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Zinc Content of Staple Grains and Domestic Water from Kanam Local Government Area, North-Central Nigeria

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Abstract

Zinc is one of the essential trace elements in human nutrition. Adequate zinc nutrition is essential for human health because of zinc's critical structural and functional roles in many enzyme systems that are involved in gene expression, cell division and growth and immunologic and reproductive functions. On account of its very important roles in strategic biologic functions in the body, inadequate dietary intake of zinc has serious health consequences. Samples of five grains (maize, guinea corn, millet, cowpea and groundnut) and domestic water sources from Kanam Local Government Area, Nigeria; a population of suspected zinc deficiency, were analyzed for their zinc content using inductively coupled plasma-mass spectrophotometry. The samples were wet-ashed according to the protocol of Hill et al. before the analysis. The objective of the study was to investigate the levels of zinc in various staple grains grown in Kanam LGA, Nigeria. Results were expressed as mean ± standard deviation. The results showed wide variation in the zinc content of the grains. The mean zinc content was highest in cowpea (40.34 ± 1.32 µg/g), followed by groundnuts (32.75 ± 0.66 µg/g), and least in yellow maize (22.35 ± 1.17 µg/g). Other samples such as red and white sorghum, white maize, and millet had zinc contents varying from 23.82 to 25.89 µg/g. Zinc content of hand-dug well water sources also varied widely from 1.921 ± 0.060 to 4.940 ± 0.103 mg/l. Phytate/zinc ratio was determined to ascertain the level of bioavailability of zinc in the foodstuffs. Based on the phytate/zinc molar ratio, cowpea appears to have the most bioavailable zinc followed by red and white sorghum, while groundnut has the least. The results are discussed and it is concluded that the staple grains, except cowpea and domestic water sources, may not be good sources of dietary zinc.

Keywords: Staple grains; Kanam; Zinc; Domestic water; Nigeria

Introduction

Zinc functions in numerous aspects of cellular metabolism. It plays important roles in growth and development, the immune response, neurological function, and reproduction [1,2]. Zinc also plays a role in cell signaling and has been found to influence hormone release and nerve impulse transmission. Recently, zinc has been found to play a role in apoptosis (gene-directed cell death), a critical cellular regulatory process with implications for growth and development, as well as a number of chronic diseases [3-5]. Lack of zinc is associated with the atrophy of the thymus [6,7], a gland which has a role in the maturation of lymphocytes, and the function of T-lymphocytes is especially vulnerable to deficiency of this mineral [1,8].

Zinc deficiency disease is primarily a consequence of consumption of zinc-deficient staple diet. Therefore, the bioavailable zinc content of the staple diet is a major determinant of differences in zinc status within and among populations [9]. Foods of animal origin, such as meat, fish, offal, milk, and eggs, are the richest dietary sources of zinc that can easily be assimilated [10]. Foods of plant origin like nuts, beans, pumpkin, okra, peas, and cassava, are also rich in zinc but the bioavailability of their zinc content is reduced by the coexistence of inhibitory substances such as phytates, hemicelluloses and lignin [11,12]. Thus, diets consisting largely of foods of plant origin are considered poor in zinc. Domestic water sources are not often taken into consideration by researchers when assessing the zinc status of a population. This has led to observed differences in the zinc status within the population solely from the standpoint of the staple food content of zinc and its anti-nutritional factors. The National Policy on Food and Nutrition Nigeria, observed that there is increasing recognition of nutrition as a necessary condition for national development as espoused in the Millennium Development Goal; and that adequate food and optimal nutritional status are the foundation blocks for the building of healthy, secure lives and thus form the basis for development in any nation [13]. The Micronutrient Initiative [14] noted that none of the studies on zinc intake in Nigeria today, has given any consideration to this fact. The U.S. Recommended Daily Allowance (RDA) is 11 mg/day for adult males and 8 mg/day for females [15]. The U.K. Reference Nutrient Intake (RNI) ranges set by the Committee on Medical Aspects of Food and Nutrition Policy (COMA) are 5.5-9.5 mg/day for males and 4.0-7.0 mg/day for females [16].

