Sources, Bioavailability And Adequacy of Zinc Intake Among Rural-Resident Men In Malawi

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Research

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Abstract

Background: Zinc deficiency (ZnD), measured using serum zinc (Zn) prevails in 66% of 20–54 year-old men in Malawi, and is higher than that of other demographic groups. We conducted this study to identify local plant and animal sources of Zn; to determine the frequency of intake of Zn-rich foods; and, to assess the bioavailability of Zn in the food sources.

Methods: We employed a descriptive cross-sectional study of 20–54 year-old men (n=101) who are residents of a rural area of Lilongwe district in central Malawi. Dietary assessment was done using a food frequency questionnaire and 24-hour dietary recall. Dietary adequacy was assessed using modified NutriSurvey 2007. Zinc bioavailability was estimated using Murphy's model of algorithm based on FAO/WHO Zn bioavailability factors.

Results: Only 20.3% of the participants were knowledgeable of Zn, and mostly cited rice, cassava, sweet potato, milk and fish as sources of Zn. Degermed-dehulled hard porridge (locally called *nsima*) (53.5%), small fish (30.7%), mangoes (69.3%), groundnuts (20.8%), pumpkin leaves (65.3%) and sunflower oil (24.8%) were the most frequently consumed foods. Slightly over one third (36.6%) of the participants met the recommended dietary allowance for Zn (mean intake of 14.4 ± 14 mg), but 1% consumed Zn that was bioavailable (mean 2.2 ± 2.5 mg).

Conclusion: Habitual intake of plant-based diets with poorly bioavailable Zn was widespread among men in this rural population in Malawi, which led to inadequate dietary Zn intake. Food systems-based operational research should be conducted to understand barriers and facilitators of adequate intake of bioavailable Zn in rural areas of Malawi.

Introduction

Zinc (Zn) is a trace element that is required as a cofactor by more than 100 enzymes in the body [1], where it plays catalytic [2], structural [3] and regulatory roles [4], in addition to antioxidant and anti-inflammatory effects in many organisms [5]. It is important to maintain adequate Zn in the body because Zn deficiency (ZnD) is associated with malfunction of the body, and is a factor in the risk of chronic diseases such as diabetes, cardiovascular, and liver diseases [6]. ZnD can be as a result of dietary inadequacies [7], diseases like diarrhoea that lead to excessive losses or impaired utilization [8], and physiological needs that increase Zn requirements in the body [9]. Dietary intake of Zn is affected by the amount of Zn available for absorption. Phytic acid, which is the storage form of phosphorus in plants, has an inhibitory effect on Zn absorption, hence it is a major factor in determining bioavailability of Zn from plant sources [10].

It has been estimated that 17.3% of the world's population has inadequate Zn intake, more so in Africa (23.9%) [11], with deficiency risk estimated at 40% [12]. Malawi is a Zn deficient country, where prevalence (measured using serum Zn concentration) ranges from 60% in children under the age of 5 years, to 66% in 20–54 year-old men [13]. Previous localised studies had already shown that ZnD was likely to be widespread in Malawi [14, 15, 16]. Owing to the consequences of ZnD such as impaired growth and development, susceptibility to diarrheal and respiratory infections [8], and some chronic diseases [17] including elements of the metabolic syndrome [18], public health nutrition has interest to improve population Zn status. Therefore, we undertook this localized study in a rural area in central Malawi, to get insights into men's dietary practices that may contribute to their vulnerability to high prevalence of ZnD. Specifically, we aimed to identify local plant and animal sources of Zn; determine frequency of intake of Zn-rich foods; and, assess bioavailability of Zn from the food sources.

Methods

2.1 Study design

We designed a descriptive cross-sectional study to recruit 101 men aged 20–54 years who were residents of Traditional Authority (TA) Chiseka, a rural area of Lilongwe district in central Malawi. Specifically, we randomly selected Mkwinda Group Village Head, which is a cluster of villages under TA Chiseka. According to the 2018 Malawi Population and Housing Census, TA Chiseka had 63,045 men and women aged ≥ 20 years [19]. Sample size was calculated using an online calculator embedded in OpenEpi version 3.01 [20]. We used the population of adults of 63,045, design effect of 1, absolute precision (confidence interval) of 5%, to calculate a representative sample of 104 men, of which 101 participated, representing a response rate of 97.1%.

