 23.60 mg/day, 39.90 µg/day, 185.51 mg/day, 2.95 mg/day and 0.55 mg/day for calcium, chromium, potassium, sodium and zinc respectively. These values were well below the dietary reference intake values for the elements except for chromium. The high dietary intake of chromium through consumption of local rice implies a serious health risk to human. The major source of contamination of rice with chromium is from the soil, so considerable attention should be given to remediation of soil's chromium level with a view to reducing the levels of chromium on Nigerian soils.

Conclusion

The findings of this study showed that the locally produced rice consumed in Ondo and Ekiti states of Nigeria contain low levels of toxic elements (Pb, As, Cd), and their estimated dietary intakes were well below the dietary reference intake values. However, the chromium levels detected in the rice samples is quite high, and this suggests the risk of chromium toxicity through rice consumption. On the other hand, the sampled rice in this study were not rich enough in sodium, calcium and potassium compared to the dietary reference intakes for these elements. It is recommended that rice diets should be supplemented with other food items such as meat, fruits and vegetables.

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