In Nigeria, about 14 million people – 8.5% of the total population - are undernourished [17]. In addition to a lack of basic protein and energy, the immediate causes of under nutrition are a lack of micronutrients such as zinc, and vitamin A among others. Almost 20% of under-fives are zinc deficient [13]. The Nigeria Food Consumption and Nutrition 2001-2003 found a prevalence of zinc deficiency in Nigeria as determined by serum zinc [18]. Plateau State was not among the states covered in the survey but shares an eco-geographical and socio-economic characteristic with the neighbouring Nasarawa State which was surveyed. Furthermore, reports of Jaryum et al., [19,20] suggest that zinc deficiency may be prevalent in Kanam LGA of Plateau State, Nigeria. This has necessitated the screening of staple foodstuffs and domestic water sources for their zinc content.

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Materials and Methods

Food samples

Samples of the staple grains grown in the area were collected randomly from farmers after harvest. The samples were taken to the Taxonomy Unit of the Department of Plant Science and Technology, University of Jos, for identification. They were identified as follows:

Maize (yellow and white varieties) - *Zea mays*

Guinea Corn (red and white varieties) - *Sorghum bicolor*

Millet - *Pennisetum glaucum*

Common beans (cowpea) - *Phaseolus vulgaris*

Groundnut - *Arachis hypogea*

Samples of well water were taken randomly from wells at different locations in the research area using 250 ml factory-fresh plastic bottles with screw caps. The bottles were rinsed several times with distilled water before used. Samples from stream and rainwater were, however, not collected because the inhabitants of the research area do not use these sources for cooking or drinking.

Sample preparation: All experiments and procedures were performed at room temperature. Samples were treated preparatory to the spectrophotometric analysis as follows: About 5 g of each food sample was pounded to a fine powder using ceramic mortar and pestle. The pestle and mortar were washed with distilled water and air-dried each time a sample was to be pounded. Fifty-one food samples, comprising of grains and nuts, weighing about 5 g were further ground and homogenized in a stainless steel household food mill for 5 minutes (particle size>300 µm). From these, 0.200 g of each was digested using a diluted oxidant mixture: 1 ml deionised H_2O+0.5 ml double-distilled HNO_3 [21]. The whole of each sample and the oxidant mixture was in 13 x 100 mm borosilicate tubes and then placed in a heating block (Isotemp Dry Bath 145, Fisher Scientific Inc., Bohemia, NY, USA) and hydrogen peroxide (0.5 ml) was added to each tube to complete the first step of the digestion process. The operating temperature for this step was 95°C. At the end of this initial digestion, almost all the samples gave a black mass residue. The tubes are then placed upright in inverted 1000 ml glass beaker, covered with a watch glass (Plate 1), and placed in a muffle furnace (Ashing Oven Lindberg, USA). The resultant ash was dissolved in distilled water, quantitatively transferred to a new trace element-free plastic bottle with screw cap and made up to 20 ml with distilled water. The sample was stored in the refrigerator pending analysis (Figure 1).

For phytate analysis, the food samples were ground in a centrifugal grinding mill equipped with a 24-tooth rotor and 1.0 mm stainless-steel ring sieve with the motor speed set at 15,000 rpm. This setting produced ground samples with a uniform particle size of less than 0.5 mm. Extraction was done for 45 minutes in a 20 ml vial with 0.5 N HCl in a ratio of 1:20 (wt/vol) while stirring. In this experiment, 0.5 g of sample and 10 ml of 0.5 N HCl were used throughout. Approximately 2 ml of crude extract from each sample was centrifuged at 18,000 × *g* for 10 min in a micro centrifuge. An aliquot of 1 ml of supernatant containing phytate was then filtered with a 1 ml syringe and a 13 mm/0.45 µm syringe filter. Filtered samples were stored at 4°C prior to HPLC analysis [22].

