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Prevalence of arsenic contamination in rice and the potential health risks to the Bahamian population—A preliminary study

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Rice is among the most important staple foods worldwide. However, the consumption of rice and rice-based food products poses a potential health risk since rice is a paddy crop that is well known to accumulate high concentrations of arsenic (As) in its grain. In The Bahamas, although rice is heavily consumed, it is not grown locally. Instead, all the consumed rice and its derived products are imported. Recent food surveys in the major rice exporting countries have shown that a significant portion of their market rice products is contaminated with As. However, to date, the prevalence of As in the rice foods available in The Bahamas remains unknown. Therefore, in this study, we surveyed the occurrence of As in a selection of rice and rice products that were on sale in the Bahamian market. A total of 21 different rice brands were collected. The concentration of As and the potential health risk were estimated by target hazard quotient (THQ), hazard index (HI), and lifetime cancer risk (LCR). Our results showed that only the blue ribbon samples had an estimated inorganic arsenic (iAs) concentration above the World Health Organization (WHO) safety limits (200 μg/kg), which is based on global average consumption. However, when we factor for average rice consumption in The Bahamas, 79% of the rice samples had iAs concentration values indicative of carcinogenic risks and 57% had iAs concentration values that suggested non-carcinogenic health risks. Based on our results, we recommend urgent follow-up studies to further test rice varieties that show the greatest LCR and HI values and to also broaden the study to include more off-brand/generic varieties, cooked rice, and drinking water.

KEYWORDS

food safety, arsenic, risk assessment, Bahamas, contamination

1 Introduction

Rice is one of the world's most important staple foods on the international market and supplies more than 50% of the world's caloric intake (Clemens et al., 2013; Majumder and Banik, 2019). However, rice consumption poses a major health risk since the soils on which rice is normally grown are polluted with As (Zhao et al., 2014; Zeng et al., 2015; Liu et al., 2016). As an illustration, rice have been identified as a major route of dietary exposure to carcinogens such as As (Clemens et al., 2013; Gonzalez et al., 2020). Arsenic has been shown to induce a variety of serious health effects and has been linked to various cancers in humans (Majumder and Banik, 2019; Oberoi et al., 2019; Arcella et al., 2021).

In The Bahamas, rice is the main staple food and is imported from other countries. According to the most recently available trade data, in 2018, net imports of rice to The Bahamas were 7,172,780 kg. Since rice is not grown in The Bahamas per capita consumption is assumed to be approximately 18.6 kg (WITS, 2018). According to the United States Department of Agriculture (USDA), of the nearly 505.4 million tons of rice produced in 2021, the bulk was produced in Asia, and 149.0 million tonnes came from China (Childs, 2022; Childs and LeBeau, 2022). Though the United States of America (USA) only produced a small fraction of the rice, the US was ranked as the third largest exporter of rice, exporting $1.9 billion worth of rice in 2021 alone (USDA, 2021). Recent rice surveys have shown that a significant amount of rice exceeded the WHO standard for As (Zavala et al., 2008; Meharg et al., 2009; Rowell et al., 2014; Lee et al., 2018; Dai et al., 2022). As an illustration, Meharg et al. (2009) reported that polished white rice available in the American and French markets on average had 0.25 mg/kg and 0.28 mg/kg As in their gains, respectively. Moreover, similar results were obtained in a study carried out in Jamaica where the white and brown rice samples had As concentrations ranging from 0.110 to 0.487 mg/kg and 0.082–0.250 mg/kg, respectively (Antoine et al., 2012).