Mkwinda had 8 villages, out of which we randomly selected 4 villages from which the study sample was drawn. Village registers were used to draw an eligible list of men, out of whom we selected eligible participants based on the following inclusion criteria: age of 20–54 years, residence in the area for not less than 2 years, in apparent good health, and giving informed consent to participate. The study protocol was approved by the National Health Sciences Research Committee in Malawi, whose approval number was 2200. We received permission to conduct the study in the area from Traditional Authority Chiseka, while informed verbal consent was obtained from every participant. A team of six trained research assistants administered a pre-tested structured questionnaire to the participants through face-to-face interviews in each participant's own home.

2.2 Dietary assessment

A food frequency questionnaire (FFQ) was administered to the study subjects to assess their usual food intake. The FFQ consisted of 63 foods that were commonly consumed in the area containing Zn, and had a part for recording how frequently each food item was consumed. The FFQ was used to determine the frequency of dietary intake. A 24-hour recall was used to collect data on actual food intake [21]. This required respondents to recall all foods that were consumed the previous day. The type of food, the time that it was consumed, and the amount of food consumed was estimated.

2.3 Data analysis

Data were entered and analyzed using IBM SPSS Statistics version 21.0 (IBM Corporation, Armonk, New York, USA) to generate descriptive statistics (frequencies, percentages and means). We modified NutriSurvey 2007 (www.nutrisurvey.de) to include some Malawian foods that were available in the study area based on nutritive values contained in the Malawian Food Composition Table 2019 [22]). The modified NutriSurvey 2007 was used to analyze nutrient intake of individuals collected through the 24-hour dietary recall to estimate the amount of Zn consumed. We calculated estimated energy and Zn intake, whose values were extracted into Microsoft Excel 2013 (Microsoft Corporation, Santa Rosa, California, USA), and exported to IBM SPSS Statistics 21 for descriptive analysis. Bioavailability was estimated using Murphy's model of algorithm in which each diet was given a Zn availability factor according to FAO/WHO classification system, and multiplied by the amount of Zn in the diet to get an estimate of bioavailable Zn [21].

Results

3.1 Characteristics of study participants

Data were collected from 101 apparently healthy adult men aged 20–54 years. The mean age of the participants was 38 years. A majority of the participants were married (87.1%), 64.4% were farmers, 69.3% had attained up to primary school education, and 79.2% of the participants were Christians. The demographic characteristics of the study population are presented in Table 1.

Table 1: Demographic Characteristics

Demographics		n	%	Mean±SD
Age (years)		101		37.8±10.5
Marital status	Single	9	8.9	
	Married	88	87.1	
	Widowed	2	2.0	
	Separated	1	1.0	
	Polygamous marriage	1	1.0	
Occupation	Farmer	65	64.4	
	Formal employment	7	6.9	
	Vocational skills	11	10.9	
	Business	14	13.9	
	Unemployed	4	4.0	
Level of education	Primary school	70	69.3	
	Secondary school	17	16.8	
	Tertiary education	1	1	
	None	13	12.9	
Religion	Christianity	80	79.2	
	African	10	9.9	
	Muslim	7	6.9	
	None	4	4	

3.2 Knowledge of Zn

Only 20.3% of the respondents had ever heard of Zn, with only 11.9 % knowing the dietary sources. When probed more to mention the sources of Zn they knew, most of them (70%) were able to mention plants but could not be specific on which plants contain Zn. Some (20%) were able to mention the plant sources like rice, cassava and sweet potato. Few of them (10%) mentioned animal sources like milk and fish. However, none of the respondents mentioned both the plant and animal sources of Zn. To some respondents their knowledge of Zn was referred to a metal as they mentioned metal as a source of Zn. It was observed that amongst the 20.3% of the participants who ever heard of Zn, only 17.8% knew about the benefits of Zn to their bodies and 10.9% knew about the consequences that may arise due to ZnD.