Zinc content determination

Concentrations of zinc in grains and water samples described in this work was determined by the inductively coupled plasma-mass spectrometry (ICP-MS) using internal standardization with gallium in 2% HNO_3 (Perkin Elmer Life and Analytical Sciences, Shelton, CT, U.S.A.) added at 0.1 µg/l concentrations to all measuring solutions for the correction of matrix effects. The ICP-MS was operated at 1,400 W forward power with a coolant flow rate of 13.5l/min. Sample delay and rinse times were 45 s with single reading. Sample uptake rate was 40 rpm.

Phytate determination

Elution of phytate was achieved with a 30 min linear gradient of 0.01 M 1-methylpiperazine, pH 4.0, to 0.5 M $NaNO_3$ in 0.01 M 1-methylpiperazine, pH 4.0, at a flow rate of 1 ml/min as described by Rounds and Nielsen [23] with modifications. A variable wavelength detector was used for post column detection of phytate at 500 nm with the signal polarity setting on negative. The system was equipped with software to control the operation and data acquisition. The detector signals and phytate peaks were processed and integrated by the chromatographic data acquisition system.

Statistical analysis

Statistical analysis was performed using the computer software, SPSS Version 17.0 (SPSS Inc., Chicago). The statistical programme was SPSS Statistics Data Editor. Data were presented as means ± standard deviations. The student's t-test was used to examine the zinc content of grains in the region. The acceptable level of statistical significance for all tests was $p<0.05$.

Results

The results of zinc content analysis were as presented on Tables 1 and 2. As could be seen from Table 1, there was, for each crop, a wide variation in zinc content. However, the wide variations were statistically significant ($p<0.05$) only in respect of the same varieties grown in the U.S.A. Both in terms of lowest and highest zinc levels detected and LGA mean values, cowpea had the highest zinc followed by groundnut, while yellow maize had the lowest zinc content followed by red sorghum. In each case, the value is statistically significant ($p<0.05$) when compared with same variety grown in the U.S.A [24].

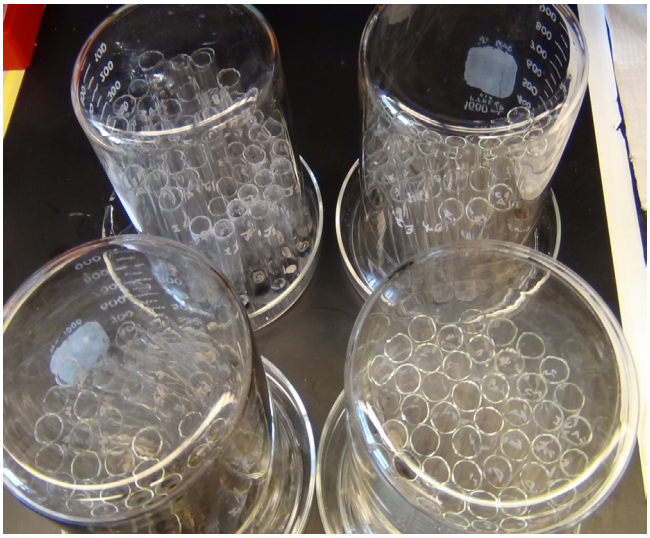

Figure 1: Samples set for ashing in oven.

The results of the analyses of random samples of domestic water sources accessible to the population surveyed were summarized on Table 2. Samples collected from the southern half of the area (5, 6, 7, 8 and 9) showed higher zinc content than those from the northern half (1, 2, 3 and 4).

Bioavailability of zinc was determined in terms of the phytate/zinc molar ratio as shown on Tables 3 and 4, while Table 3 showed the phytate content of the foodstuffs.

The level of this anti-nutritional factor, phytate, in the staple grains also varies widely (Table 3) among samples of each crop. However, the wide variations are statistically significant ($p<0.05$) only in the case of groundnut. Both in terms of the lowest and highest level of phytate and the LGA mean cowpea has the lowest phytate content while groundnut has, by far, the highest. The mean phytate content of groundnut is several fold higher than that of each of the other crops: white maize (≈ 5.0), yellow maize (5.4), white sorghum (6.7), red sorghum (7.0), millet (≈ 6.0) and cowpea (14.8). Thus, in terms of phytate content, cowpea is also the best staple grain source of dietary zinc; groundnut being by far the poorest (Table 3).

