Bioaccumulation of zinc in crops and its contribution to Zn intake by Cuban population

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Abstract
Zinc content and Zn bioaccumulation in crops (rice and some vegetables and condiments) cultivated in 18 Cuban urban and suburban areas are reported. Zinc content in food and the corresponding farming soil samples was determined by X-ray fluorescence analysis and by atomic absorption spectrometry. The quality of the analysis was verified using the Certified Reference Materials IAEA 393 «Algae», MA-B-3/TM «Fish Tissue Lyophilised», IAEA V-10 «Hay» and IAEA Soil-7. The obtained results show rice, of the studied crops, as the major Zn bioaccumulator and important Zn source in Cuban human diet.

Key words: *Cuba, diet, biological accumulation, soils, crops, X-ray fluorescence analysis, absorption spectroscopy*

Bioacumulación de zinc en cultivos y su contribución a la ingestión de Zn por la población cubana

Resumen
Se reportan los contenidos de zinc y su bioacumulación en cultivos (arroz, vegetales y condimentos) procedentes de 18 áreas de agricultura urbana y suburbana. El contenido de zinc en los alimentos, así como en sus correspondientes suelos de cultivo, fue determinado por fluorescencia de rayos X y por espectrometría de absorción atómica. La calidad del estudio se verificó mediante el análisis de los Materiales de Re-ferencia Certificados IAEA 393 «Algae», MA-B-3/TM «*Fish Tissue Lyophilised*», IAEA V-10 «Hay» e IAEA *Soil*-7. Los resultados mostraron al arroz, de los cultivos estudiados, como el cultivo de mayor bioacumulación de zinc y como fuente importante de Zn en la dieta de nuestra población.

Palabras clave: *Cuba, dieta, acumulación biológica, suelos, cosechas, análisis por fluorescencia de rayos X, espectroscopia de absorción*

Introduction

Trace elements play an important role in human nutrition and health, and hundreds of millions of people around the world suffer the consequences of trace ele-ment deficiencies [1]. Among those, zinc is an essential microelement, which people solely ingest from their diet. The World Hearth Organiza-tion (WHO) recommends a daily optimal intake for adults of 12-15 mg of zinc [1]. Zinc influences cell division, growth and development as well as sexual maturation. It is also a membrane stabilizer and essential for the integrity of the immune system [2]. Moreover, zinc is required by more than 100 enzymes as cofactor, and it seems to help in the proper storage and release of insulin, growth and re-pair of tissues, the ability to taste food, mineralization of bone, blood clotting, the function of vitamin A and the functions of the thyroid hormones [3]. Inadequate zinc nutrition is becoming a considerable public health problem nowadays, with the WHO lastly highlighting zinc deficiency as one of the 10 major factors contributing to the burden of disease in developing countries [4].

Rice is the main garniture in Cuban diet, with population consuming (in average) around 200 grams per day. However, urban and suburban agriculture in Cuba have accomplished a considerable increment in the ingestion of fresh vegetables (tomato, lettuce, cabbage, cucumber, gumbo, etc.) in the last decades [5]. Furthermore, garlic, onion, red pepper and parsley are quite popular condiments in Cuban cuisine. The present study summarizes zinc content determination in regular consumption foodstuff (rice, some vegetables, fruits and condiments) and its corresponding farming soils using nuclear and related techniques in order to determinate its contribution to the net Zn intake within the Cuban population´s diet.

Materials and methods

The edible parts of different crops (rice, vegetables, fruits and roots samples) and its corresponding farming soils were collected in 18 urban and suburban agricultural areas from La Habana, Matanzas and Cienfuegos cities. Composite samples, consisting on four subsamples, were collected at each site (approximately 5 x 5 m). Zinc concentrations in soils were estimated by X-ray fluorescence analysis (XRF) using Certified Reference Materials (CRM) as standards, a ^{238}Pu (1.1 GBq) excitation source with ring geometry and a Canberra Si(Li) detector-based XRF spectrometer at Nuclear Analytical Lab at InSTEC (150 eV energy resolution at 5.9 keV, Be window thickness = 12.0 μm) coupled to a MCA, following the methodology described in [6]. On the other hand, the zinc content in rice samples was determined by XRF using set of Zn-doped cellulose samples for calibration [7], while Zn contents in the rest of the crops was determined by AAS (Buck Scientific 210 VGP) according to the procedure established and validated in the Environmental Analytical Lab at InSTEC [8] (PNO09 2007).