These results raise a serious concern about the potential risk of dietary exposure to As, especially from the consumption of rice among the Bahamian people. This is of particular importance given that plain rice, peas/bean, and rice are ranked among the most consumed staple foods in The Bahamas. Although market rice surveys have been conducted in other jurisdictions (Jorhem et al., 2008; Food and Agriculture Organization of the United Nations, 2014; Chen et al., 2018), to the best of our knowledge, a survey of As contamination in rice available in The Bahamas has not been carried out. Therefore, the main aims of this study were to investigate the prevalence of As contamination in market rice available on the Bahamian market and to estimate the associated As health risks. Thus, in this study, we tested 42 rice varieties on the Bahamian market for As. We also calculated the As target hazard quotient (THQ), hazard index (HI), and lifetime cancer risk (LCR) values for all samples based on WHO and/or the European Food Safety Authority (EFSA) standards. The findings of this study are anticipated to serve as a preliminary assessment of potential health risks associated with consuming Bahamian market rice.

2 Methods

2.1 Measurements

2.1.1 Sample collection

Imported rice samples were collected from the major grocery stores in New Providence Island including Super Value Food Store, Quality Supermarkets, John Chea Food Store, and Extra Value. A total of 71 samples were purchased, accounting for 21 different brands and 42 varieties (Supplementary Tables S1, S2). For the purpose of this study, we refer to "variety" as a particular brand and type; therefore, Mahatma long grain and Extra long grain would be considered as two different varieties.

2.1.2 Rice sample preparation

The bag was agitated, and a 10 g of rice sample was poured out into a clean Petri dish. The rice grains were ground and digested following the technique utilized by Williams et al. (2009). Briefly, 0.5 g of rice powder sample was digested using 10 ml of a 1:1 ratio of HNO_3 and H_2O_2 in a 50-ml polypropylene digestion tube. The samples were microwave digested in a MARS 6TM Microwave Digestion System (CEM, United States). First, the samples were heated to 55°C and held for 10 min, and then the temperature was increased to 75°C for 10 min. Lastly, the samples were heated to 95°C and digested at this temperature for 30 min. The digested samples were then filtered through a 0.45-μm filter and diluted with deionized water. To determine the As speciation, 1.5 g of ground rice powder was extracted with 15 ml of 0.28 M of HNO_3 at 95°C for 90 min in 50 ml of polypropylene. Heating blocks were used to maintain the samples at 95°C for 90 min.

2.1.3 Sample analysis

The total heavy metal and As concentrations of the rice samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS, NexION 300X, Perkin Elmer, US). The As speciation (to determine percentages of inorganic and organic arsenic) was determined using ion chromatography with inductively coupled plasma mass spectrometry (IC-ICP-MS) as described in the literature (Yuan et al., 2021). Briefly, the IC used in this study was equipped with a standard 25 μL sample loop and an anion-exchange column. The As species were separated using 20 mmol L^{-1} NH_4HCO_3 at pH 10 as the mobile phase at a flow rate of 1.0 ml min^{-1}. All standard curves were prepared in neutral conditions. A rice reference (GBW€080684) purchased from the National Research Centre of China was used to determine the accuracy of the analytical method. The rice sample recoveries of total As were within the range of 95.55–105.5% (n = 5).

2.2 Risk assessment analysis

2.2.1 Estimated daily intake

The EDI of the As by rice consumption was calculated using the following equation:

$$EDI = (C \times Con \times EF \times ED) / (Bw \times AT),$$

where C is the concentration of the As (μg/g) in the rice sample, Con is the daily average consumption of rice (g/person/day), EF is the exposure frequency (365 days/year), ED is the exposure duration (70 years), Bw is the average body weight (kg person^{-1}), and AT is the average time exposure for non-carcinogens (365 days ×70) (Antoine et al., 2012; Chen et al., 2018). An average body weight of 82.0 kg (based on reported BMI values for The Bahamas) (World Bank, 2022) was assumed.