Grains	Zinc content (µg/g) Range*	LGA Mean[a]
White Maize	21.15 ± 0.25-36.02 ± 1.44	24.38 ± 1.11
Yellow Maize	18.59 ± 0.27-26.92 ± 0.66	22.35 ± 1.17
White Sorghum	20.65 ± 0.20-28.81 ± 0.54	24.79 ± 0.59
Red Sorghum	18.92 ± 0.83-33.61 ± 2.30	23.82 ± 0.93
Millet	19.17 ± 0.44-33.30 ± 1.09	25.89 ± 0.84
Groundnuts	27.93 ± 0.89-37.84 ± 0.92	32.75 ± 0.66
Cowpea	24.52 ± 0.56-52.84 ± 0.76	40.34 ± 1.32

Note: Tabulated values are means ± SD of 3 determinations
*n=9 sampling areas
[a]Statistically significant, $p<0.05$
Table 1: Zinc content of staple grains grown in various parts of Kanam LGA where the under-5 year's children were surveyed.

Sample S/No.	Zinc content (mg/L)
1	2.017 ± 0.260
2	1.991 ± 0.020
3	1.928 ± 0.072
4	1.945 ± 0.073
5	1.995 ± 0.003
6	1.921 ± 0.060
7	4.640 ± 3.10
8	4.940 ± 0.103
9	4.791 ± 0.269

Note: *Tabulated data are means ± S.D. of three determinations per sample

Table 2: Zinc content of domestic water sources (hand-dug wells) from different parts of the study area.

Grains	Phytate content (mg/g) Range*	LGA Mean
White Maize	4.22 ± 0.87 – 6.01 ± 0.35	5.40 ± 1.02
yellow Maize	4.86 ± 0.24 – 5.23 ± 0.71	4.99 ± 0.21
White Sorghum	2.16 ± 0.98 – 5.48 ± 1.56	3.98 ± 1.68
Red Sorghum	2.90 ± 0.22 – 4.83 ± 0.50	3.80 ± 0.97
Millet	3.72 ± 1.02 – 5.05 ± 0.37	4.48 ± 0.69
Groundnuts	24.74 ± 2.17 – 30.26 ± 2.87	26.72 ± 3.07
Cowpea	1.45 ± 0.13 – 2.11 ± 0.46	1.80 ± 0.31

Note: Tabulated values are means ± SD of 3 determinations

* n = 9 sampling areas
Table 3: Phytate content of grains grown in farmlands in the study areas.

Table 4 summarizes the stoichiometric relationship between the zinc content and phytate content values of the staple grains, expressed as phytate:zinc molar ratio, an index of zinc bioavailability. For each grain, there are variations in the phytate:zinc ratio values among samples.

Discussion

There is a wide variation in the zinc content of the grains and domestic waters studied. McKenzie-Parnell and Guthrie [25], in a similar research, found a sevenfold variation in zinc content among cereal in New Zealand. Among the staple grains of the area studied, cowpea appears to be the richest source of dietary zinc (based on zinc content values) followed by groundnut while yellow maize and red sorghum are the poorest, in that order. The values of phytate/zinc molar ratio are generally higher than the FAO/WHO cut-off for positive zinc bioavailability except in the case of cowpea. According to World Health Organization [26], diets with phytate/zinc molar ratio over 15 are low bioavailable diets with zinc absorption of 15%. Diets with phytate/zinc molar ratio between 5 and 15 are of moderate bioavailability with 30% of zinc absorption. Diets with molar ratio under 5 are of high zinc absorption level (50%). The latter are refined diets with low amounts of fibres with animal proteins as a main source of energy [26]. In 2007, Ma et al. [27] reported that, in China, phytate/mineral ratios of rural residents were generally higher than that of their urban counterparts. Our study is rural-based and also consistent their report. Both in terms of phytate:zinc molar ratio of the individual field samples and LGA mean, cowpea has the least ratio value, which falls below zinc bioavailability cut-off point of 10, thus suggesting that cowpea zinc source is the most bioavailable of these staple grains.