The accuracy was evaluated using the SR criterion, proposed by McFarrell [9]:

$$SR = \frac{|C_X - C_W| + 2\sigma}{C_W}.100\ \%$$

where C_X –experimental value, C_W –certified value and σ is the standard deviation of C_X. On the basis of this criterion, the similarity between the certified value and the analytical data obtained by the proposed methods is divided into three categories: SR ≤ 25% = excellent; 25 < SR ≤ 50% = acceptable, SR > 50% = unacceptable. The analysis of five replica of the CRMs IAEA 393 «Algae», MA-B-3/TM «Fish Tissue Lyophilised», IAEA V-10 «Hay» and IAEA Soil-7 is presented in Table 1. Both, XRF and AAS methodologies, show "excellent" (SR ≤ 25%) results and a very good correlation (R = 0.999) between the certified and measured values.

In order to estimate the rate at which Zn appears in the selected specie and associated soil, the biotasoil bioaccumulations factors (BFs) were calculated in the studied samples according to the formula [10]:

$$BF\ (\text{in }\%) = 100.\frac{C_{CROP}}{C_{SOIL}}$$

where C_{CROP} and C_{SOIL} are the mean concentrations of Zn in the food sample and its corresponding soil, respectively.

Table 1. Accuracy test for zinc content* determination in CRMs

CRM	Method	Certified value	Measured value	SR (%)
IAEA 393	XRF	141	138 ± 2	4
MA-B-3/TM	XRF	109.2	114.7 ± 1.4	7
IAEA V-10	AAS	22	22 ± 1	9
IAEA Soil-7	XRF	104	104 ± 5	9

* - in mg.kg^{-1} dry weight, n = 5.

Results and Discussion

Zinc content in all studied food samples are shown in Table 2. The highest mean content and bioaccumulation values were found in the studied rice samples (35.9 mg.kg^{-1} fresh weight and 41.0%, respectively), while the lowest content was found in tomato fruits. As it is well known, rice is one of the most frequently consumed cereals worldwide, especially in developing countries. For this reason, in the last decade different studies were performed (supported by FAO) in order to solve the Zn deficiency in rice. For example, positive results were obtained by doping rice seeds with $ZnSO_4$ or using Zn doped fertilizers [11] and applying biotechnological techniques to increase the essential metal absorption by plants [12]. Cuba was part of these FAO studies evidencing the high Zn content in our cultivated rice. Thus, around the 70% of the established Zn daily intake by Cuban regulations (1 mg.kg^{-1} body weight day^{-1}) [13] is supplied by rice consumption.

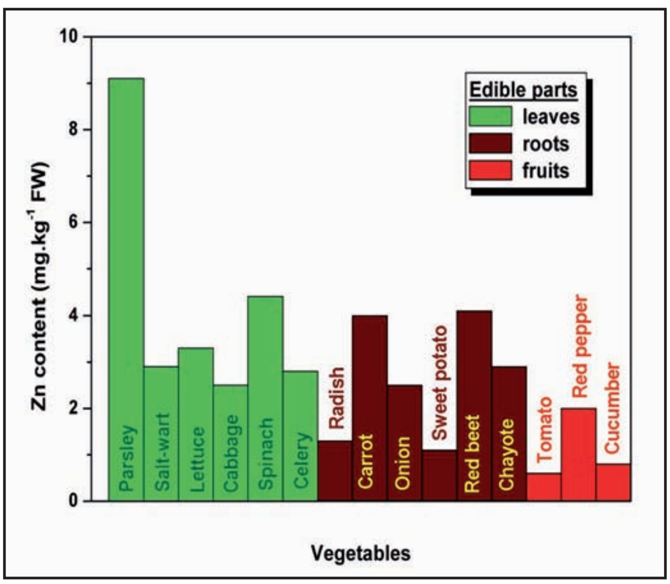
For the rest of the studied crops (vegetables and condiments), the determined Zn concentration (and the corresponding bioaccumulation) is very low when compared to rice Zn content and bioaccumulation. The concentration values are similar to those reported by other authors and, for the major part of the studied fruits and vegetables, the Zn content does not exceed its maximum allowable limit (10.0 mg kg^{-1} fresh weight) specified by Cuban regulations [13]. In the studied vegetables, on average, higher zinc content was found in those with leaves as edible parts (Figure), compared with vegetables of which edible parts are roots and fruits.

