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Exposure to the global rice trade: A comparative study of arsenic and cadmium in rice consumed in Haiti

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Abstract
Rice makes up nearly a quarter of dietary intake in Haiti. Rice consumption began to rapidly increase during the mid-1980s and 1990s, corresponding to policy interventions that promoted the importation and consumption of U.S.-grown rice, soon making Haiti the second largest export market for American rice worldwide. Haitian growers also cultivate and sell local rice. Rice consumption can be a significant source of exposure to toxic metals since rice plants accumulate arsenic and cadmium from their environment. In August 2020, we collected

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samples of local (*n*=48) and imported (*n*=50) rice from vendor sites in the Lower Artibonite Valley region of Haiti. Cadmium and arsenic concentrations were measured via inductively coupled plasma mass spectrometry. Levels were compared between local versus imported commercial rice samples. For arsenic, we conducted a simulation study to estimate the intake of arsenic from varied quantities of local or imported rice samples on a per-body weight basis for adults and young children. We found that median concentrations were nearly two-fold higher for both arsenic and cadmium in imported rice (0.15 μg/g and 0.007 μg/g) compared to local rice (0.07 μg/g and 0.003 μg/g). Our simulation of arsenic intake through rice consumption suggests that adults of varying weights consuming 3 or more cups of imported rice per day would exceed a daily minimum risk level for toxicity. The simulation also suggests that most children consuming 1 or more cups of local or imported rice per day would exceed a health-based arsenic intake limit. In Haiti, imported rice had an average level of arsenic twice that of locally grown product, with some imported sources exceeding the international limits recommended to protect human health. Current consumption patterns of imported rice over the long-term for children and adults may adversely impact health in Haiti. Strengthening community food systems can promote better health.

Keywords
environmental health, metals, toxicology, public health, children's health, sustainable agriculture, food systems, Caribbean

Abbreviations

ATSDR: U.S. Agency for Toxic Substances and Disease Registry
EC: European Commission
EFSA CONTAM Panel: European Food Safety Authority Panel on Contaminants in the Food Chain
EPA: U.S. Environmental Protection Agency
FAO: Food and Agriculture Organization of the United Nations
FDA: U.S. Food and Drug Administration
IARC: World Health Organization (WHO) International Agency for Research on Cancer
IHME: Institute for Health Metrics and Evaluation
ICP-MS: Inductively coupled plasma mass spectrometry
JECFA: Joint FAO/WHO Expert Committee on Food Additives
NSF: National Sanitation Foundation International Laboratory
USAID: U.S. Agency for International Development

Introduction

Despite evidence of rice cultivation among Haiti's pre-colonial Taino populations (Denevan, 1970; Rouse, 1992), it was not until the late twentieth century that—by design—this grain became the overwhelming staple of the Haitian diet. Through U.S.-driven policy reforms and marketing campaigns, rice now accounts for around a quarter of daily caloric intake (Cochrane et al., 2016), with Haitians consuming about 85 kg (187 lbs.) annually per capita in 2020—an increase from 66 kg (146 lbs.) per capita annually in 2010 (Food and Agriculture Organization of the United Nations [FAO], 2023). In comparison, the average American consumes 12 kg (27 lbs.) of rice each year (USA Rice, n.d.). For most Haitians, eating rice begins during infancy and remains integral to sustenance thereafter; "You have not eaten [a meal] if you didn't eat rice," is a common saying throughout the country. Lifelong daily rice consumption, however, is not without risk. Given rice plants' propensity to absorb and concentrate arsenic and cadmium in their grain (Zhao & Wang, 2020), we set out to compare levels of these chemicals among a variety of rice products consumed in Haiti.

