Environmental Pollution 159 (2011) 2435–2442

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Inorganic arsenic and trace elements in Ghanaian grain staples

Eureka E. Adomako [a,b,*], Paul N. Williams [c], Claire Deacon [a], Andrew A. Meharg [a,*]

[a] Institute of Biological and Environmental Sciences, University of Aberdeen, Cruickshank Building, St Machar Drive, Aberdeen AB24 3UU, UK
[b] Department of Botany, University of Ghana, P. O. Box LG 55, Legon, Accra, Ghana
[c] Lancaster Environment Centre, Lancaster University, Bailrigg, Lancaster LA1 4YQ, UK

ARTICLE INFO

Article history:
Received 15 February 2011
Received in revised form
21 June 2011
Accepted 24 June 2011

Keywords:
Inorganic arsenic
Rice
Maize
Sorghum
Millet
Ghana

ABSTRACT

A total of 549 samples of rice, maize, wheat, sorghum and millet were obtained from markets in Ghana, the EU, US and Asia. Analysis of the samples, originating from 21 countries in 5 continents, helped to establish global mean trace element concentrations in grains; thus placing the Ghanaian data within a global context. Ghanaian rice was generally low in potentially toxic elements, but high in essential nutrient elements. Arsenic concentrations in rice from US (0.22 mg/kg) and Thailand (0.15 mg/kg) were higher than in Ghanaian rice (0.11 mg/kg). Percentage inorganic arsenic content of the latter (83%) was, however, higher than for US (42%) and Thai rice (67%). Total arsenic concentration in Ghanaian maize, sorghum and millet samples (0.01 mg/kg) was an order of magnitude lower than in Ghanaian rice, indicating that a shift from rice-centric to multigrain diets could help reduce health risks posed by dietary exposure to inorganic As.

1. Introduction

Rice, maize, sorghum and millet are the four main grains produced and consumed in Ghana. While maize and sorghum contribute 59% and 20% respectively of annual grain production, rice and millet respectively contribute only 11% each (Oteng, 2005). In spite of its relatively low production level, per capita consumption of rice is second only to maize among Ghanaian grains (Bam et al., 1998; Quaye et al., 2000) and is taking over from traditional root crop staples such as yam and cassava (Asafo, 1985). In 1972, per capita rice consumption was estimated at 21 g/day/person but this increased to 36 g/day/person in 1994 and reached 55 g/day/person in 1996 (Adu-Kwarteng et al., 2003). It is generally accepted that per capita rice consumption in Ghana has increased considerably since 1996, but there is no published data on per capita consumption beyond this date. Although local rice production has increased steadily over the past few decades, the level of production is still inadequate; hence, large quantities are imported in order to meet consumer demand (Abdulai and Huffman, 2000). It is estimated that over US$100 million are spent annually on rice imports into Ghana (Bam et al., 2007). Currently, more than 60% of all rice consumed in Ghana is imported from the US and a number of Asian countries, notably Thailand.

It has been shown that in populations not suffering from elevated As in drinking water, exposure to inorganic As, a chronic exposure human carcinogen (IARC, 2004; NRC, 2001), is dominated by the intake from rice consumption (Meacher et al., 2002; Meliker et al., 2006; Tsuji et al., 2007; Williams et al., 2007a,b; Yost et al., 2004). To date, however, rice research in Ghana has focused on the production of improved varieties with better production yields. While some attention has been given to rice macro-nutrient composition for purposes of both human and animal feeding (Amissah et al., 2003; Adu-Kwarteng et al., 2003), there is little published data on the levels of potentially toxic elements (PTEs) in imported or locally produced rice from Ghana. The reports of elevated As in US-grown rice by Williams et al. (2005, 2007a,b) and elevated Cd in mine-impacted Thai rice by Simmons et al. (2003, 2005) raise an issue of potential contamination of Ghana's imported rice. On the local front, there is also a potential risk of As transfer to rice irrigated with mining-polluted surface waters (Adomako et al., 2010). This current study, therefore, set out primarily to determine the levels of As and other trace elements in locally produced Ghanaian rice and to compare these with the country's imported rice. It also reports on the trace element composition of the other grain staples in Ghana (i.e. maize, sorghum and millet) as an additional source of comparative data. The study further explores consumer preferences and other socio-economic parameters to inform calculation of the baseline rate of rice consumption by the average Ghanaian. The health risks posed by dietary exposure to As via rice consumption are also discussed.

* Corresponding authors.
E-mail addresses: eadomako@ug.edu.gh, eeadomako@yahoo.co.uk (E.E. Adomako), a.meharg@abdn.ac.uk (A.A. Meharg).

0269-7491/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envpol.2011.06.031

2. Materials and methods

2.1. Market basket surveys

Surveys were conducted in markets and supermarkets in different regions of Ghana to obtain samples of indigenous and imported grains on sale for human consumption. In order to place the Ghanaian data within the global context, market grain samples were also obtained from major conurbations in the EU, US and Asia. The market surveys yielded an extensive dataset of 549 grain samples, which comprised rice, maize, millet, wheat and sorghum originating from over 21 countries in 5 continents (see Table S1 in supplementary data for details). It must be noted that all 549 samples were whole grain; no wholemeal or white flour samples were analysed in this study.