In Cuba, from the studied vegetables, only lettuce, cabbage, onions, tomato, red pepper and cucumber are frequently consumed. Assuming an average daily consumption (in one month) of rice – 200 g, vegetables whose edible parts are leaves – 100 g, vegetables whose edible parts are roots – 100 g and vegetables whose edible parts are fruits – 100 g, the Daily Dietary Intakes (DDI) of Zn in Cuba would be around 8.8 mg per day. This value is similar to the recommended medium level for

Table 2. Zinc content in Cuban (C_{CROP}) and worldwide reported (C_{REP}) crops, in its corresponding soils (C_{SOIL}) and Bioaccumulation Factors (n – number of studied sites)

Crop	n	C_{CROP} (a)	C_{REP}	C_{SOIL} (b)	BF (%)
Rice	5	35.9 ± 1.8	37.9 [10]	87 ± 10	41.2
Lettuce	10	3.3 ±1.7	11.7 [14] 5.1 [15]	145 ± 73	2.3
Tomato	9	0.6 ± 0.3	1.4 [14] 0.7 [16] 0.9 [17]	145 ± 81	0.4
Radish	5	1.3 ± 0.3	3.2 [18]	150 ± 130	0.9
Salt-wort	6	2.9 ± 0.8	NA	107 ± 55	2.7
Carrot	5	4.0 ± 1.0	2.6 [14] 6.1 [16] 5.8 [18]	112 ± 22	3.6
Onion	5	2.5 ± 1.2	1.7 [14]	177 ± 63	1.4
Red pepper	5	2.0 ± 0.8	2.9 [19]	106 ± 54	1.9
Parsley	4	9.1 ± 5.3	5.0 [17] 4.9 [20]	95 ± 55	9.6
Sweet potato	4	1.1 ± 0.3	1.6 [20]	65 ± 13	1.7
Cabbage	5	2.5 ± 3.5	2.2 [14] 2.2 [17] 2.0 [16]	142 ± 47	1.7
Red beet	4	4.1 ± 1.5	2.6 [16]	106 ± 8	3.9
Spinach	4	4.4 ± 2.9	7.0 [19] 5.9 [21]	124 ± 13	3.5
Garlic	4	12.6 ± 7.3	11.7 [18]	174 ± 57	7.2
Celery	4	2.8 ± 1.8	2.9 [17] 2.9 [20]	133 ± 16	2.1
Chayot	4	2.9 ± 2.3	2.5 [10]	70 ± 15	4.1
String bean	4	6.3 ± 2.3	NA	133 ± 74	4.7
Cucumber	4	0.8 ± 0.2	0.8 [16] 1.3 [17] 1.3 [20]	112 ± 13	0.7
Gumbo	5	5.5 ± 1.6	5.8 [20]	164 ± 90	3.3

(a) – Main ± SD in $mg.kg^{-1}$, fresh weight.
(b) – Main ± SD in $mg.kg^{-1}$, dry weight.
NA – non available



Comparison of average Zn content in individual groups of vegetables

Zn intake (8.7 mg per day) [1] and it is the 80% of the US Recommendable Dietary Allowances (11.0 mg per day) [22].

This seems to indicate that Cuban population would be able to meet the normative requirements if consuming diets of uniformly low zinc bioavailability. It is also apparent that dietary intake data taken alone (without consideration of the bioavailability) does not allow a reliable assessment of whether a particular population has an adequate or inadequate nutrition.

The bioavailability of zinc from different diets depends on many factors. High availability is found only in refined diets low in cereal fibre and phytic acid contents, and with adequate proteins, mainly from non-vegetable sources such as meat and fish. Therefore, Zn content in meat and fish tissues remains to be assessed by a specific study to estimate a more accurate Zn DDI of the Cuban population.

Conclusions

The combination of XRF and AAS allowed the Zn content determination in an important group of food samples, as well as its bioaccumulation and its contribution to the Daily Dietary Intake of Zn in Cuba. Higher zinc contents were found in vegetables whose edible parts are leaves. The obtained result shows rice as the main Zn bioaccumulator and major contributor to Zn DDI within the studied crops. Although a large portion of the Cuban population´s diet has been studied, analysis of additional foodstuff, such as fish and meat, still remains necessary for a complete Zn DDI report.

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