The mid-1980s marked a shift in Haiti's rice consumption patterns, corresponding in large part to a massive influx of U.S.-grown rice heavily subsidized under the 1985 farm bill. With the end of nearly three decades of autocratic Duvalier family rule in 1986, a civilian-military junta, under pressure from international financial institutions, implemented widespread economic reforms which included the lowering of rice import tariffs. What became known as "Miami rice"—because of its port of origin—began pouring into Haiti, selling at prices far below the market value of domestic product. Before this time, rice accounted for only 7% of the average Haitian diet, as more readily available and affordable starchy roots and corn made up the primary staples for most of the population (Cochrane et al., 2016). With imported rice flooding the market, demand for this cheap foreign food—entangled also in the influence of racially coded class hierarchies on dietary aspirations—outstripped Haiti's previous self-sufficiency.

The early 1990s saw U.S.-based rice corporations take advantage of political turmoil to sign years-long import contracts, securing their hold on the Haitian market (Moore & Koski-Karell, 2022). Then in 1995, pressure from the U.S. Agency for International Development (USAID), the Inter-American Development Bank, the FAO, U.S. agribusiness consultants, Chemonics International, and President Bill Clinton—who later publicly apologized for his role (Building on success, 2010)—forced Haiti to further lower its tariffs on imported rice from 50% to 3% (Watkins & Fowler, 2002). Within a decade, Haiti became one of the top five export destinations for U.S. rice (Boriss, 2006). With the continued importation of subsidized rice, a growing population, and marketing campaigns promoting the consumption of U.S. rice, Haiti now ranks as the top market for U.S. long-grain milled rice (Childs, 2020). Today, almost 90% of Haiti's rice supply is imported (World Bank, 2020), with 98.5% of that imported rice coming from the U.S., particularly mid-southern states such as Louisiana, Texas, and Arkansas (USA Rice, 2020).

In the face of many structural barriers, a warming climate, and government disinvestment, Haitian *peyizan* (peasants, the word smallholder rural agriculturalists typically use to describe themselves) are still cultivating rice, primarily in the Lower Artibonite Valley region. It was there in 2017 when a *peyizan* organization approached one author (Dr. Koski-Karell) with a desire to investigate the safety of "Miami rice." Although members of their community and across the area almost only ate rice grown locally, some were reporting gastrointestinal symptoms (abdominal pain, bloating, and diarrhea) during the rare times they consumed foreign rice. While the exact cause of these symptoms would be difficult to determine, Dr. Koski-Karell took the inquiry seriously. With a team of Haiti- and Michigan-based researchers, and in collaboration with the *peyizan* organization, our group developed a study to measure levels of heavy metals (arsenic and cadmium) in rice found in Haitian markets. Given the high degree of pesticide and herbicide use, industrial and mining pollution, and naturally occurring arsenic content of soils in the Mississippi River Valley where much of the rice is grown (Ori et al., 2008; Williams et al., 2007a), we hypothesized that rice imported from the U.S. would have higher heavy metal concentrations than rice grown through community food systems in Haiti.

Rice has a propensity to accumulate up to tenfold more arsenic in its grain than other cereals (Williams et al., 2007b), making it a major source of arsenic exposure among populations who use it as a principal dietary food. Rice can also concentrate other toxic metals including cadmium. Rice plants take up arsenic and cadmium from the soil and irrigation water where they grow, levels of which vary geographically due to natural as well as anthropogenic activities (Majumder & Banik, 2019). While there is evidence suggesting variable relationships between arsenic species and toxicity to humans, the World Health Organization (WHO) International Agency for Research on Cancer (IARC) classifies both arsenic (as a single element) and inorganic arsenic compounds (including arsenic trioxide, arsenite, and arsenate) as carcinogenic to humans (IARC, 2012). Long-term exposure to these chemicals causes cancer of the lung, bladder, and skin and is also linked to kidney, liver, and prostate cancers (IARC, 2012). Additionally, the IARC classifies organic arsenic compounds dimethylarsinic acid and monomethylarsonic acid as possibly carcinogenic to humans (IARC, 2012). Other adverse health effects associated with chronic or early life exposure to arsenic include diabetes, pulmonary disease, cardiovascular disease, adverse pregnancy outcomes, infant mortality, and developmental delay (TatahMentan et al., 2020; WHO, 2022). Cadmium is another toxic metal that can be taken up by rice and other plants used by humans (TatahMentan et al., 2020). Cadmium is carcinogenic to humans, with evidence associating it with lung, kidney, and prostate cancers (IARC, 2012), while also exerting toxic effects on the renal, respiratory, and skeletal systems (WHO, 2022). The accumulation of arsenic and cadmium in human bodies poses a serious risk to global health, especially among populations using rice as a dietary staple (Awika, 2011). Infants and young children are especially vulnerable to elevated toxicity because of their higher consumption rate of rice relative to body mass compared to adults, and the intricate developmental processes that toxic exposures can disrupt (European Food Safety Authority Panel on Contaminants in the Food Chain [EFSA CONTAM Panel], 2009; Gardner et al., 2013; Kippler et al., 2012).