2.3 Carcinogenic risk

2.3.1 Lifetime cancer risk

The potential of developing cancer is expressed in terms of LCR. The following equation was used to estimate the LRC:

$$\text{LCR} = \text{EDI} \times \text{SF},$$

where SF is the cancer slope factor for a contaminant. This constant is proportional to the likelihood of a contaminant promoting cancer over a lifetime. It can be estimated from epidemiological studies or animal trials. In this study, the cancer slope factor used for iAs is 1.5 mg/kg per day. This value is a standard constant used in the absence of local epidemiological studies and was obtained from the Integrated Risk Information System (IRIS), which is prepared and maintained by the US Environmental Protection Agency (US Environmental Protection Agency-USEPA, 2007) (EPA, 2007). LCR values of below 1×10^{-4} are deemed acceptable according to US EPA standards (US Environmental Protection Agency-USEPA- National Center for Environmental Assessment, Office of Research and Development, 1986).

2.4 Non-carcinogenic risk

2.4.1 Target hazard quotient

The potential non-carcinogenic risks of As can be expressed as THQ, which is the ratio of EDI for As to its oral reference dose (RfD). The RfD varies for each element, and the value used for As was 0.3 μg/kg per day. The following equation was used to estimate the THQ:

$$THQ = EDI / RfD.$$

A THQ value less than one indicates that there is no significant risk of non-carcinogenic effects to the consumer. However, a THQ exceeding one indicates a potential risk of non-carcinogenic effects (US Environmental Protection Agency-USEPA- National Center for Environmental Assessment, Office of Research and Development, 1986; EPA, 2007).

2.4.2 Hazard index

The hazard index (HI) gives the cumulative effect of multiple metal/metalloid contaminants since rice grains may be contaminated with two or more contaminants; therefore, it is important to take into account the additive and/or interactive effects that may result from the exposure of two or more contaminants (Salama and Radwan, 2005; Dai et al., 2016; Brathwaite and Mohammed, 2018). However, our preliminary results indicate that the HI contribution from other metals was negligible, so we take HI to be approximately equal to THQ_{iAs}, that is:

$$HI = \sum_{n=1}^{i} THQ_n \approx THQ_{iAs} ,$$

where THQ_n is the THQ value of element n and THQ_{iAs} equals the contribution from inorganic arsenic.

2.5 Statistical analysis

Statistical analysis was performed using Excel 2022 and Origin 2017 (Origin Lab Corporation, United States). Preliminary data processing was accomplished using Excel 2022, and the figure was drawn using Origin 2017.

3 Results and discussion

The aim of this study was to measure the As concentration and to estimate the associated As health risks of consuming different rice varieties available on the Bahamian market. Our results showed a large variation in As contaminants in rice grain across the Bahamian market, ranging from 4.85 to 269.4 μg kg^{-1} with an average of 88.4 μg kg^{-1}. A similar average As concentration of 87.0 μg kg^{-1} was reported by Praveena and Omar (2017) from Malaysia. As shown in Figures 1A and B, only one of the 42 rice varieties contained an estimated iAs concentration above the WHO (200 μg/kg body weight) safety limits after accounting for the organic As portion (Supplementary Figure S1) (Meharg et al., 2009; Moe et al., 2016). It is important to note that the sample containing iAs above the permissible limit was unpolished. The elevated As in the rice grain may be due to the presence of the bran layer and