3.3 Frequency of intake of Zn rich foods

Some foods were consumed frequently due to seasonal availability for example, mango fruits and pumpkin leaves. It was evident that hard porridge (*nsima*) made from dehulled-degermed maize flour commonly known as *gramil* (53.5%) was the most consumed staple among the participants, with sweet potato being the least consumed staple (66.3% of the participants did not consume sweet potato in a month). Whole grain maize flour was also consumed daily by 36.6% of the participants, while rice was consumed at least once per week by 25.7% of the participants.

Small fish (30.7%) were the most frequently consumed animal source food whilst insects were the least consumed since 75.2% of the respondents reported of never having eaten any in the past month. Only 28.7% of the respondents reported consuming beef once in a month. In addition, poultry was consumed once a week by 21.8% of the participants. In terms of legumes, groundnuts (20.8%) was the most frequently consumed legume, whereas 85.1% of the respondents reported of not consuming any chick peas in the past month. Beans (26.7%) were consumed often at 4-6times a week. Results also revealed that 93.1% of the participants used tomato in their daily meal and pumpkin leaves (65.3%) being the most frequently

consumed vegetable and carrots the least consumed vegetable, with 65.3% of the participant reporting that they had never consumed it in a month. Cabbage was highly consumed at 4–6 times a week (22.8%).

A bigger proportion of the participants consumed mangoes daily (69.3%) and apple was the least consumed fruit (15.3%). Fruit consumption among the participants was generally low. Only 24.8% of the participants used cooking oil made from sunflower every day. Groundnut flour was reported to be consumed 4–6 times a week by 29.7% of the respondents. The results for the consumption of foods containing Zn are shown in Table 2.

Table 2
Frequency of consuming Zn-containing foods

Food type	Food Frequency															
	Daily		2–3 times/week		4–6 times/week		Once/week		Once/3weeks		Once/month		2–3 times/month		Rarely/never	
	N	%	N	%	N	%	n	%	n	%	N	%	n	%	n	%
Staples	37	36.6	14	13.9	7	6.9	9	8.9	2	2.0	6	5.9	0	0	26	25.7
Whole grain maize flour																
Dehulled-degermed maize flour	54	53.5	12	11.9	5	5.0	6	5.9	1	1.0	6	5.9	1	1.0	16	15.8
Fermented refined maize flour	10	9.9	2	2.0	5	5.0	10	9.9	7	6.9	15	14.9	1	1.0	51	50.5
Roasted Maize	17	16.8	27	26.7	6	5.9	17	16.8	4	4.0	11	10.9	3	3.0	16	15.8
Boiled maize	13	12.9	31	30.7	8	7.9	14	13.9	7	6.9	10	9.9	3	3.0	15	14.9
Rice	2	2.0	21	20.8	5	5.0	26	25.7	8	7.9	24	23.8	2	2.0	13	12.9
Bread	15	14.9	18	17.8	13	12.9	11	10.9	4	4.0	11	10.9	3	3.0	26	25.7
African cake	15	14.9	11	10.9	3	3.0	11	10.9	3	3.0	10	9.9	3	3.0	45	44.6
Doughnuts	25	24.	27	26.7	11	10.9	16	15.8	1	1.0	5	5.0	3	3.0	13	12.9
Banana flitters	13	12.9	29	28.7	14	13.9	9	8.9	5	5.0	6	5.9	3	3.0	22	21.8
Raw cassava	19	18.8	27	26.7	14	13.9	14	13.9	2	2.0	7	6.9	4	4.0	14	13.9
Boiled cassava	13	12.9	24	23.8	11	10.9	18	17.8	6	5.9	10	9.9	1	1.0	18	17.8
Roasted	8	7.9	11	10.9	3	3.0	10	9.9	2	2.0	3	3.0	0	0	64	63.4
Boiled-Irish potato	1	1.0	14	13.9	9	8.9	11	10.9	2	2.0	13	12.9	1	1.0	50	48.5
Chips	18	17.8	27	26.7	10	9.9	17	16.8	4	4.0	10	9.9	4	4.0	11	10.9
Boiled sweet potato	5	5.0	13	12.9	7	6.9	9	8.9	2	2.0	8	7.9	1	1.0	56	55.4
Roasted sweet potato	1	1.0	9	8.9	8	7.9	7	6.9	1	1.0	7	6.9	1	1.0	67	66.3
Sweet beer	22	21.8	28	27.7	11	10.9	14	13.9	4	4.0	6	5.9	5	5.0	11	10.9
Animal sources																
Beef	0	0	2	2.0	0	0	11	10.9	1	1.0	29	28.7	1	1.0	57	56.4
Goat meat	3	3.0	20	19.8	3	3.0	16	15.8	7	6.9	23	22.8	1	1.0	39	38.6
Pork	4	4.0	22	21.8	6	5.9	17	16.8	5	5.0	7	6.9	1	1.0	39	38.6
Poultry	10	9.9	18	17.8	12	11.9	22	21.8	5	5.0	15	14.9	7	6.9	12	11.9
Tilapia	1	1.0	9	8.9	4	4.0	3	3.0	4	4.0	20	19.8	0	0	60	59.4
Copadichromis inornatus	5	5.0	31	30.7	11	10.9	11	10.9	4	4.0	10	9.9	4	4.0	25	24.5
Catfish	1	1.0	1	1.0	6	5.9	4	4.0	4	4.0	17	16.8	0	0	68	67.3
Lake sardine	13	12.9	41	40.6	15	14.9	11	10.9	3	3.0	5	5.0	0	0	13	12.9
Small fish	31	30.7	27	26.7	19	18.8	8	7.9	2	2.0	2	2.0	0	0	9	8.9
Rhamphochromis esox	1	1.0	10	9.9	8	7.9	15	14.9	9	8.9	14	13.9	1	1.0	43	42.6
Barbus paludinosus	3	3.0	18	17.8	9	8.9	19	18.8	12	11.9	9	8.9	2	2.0	29	28.7