Over the past decade, several national governments and international authorities have established limits for inorganic arsenic (iAs) or total arsenic levels in rice and rice-based products. Through the Codex Alimentarius Commission, the FAO set a maximum level of 0.2 μg/g iAs for polished rice in 2014 (Codex Alimentarius Commission, 2014). The European Union limits iAs to 0.1 μg/g in rice used for infant food production, given the higher vulnerability of this age group (European Commission [EC], 2015). The U.S. Food and Drug Administration proposed the same in 2020, but the action level is still undergoing review, and is therefore not yet legally enforceable (U.S. Food and Drug Administration [FDA], 2020). Argentina, Brazil, Paraguay, and Uruguay limit total arsenic levels to 0.3 μg/g in rice and rice products (Planer-Friedrich et al., 2022). Currently, the responsibility for testing rice in local markets rests with each government authority respective to that country. However, "Years of inadequate policy attention and underinvestment have stunted the development of coherent national food safety management systems in many low- and middle-income countries," (Jaffee et al., 2019, p. xxii). Moreover, a dearth of publicly shared food safety data contributes to an absence of effective consumer knowledge and representation. In Haiti, the ministries of Commerce and Industry and of Public Health and Population hold responsibility for consumer safety and food safety, respectively, yet lack access to the mass spectrometry instruments needed to quantify arsenic and cadmium levels in the rice consumed by the population. This leaves both the government and consumers unaware of the potential risks certain foods pose to human health.

The objective of this study was to perform a comparative analysis of arsenic and cadmium concentrations in rice consumed in Haiti from both local and imported sources. For this project, 98 total samples of imported (commercial and donated) and local rice were collected from Haitian vendor sites—including open-air markets, rice mills, and supermarkets—in August 2020. Total arsenic and cadmium concentrations were analyzed via inductively coupled plasma mass spectrometry (ICP-MS). We also simulated estimated arsenic intake from rice in adults and children to evaluate whether it would exceed maximum recommended levels set to protect health.

Applied Research Methods

This study utilized a market-based approach, collecting rice from multiple vendor sites in the selected region (Lower Artibonite Valley, Haiti). The study was designed to have the statistical power to detect small differences (<2-fold) in arsenic and cadmium concentrations when comparing imported and local samples. To achieve this statistical power, at least 48 samples per group were needed.

Rice Collection

For local rice collection, the field researcher visited four open-air markets and five rice mills in the Lower Artibonite Valley. At each site, he purchased one cup of rice from different Haitian vendors selling locally produced rice. Across the markets, 21 vendors were selected randomly as the field researcher walked among their stalls. Care was taken to sample from vendors demonstrating both high and low traffic of clientele. Rice mill sites in the surrounding area were also selected randomly and at varying distances to the nearest urban areas. There, the field researcher purchased samples directly from vendors before their product reached the market.

For imported rice collection, the field researcher collected samples at two major supermarkets in the city of Saint-Marc and the same open-air markets sampled for local rice. One cup of imported rice was collected from each sample. A priori, the study team determined that four brands (Tchako, Mega, Bongu, and Riceland) should be included in the collection due to their widespread availability and consumption in Haiti. Other brands were selected randomly for a total of 14 brands represented in the final sample. Also collected were two samples from bags of rice donated to the local community through non-governmental organizations. Differentiating these rice supply chains is important from a policy perspective on their regulation, and also informs ethical considerations about their presence in Haitian food systems as commodities or aid.