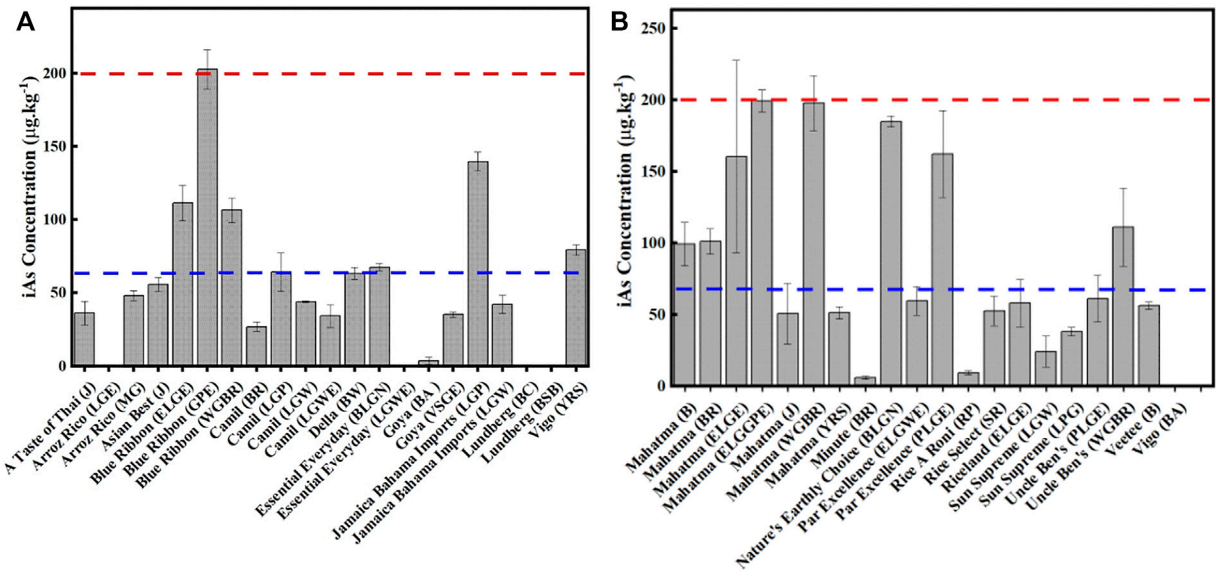

FIGURE 1
(A,B) Estimated inorganic arsenic (iAs) content in commonly found rice and rice products. The red line indicates the maximum threshold of iAs content as determined by WHO. The blue line indicates the average of the 42 rice varieties.

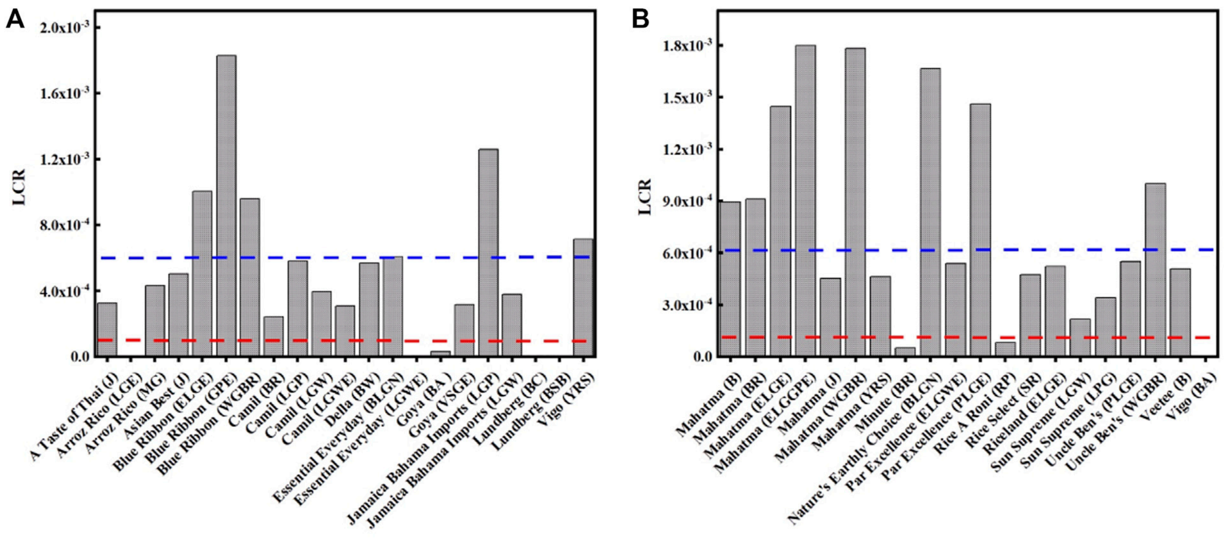

FIGURE 2
(A,B) Estimated lifetime cancer risk of various rice varieties based on a cancer slope function for iAs of 1.5 mg/kg per day. The red line denotes recommended threshold of 1.4×10^{-4}, and the blue line denotes the average value of 6×10^{-4} based on all LCR values for all 42 varieties.