Food type	Food Frequency																
	Daily		2–3 times/week		4–6 times/week		Once/week		Once/3weeks		Once/month		2–3 times/month		Rarely/never		
Milk	12	11.9	6	5.9	12	11.9	19	18.8	8	7.9	13	12.9	0	0	31	30.7	
Eggs	8	7.9	17	16.8	19	18.8	13	12.9	5	5.0	12	11.9	5	5.0	22	21.8	
Liver	1	1.0	5	5.0	4	4.0	7	6.9	6	5.9	11	10.9	1	1.0	66	65.3	
Insects	2	2.0	5	5.0	2	2.0	3	3.0	5	5.0	8	7.9	0	0	76	75.2	
Fruits																	
Pineapple	0	0	2	2.0	3	3.0	5	5.0	0	0	14	13.9	1	1.0	73	72.3	
Loquat	4	4.0	0	0	5	5.0	7	6.9	3	3.0	10	9.9	0	0	72	71.3	
Mango	70	69.3	18	17.8	10	9.9	2	2.0	0	0	0	0	0	0	1	1.0	
Paw paw	2	2.0	10	9.9	11	10.9	6	5.9	7	6.9	11	10.9	2	2.0	52	51.5	
Apple	0	0	0	0	3	3.0	3	3.0	1	1.0	9	8.9	0	0	85	84.2	
Baobab	0	0	1	1.0	7	6.9	5	5.0	2	2.0	9	8.9	1	1.0	76	75.2	
Vegetables																	
Cabbage	7	6.9	5	5.0	23	22.8	13	12.9	10	9.9	20	19.8	5	5.0	18	17.8	
Carrots	0	0	1	1.0	9	8.9	6	5.9	3	3.0	14	13.9	2	2.0	66	65.3	
Cassava leaves	17	16.8	7	6.9	10	9.9	14	13.9	4	4.0	11	10.9	2	2.0	35	34.7	
Green beans	3	3.0	12	11.9	16	15.8	12	11.9	4	4.0	10	9.9	0	0	42	41.2	
Okra	17	16.8	14	13.9	15	14.9	19	18.8	4	4.0	5	5.0	1	1.0	26	25.7	
Black jack	15	14.9	21	20.8	26	25.7	19	18.8	4	4.0	6	5.9	4	4.0	6	5.9	
Amaranth	17	16.8	29	28.7	23	22.8	13	12.9	2	2.0	9	8.9	2	2.0	6	5.9	
Chinese	17	16.8	20	19.8	20	19.8	14	13.9	7	6.9	5	5.0	2	2.0	16	15.8	
Tomato	94	93.1	5	5.0	2	2.0	0	0	0	0	0	0	0	0	0	0	
Cat’s whiskers leaves	19	18.8	8	7.9	13	12.9	4	4.0	2	2.0	10	9.9	0	0	45	44.6	
Jewsmallowleaves	20	19.8	21	20.8	25	24.8	10	9.9	3	3.0	4	4.0	2	2.0	16	15.8	
Pumpkin leaves	66	65.3	18	17.8	15	14.9	2	2.0	0	0	0	0	0	0	0	0	
Rape	6	5.9	18	17.8	27	26.7	16	15.8	4	4.0	8	7.9	0	0	22	21.8	
Roselle leaves	15	14.9	7	6.9	17	16.8	8	7.9	10	9.9	12	11.9	1	1.0	31	30.7	
Legumes																	
Beans	5	5.0	23	22.8	27	26.7	19	18.8	4	4.0	9	8.9	2	2.0	12	11.9	
Cowpeas	2	2.0	13	12.9	22	21.8	13	12.9	3	3.0	23	22.8	1	1.0	12	11.9	
Pigeon pea	1	1.0	4	4.0	8	7.9	8	7.9	3	3.0	23	22.8	1	1.0	24	23.8	
Bambara nuts	0	0	2	2.0	11	10.9	6	5.9	6	5.9	17	16.8	0	0	59	58.4	
Groundnuts	21	20.8	23	22.8	22	21.8	12	11.9	4	4.0	5	5.0	1	1.0	13	12.9	
Soy beans	15	14.9	21	20.8	14	13.9	13	12.9	6	5.9	8	7.9	1	1.0	23	22.8	
Chick pea	0	0	2	2.0	2	2.0	1	1.0	4	4.0	6	5.9	0	0	86	85.1	
Fats and oils																	
G/nut flour	14	13.9	25	24.8	30	29.7	15	14.9	5	5.0	1	1.0	5	5.0	6	5.9	
Sunflower	25	24.8	16	15.8	13	12.9	10	9.9	5	5.0	3	3.0	0	0	3	3.0	