2.2. Sample preparation and analysis

All the grain samples were analysed for total As, Cd, Co, Cu, Mn, Pb, Se and Zn concentrations. The sample preparation and analytical procedures used for total element detection are identical to those described by Adomako et al. (2009) for paddy rice samples, except that the market rice samples did not require de-husking. For determination of As speciation in a subset of the samples, 1% nitric acid was used for As extraction as described by Zhu et al. (2008) and the extracts were analysed by High Performance Liquid Chromatography (HPLC)-ICP-MS as described by Williams et al. (2005). As with the previous studies, powdered rice NIST CRM 1568a was used to monitor analytical performance for both total element detection and As speciation and percentage recoveries were within the ranges reported for earlier analyses (Adomako et al., 2009, 2010; Zhu et al., 2008). A summary of the quality control data for total element detection and As speciation is provided in the supplementary data (Table S2).

2.3. Questionnaire administration

In almost every region of Ghana where market surveys were conducted, questionnaires were also administered to determine consumer preferences and to gather data for the estimation of baseline rice consumption by the average Ghanaian. This social survey covered a total of 204 respondents representing a cross-section of the Ghanaian public (Table 1).

Table 1
Socio-economic profile of respondents to questionnaire designed to determine the extent of rice consumption in Ghana.

Demographic variable	No. of respondents	% Respondents
Gender		
Male	123.0	60.3
Female	81.0	39.7
Age		
12–20	45	22.0
21–30	75	36.8
31–40	44	21.6
Over 40	40	19.6
Region of residence		
Ashanti	14	6.9
Brong-Ahafo	23	11.3
Central	7	3.4
Eastern	20	9.8
Greater-Accra	59	28.9
Western	81	39.7
Highest level of education		
None	9	4.5
Basic school certificate	57	28.2
Secondary school certificate	53	26.2
Diploma	23	11.4
Bachelors	49	24.3
Postgraduate	11	5.4
Income status		
Unemployed	8	3.9
Student	58	28.4
Low	58	28.4
Middle	70	34.3
High	10	4.9
Source of water for domestic use		
Pipe-borne	138	67.6
Stream/River	2	1.0
Groundwater (well/borehole)	60	29.4
Combinations of the above	4	2.0
For how long has respondent eaten rice?		
<10 years	7	3.4
11–20 years	63	30.9
>20 years (since childhood)	134	65.7
Most preferred staple apart from rice		
Root crops (yam, cassava)	106	52.0
Maize	72	35.3
Plantain	20	9.8
None	6	2.9
Ranking of rice among staples		
First	87	42.6
Second	55	27.0
Third	37	18.1
Fourth	25	12.3

3. Results and discussion

3.1. Global mean concentrations of trace elements in grains

The phrase ‘global mean concentration’ is used in this paper to refer to the mean concentration obtained for all samples of a particular grain analysed for the current study. The descriptive statistics of trace element concentrations in all grain samples collected from around the globe are summarised in the supplementary data (Table S3a). One-way analysis of variance (ANOVA) performed on global trace element concentrations versus grain type showed significant differences ($P < 0.001$) in global mean concentrations of As, Cd, Co, Cu, Mn and Zn, with wheat recording the highest mean concentrations of Cu (6.05 mg/kg), Mn (37.4 mg/kg), Se (0.16 mg/kg) and Zn (23.2 mg/kg). The analysis also showed that global mean concentrations of As, Cd, Co, Cu and Mn in all rice types were significantly higher than in the maize samples (see supplementary data, Table S3b).

Global mean As concentration in white rice (0.14 mg/kg) was almost 3 times higher than in wheat (0.05 mg/kg) and 14 times higher than in maize (0.01 mg/kg). It is worth noting that the global mean As content of white rice obtained in this study agrees well with the mean of 0.15 mg/kg reported by Meharg et al. (2009). The mean Se content of all white rice samples analysed for this study (0.11 mg/kg) was also found to be comparable to the mean of 0.10 mg/kg reported by Williams et al. (2009).

3.2. Concentrations of trace elements in locally produced Ghanaian grains

The descriptive statistics of trace element concentrations in Ghana-grown rice, maize, sorghum and millet samples are provided in the supplementary data (Table S4a). One-way ANOVA performed on trace element concentrations in locally produced Ghanaian grains showed no significant differences in total As concentrations in maize, sorghum and millet samples. Mean total As concentration in Ghana-grown white rice (0.11 ± 0.02 mg/kg) was, however, 10 times higher ($P < 0.001$) than in the indigenous maize, sorghum and millet samples (0.01 mg/kg) (Table S4b). Thus, of the 4 main cereals produced and consumed in Ghana, rice was found to be the dominant source of potential dietary exposure to As. Previous studies have also shown that in non-seafood eating populations, rice is the major As exposure pathway (Meliker et al., 2006; Robberecht et al., 2002; Schoof et al., 1999) since aerobically grown cereals such as wheat and barley are much less efficient at transferring As to grain than anaerobically grown rice (Williams et al., 2007a, 2007b).

Total Cd, Co, Cu and Mn concentrations were found to be significantly higher ($P < 0.001$) in the Ghanaian rice samples than