cereal germ (Chen et al., 2018; Majumder and Banik, 2019). Previous studies have shown that a large portion of trace contaminants, especially As, is accumulated in the rice husk (Chen et al., 2018; Majumder and Banik, 2019). Thus, it is speculated that the unpolished rice had a higher concentration of As than the polished rice due to the presence of the husk. Although a large portion of the Mahatma rice brand (43%) contained total As above the maximum permissible limits established by WHO, it should be noted that 20–50% of the total As consisted of the non-toxic dimethylarsinic acid (DMA).

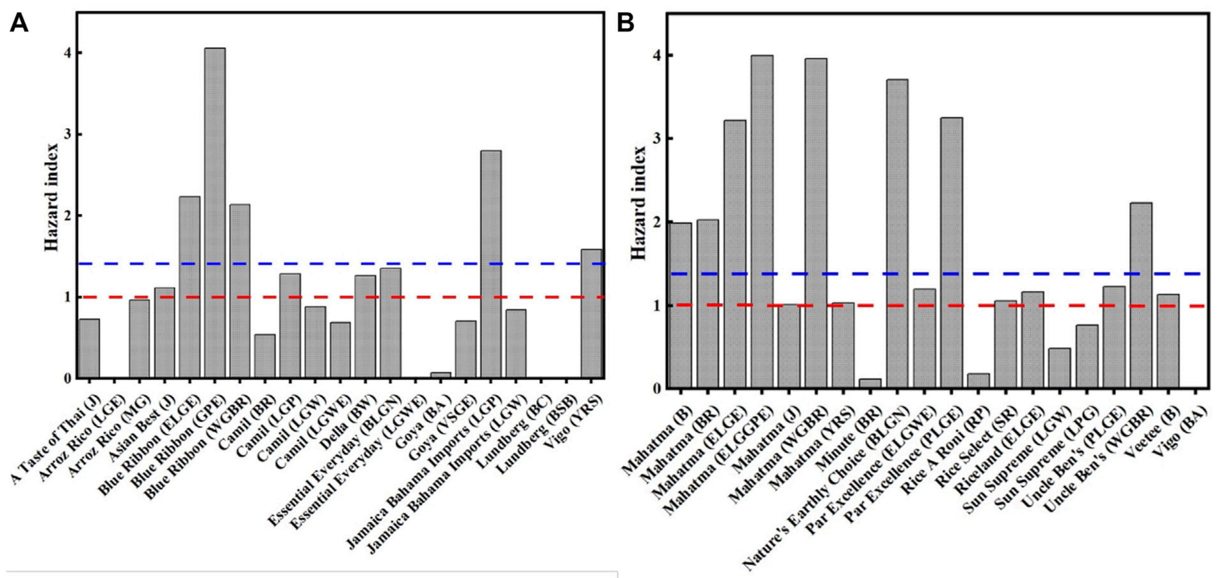

FIGURE 3
(A,B) Hazard index for all rice varieties under the assumption that HI ≈ THQ_{iAs}. The blue line indicates the average HI value of the overall 42 rice varieties. HI values above 1 indicate non-carcinogenic risks.

DMA has been reported to be less toxic to humans and is therefore not taken into consideration when estimating health risks associated with consuming rice (Moe et al., 2016). Thus, this significantly reduces the non-cancerogenic risk of consuming the Mahama rice product, since only iAs is considered when calculating such risks (Liao et al., 2018).