Several studies have reported that that zinc intake is related to serum/plasma zinc concentrations [28] and hence the zinc status in children [19]. Moran et al. [28], further observed that although suboptimal zinc status may be caused by inadequate dietary intake of zinc in some cases, inhibitors of zinc absorption are likely the most common causative factor, and recent evidence in adults suggests that the inhibitory effect of dietary factors such as phytate on zinc absorption is likely to be much greater than previously recognized [29].

Overall, 55.56% of the water samples analyses had zinc content below 5.0 mg/l, while 33.33% had zinc content close to 5.0 mg/l, the WHO Interim Standard for Drinking-Water Quality [30]. In natural surface waters, the concentration of zinc is usually below 10 µg/litre, and in ground waters, 10-40 µg/litre [31]. Based on a 1981 national survey of trace metals in drinking water supplies, it was estimated that the average daily intake of zinc from drinking water for Canadian adults is ≤ 13.0 µg/day [32]. In a 1984 study, this value ranged from 33.8 to 97.5 µg/day and was found to be highly dependent on the sampling strategy [33]. Although drinking-water makes a negligible contribution

Grain	Phytate Content (Mole)	Zinc Conc. (Mole)	Phytate:Zinc Molar Ratio (x:1)
White Maize	0.008177	0.000373	21.93
Yellow Maize	0.007566	0.000342	22.14
White Sorghum	0.006035	0.000379	15.92
Red Sorghum	0.005753	0.000364	15.79
Millet	0.006788	0.000396	17.15
Groundnut	0.040485	0.000501	80.85
Cowpea	0.002727	0.000617	4.42

Note: Tabulated values are means of values for 9 sampling areas for each crop.
Table 4: Phytate: zinc molar ratios of grains from farmlands in the study areas.

to zinc intake, the concentrations of zinc in well waters of the research area are 100 times higher than the usual range for underground waters. On the average, the zinc concentration of the water samples in this study is close to values reported by Kanadi and Okoye [9] of 2.0 mg/l for rainwater run-off from galvanized metal roofs

In the opinion of Hambidge et al. [34], if zinc homeostasis were 100% efficient, the quantity of zinc absorbed would coincide with the amount of ingested zinc. Unfortunately, this is not the case as phytate, the one outstanding dietary factor that impairs the bioavailability of zinc, is co-ingestion with zinc in cereal-based foodstuffs. Gibson et al. [35] reported that food preparation and processing methods can reduce the phytate content of cereal- and/or legume-based complementary foods in the household which include soaking, germination, fermentation, and pounding. This processing method was recently concurred by Annor et al. [36] in Ghana that Maize and millet that went through the processes of soaking in water, milling and fermentation, before finally used in the preparation/cooking of *kenkey* and *hausa kooko* respectively had low levels of phytate in these foods.

Conclusion

The results of this investigation revealed a high zinc content in the staple foods analyzed, which could be sufficient to prevent dietary zinc deficiency among the population studied. But high phytate, expressed in terms of phytate/zinc molar ratio, in these grains (except in cowpea) would inhibit the availability of zinc to the system. The concentrations of zinc in the well waters studied are higher in samples from the southern part of the area than in the northern part. On the average, the zinc content of these water samples is several folds higher than is commonly obtained in underground waters. Because the bioavailability of zinc in the staple foodstuffs is rendered unavailable by the presence of high phytate content, domestic water alone will not be able to meet up the RDA for this population. Thus, the population studied may be at the risk of zinc deficiency.

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Author Contributions

KHJ conceived and designed the research. ZSCO and BJS oversaw the implementation and analytical strategy of the study. KHJ analyzed the data with statistical support from the Computer Centre of the University of Jos, Nigeria, and wrote the draft paper. KHJ had primary responsibility for the final content. All authors read and approved the final manuscript.

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