Food type	Food Frequency															
	Daily		2–3 times/week		4–6 times/week		Once/week		Once/3weeks		Once/month		2–3 times/month		Rarely/never	
Seeds																
Pumpkin seed	10	9.9	5	5.0	8	7.9	2	2.0	2	2.0	11	10.9	0	0	63	62.4
Sesame	0	0	0	0	2	2.0	3	3.0	2	2.0	3	3.0	0	0	91	90.1

3.4 Energy, iron and zinc intake

Mean energy intake of the participants was 1470 ± 706 kcal, which fell below the estimated energy requirement of 2200 kcal/day for males. Only 14.85% of the participants met the daily energy requirement. The mean iron intake of the participants was 22.7 mg, which is almost three times higher than the recommended dietary requirements of 8 mg/day in men. 60.3% of the participants met their Recommended Dietary Allowance (RDA) for iron. The mean Zn intake was 14.4 ± 14.1 mg, which was above the recommended dietary allowance of 11 mg for adult men. Only 36.6% of the participants met their RDA for Zn but < 1% had Zn which was available to the body with mean 2.2 ± 2.6 mg. It revealed that only 11.8% of the diets had Zn which was highly bioavailable, while 41.2% had moderately bioavailable Zn and 46.5% had low Zn bioavailability. Low Zn bioavailability diets are those that have a phytate: Zn molar ratio above 15, in which only 15% of the Zn is absorbed, moderate bioavailable Zn diets are those with phytate: Zn molar ratio of 5–15 and about 30% of Zn is absorbed and high Zn bioavailability diet are those with phytate: Zn molar ratio of < 5 and 50% of Zn is absorbed.