Rice is widely consumed in The Bahamas as one of the main staple foods, and this may pose a health risk as rice consumption is recognized as one of the main routes of human exposure to As. Therefore, increasing rice consumption will result in increased exposure and risk of As contamination to Bahamian consumers. Our preliminary results show that on average, an adult living in The Bahamas consumes 486.5 g of rice per day, which is comparable to what is consumed in China and East Asia (Qian et al., 2010; Fu et al., 2015; Dai et al., 2016; Liao et al., 2018). The EDI and THQ values for As are shown in Figures 2A and B and Figures 3A and B. Approximately 79% and 57% of the samples had carcinogenic and non-carcinogenic risk, respectively, above WHO/US EPA guidelines (Figures 2A and B and Figures 3A and B) for As. This discrepancy between iAs concentration and health risk is due to relatively high rice consumption in The Bahamas. Djahed et al. (2018) observed a similar carcinogenic risk in rice available in the city of Iranshahr, Iran market.

To be clear, in arriving at our values, we have assumed a constant iAs percentage of 75% of total As across all rice varieties. Although we have performed speciation measurements on multiple samples with iAs ranging from 40% to 97% (Supplementary Figure S1), we note the large variation in iAs speciation samples of the same brand varieties bought at different grocery stores. In two of the three cases where the same brand varieties were measured, iAs speciation percentages differed by approximately 20%. Given this, we have opted to use the constant 75% until further measurements with larger data sets can be performed. We cannot overemphasize the large uncertainties in arriving at our results and, therefore, the need to proceed with caution when interpreting these results and also the need for follow-up studies.

For example, the R*f*D, which is used to calculate non-carcinogenic risk, is an estimate with assumed uncertainties that could span an order of magnitude. Furthermore, the cancer slope factor used is subject to large uncertainties since it is based on a more than forty-year-old study of skin cancer in Taiwanese citizens (Tseng et al., 1968; Tseng, 1977). Although this value is commonly used to calculate broad carcinogenic risk, it is possible to determine better estimates for The Bahamas. However, this would require significant resources and long-term epidemiological studies. What is more achievable and useful in the short term is a national total diet study for The Bahamas.

This study is, to the best of our knowledge, the first of its kind in The Bahamas and served as a preliminary evaluation of As in various rice grains sold locally for potential health risks due to consumption. Although potential health risks were found, further studies should be conducted to corroborate these findings. It is also important to note that rice is just one source of As contaminants in staple foods. Additional studies of water and cereals are likely to reveal additional risks from those sources. Therefore, continuous monitoring and regular evaluation of the Bahamian marketed rice products, cereals, and water are recommended.

4 Conclusions and future prospects

Various brands of Bahamian marketed rice and rice products were investigated for their As content. Arsenic was determined to be the major contributor to human health risk. Our results showed that 2% of the samples had an estimated iAs concentration above the WHO (200 μg/kg) safety limits. Average As concentration values across all rice varieties suggest both carcinogenic and non-carcinogenic risks. However, these risks appear to be driven by consumption patterns rather than relatively high As contamination levels. This study is the first of its kind in The Bahamas and served as a preliminary evaluation of As in various rice grains sold locally for potential health risks due to consumption. Nonetheless, the results obtained here are subject to large uncertainties, and care should be exercised in the interpretation. Given the large incidences of obesity and cancer within The Bahamas, as well as the prevalence of rice in the Bahamian typical diet, follow-up studies would help to elucidate the role that rice, As, and other metalloids play in promoting disease and mortality in The Bahamas. In terms of immediate next action steps, we recommend the following:

1) Replicate parts of this study to focus on those varieties with the highest levels of inorganic arsenic. Similar results may justify the need for urgent action.
2) Expand the study to examine metal contaminants in cooked rice from various restaurants and eateries. This may give a more accurate representation of consumption levels of metal contaminants.
3) Conduct a survey to get a better understanding of the consumption patterns of rice and rice-based products. Rice products consumed by infants and children should be given particular attention since the effects of inorganic arsenic on infants and children have been shown to be more pronounced.
4) Expand the study to determine the effects of washing rice as well as cooking rice in a high water to rice ratio on levels of arsenic.
5) Conduct future studies on rice-based products especially those consumed by infants and children.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CW and WG contributed to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.1011785/full#supplementary-material

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