Discussion

4.1 Zinc intake

Evidence shows that a majority of the participants (53.5%) ate dehulled-degermed maize flour as their main staple food in which a certain amount of phytic acid (PA) is removed, which improves bioavailability of Zn. The removal of maize bran reduces the amount of phytic acid to 526.5mg/100g from 743mg/100g of whole grain maize flour [23]. This method removes a certain amount of PA but the best probable method of improving bioavailability of Zn in maize flour is through soaking, which reduces PA levels to 161.5mg/100g in maize flour which has been soaked for three days. However, the consumption of dehulled-degermed maize flour could not improve the uptake of Zn as compared to whole grain maize flour, rice and wheat flour because some Zn is lost during processing. Zn from animal source foods is found in credible amounts and readily available for the body, some of the participants (30.7%) consumed fish in their daily meals and 19.8% consumed goat meat at least 2 to 3 times in a week. This showed that a lot of people did not consume meat frequently and their diets were more plant-based, which indicates consumption of more PA, thereby reducing the amount of Zn absorbed. Rural diets in developing countries including Malawi are predominantly plant-based; consumption of animal-protein foods such as meat, poultry and fish is often small because of economic, cultural and/or religious constraints [21]. As a result, the amount of Zn available for absorption from such diets is low, and is probably the primary cause of ZnD.

4.2 Bioavailability of Zn

Dietary components of the food are known to modify the bioavailability of Zn, some enhance absorption and others inhibit absorption [21]. Organic acids such as lactic and citric acids may enhance the absorption of Zn, while PA and calcium (Ca) inhibit the absorption of Zn. However, the amount of Ca in most plant-based diet is too low to have an inhibitory effect on Zn [9]. A consideration between intake and absorption is important, because although some intakes of Zn may be acceptable, the level of phytate inhibition in the diet may mean inadequate amounts of Zn is absorbed. The risk of ZnD was estimated to be at 40% in African countries despite having a mean supply of 12.9 mg/capita/day which was above the RDA [12]. Cereals, nuts and legumes contributed a high amount of Zn consumption to the populations. However, the risk of ZnD in a normal mean supply population meant that, the amount that was absorbed in the intestines was probably reduced from what was consumed. It is also evident from the study that the amount of Zn that was ingested from the foods was not available for absorption, which may contribute to the high prevalence of Zn deficiency among adult men. Even though the amount of iron seems to be high, it is also likely that little was absorbed because Zn and iron may be affected by many of the same dietary factors including phytate [24]. Consumption of food with high phytic acid is associated with low absorption of Zn [25]. A study showed that consumption of low phytic acid maize contributed to an increased absorption of Zn as compared to local polenta maize which had phytic acid: Zn ratio of 36:1. Even though the PA: Zn ratio was 17:1 which is above 15, there was an improvement in the absorption of Zn in low PA maize.

Conclusions

The most frequently consumed Zn-containing foods among men in this rural central Malawian population were degermed-dehulled maize thick porridge, pumpkin leaves, groundnuts, mango and fish. Slightly over one third of the participants met the recommended dietary allowance for Zn, but 1% consumed Zn that was bioavailable. Adding to the pool of knowledge which has consistently shown that habitual intake of plant-based

diets with poorly bioavailable Zn leads to inadequate dietary Zn, our study has demonstrated that in addition to children, rural resident adult Malawian men are equally affected. Food systems-based operational research should be conducted to understand barriers and facilitators of adequate intake of bioavailable Zn in rural areas of Malawi.

Declarations

Ethical approval and consent

Ethical approval was granted by the National Health Sciences Research Committee (NHSRC) with an approval number 2200. Verbal and written informed consent were obtained from the authorities (T/A Chiseka and SGV Mkwinda) and participants also gave written and verbal informed consent prior to interviews. Participation in the study was voluntary and participants were allowed to withdraw at any time of the study.

Publication consent

Verbal and written consent for publication from participants was obtained during data collection.

Availability of data materials

The datasets used and/or analysed during this study are available from the corresponding author on reasonable request.

Competing interest

The authors declare no competing interest.

Authors contribution

AAK conceived the study. AAK and LP designed the study. LP collected, entered and analysed the data and drafted the manuscript. AAK revised the manuscript for intellectual content. AAK and LP gave final approval of the published version. Both authors take responsibility for appropriate portions of the content.

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LP was an undergraduate student in department of Human Nutrition and Health, Faculty of Food and Human Sciences at LUANAR. AAK is the head of department of Human Nutrition and Health, Faculty of Food and Human Sciences

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