At the time of sample collection, information about each sample was recorded. For local samples, we recorded information about the exact amount purchased, village or city and market of purchase, location of farm where rice was grown, processing details, and type of rice. For imported samples, we collected information about exact amount purchased, cost, village or city and market of purchase, brand, type of rice, and the country it was imported from.

After samples were collected, approximately 100 g were randomly sampled from the cup of rice, placed in a paper envelope, sealed, and labeled with a sample ID. All samples were collected in August 2020 and stored at room temperature. In September 2020, samples were shipped to Michigan, U.S., and stored at 39.2°F (4°C) until metal analysis.

Metals Analysis

Total arsenic and cadmium concentrations were measured in dried rice samples via ICP-MS. Rice samples were delivered to the National Sanitation Foundation (NSF) International Laboratory (Ann Arbor, MI, USA). The NSF International Laboratory is certified and accredited for exposure assessment by several U.S. based governing bodies. Approximately 10 mg of rice per sample were used for analysis. Quality control procedures included running blanks to calculate limits of detection (LOD) and standards of known concentrations of arsenic and cadmium. Four samples were run in duplicate, and the results from duplicates were used to assess precision. For arsenic analysis, the relative standard deviation (RSD) between duplicate measures was low indicating high precision (average RSD 6.8%). For cadmium, of the three duplicated samples with concentrations above the LOD, the method gave the same values for each pair (RSD 0%). All other quality control standards routinely used by the laboratory were met during the analysis.

Data Analysis

Descriptive statistics were computed for arsenic and cadmium concentrations in all rice samples and in groups of samples stratified by source (local, imported all, imported commercial-only). Descriptive statistics were also calculated for commercial imported rice samples stratified by country of origin and brand. Metal concentrations below the LOD were replaced with LOD/(square root of 2) prior to calculations or statistical tests when appropriate.

To compare arsenic concentrations in local versus imported commercial rice samples, a pooled two-sample t-test was used. Assumption of equal variances and normally distributed data was checked first. For cadmium concentrations, variances were not equal in local and imported sample groups and values were not normally distributed. Thus, the Wilcoxon two-sample test was used to compare groups. Statistical tests were not used to compare imported samples stratified by source country or brand since some sample groups were very small (1 or 2 samples). In statistical analyses, the two donated samples were excluded since this group was not big enough to assess differences in between local, imported-donated, and imported-commercial, and the original focus of our study was on imported commercial rice.

For arsenic, we conducted a simulation study to estimate the intake of arsenic from local or imported rice samples on a per-body weight basis for adults and compared results to standards set to protect health by several regulatory bodies. We included a range of weights that would encompass most Haitian adults (100 to 243 lb. or 45 to 110 kg). In the calculations, we assumed that 80 g of dried rice is the equivalent of one cup of cooked rice. We simulated intake for adults consuming 1, 2, 3, or 4 cooked cups of rice per day. These portions are realistic quantities for Haitian adults, as the FAO estimates a yearly rice intake of 85 kg/capita in Haiti, or about 2.9 cups of cooked rice per capita per day (FAO, 2023). In the simulations, we estimated body burden of arsenic if adults consumed local or imported (commercial) rice with (a) the median arsenic concentration or (b) the 75th percentile concentration. Since rice is a staple food for many children in Haiti, we conducted a similar simulation study representing 9-month-old to 5-year-old children (body weights ranging from 16 to 46.5 lb. or 7.3 to 21.1 kg) and consumption of 0.5, 1, or 1.5 cups of cooked rice per day. Weights were selected to range from the 15% percentile for 9-month-old girls to the 85% percentile for 5-year-old boys according to the WHO.

Descriptive statistics and comparisons of sample groups were performed in SAS (version 9.4). Simulation analyses were performed and results visualized using R (version >4.0). Two-sided p-values<0.05 were considered statistically significant unless otherwise noted.

Results

Arsenic and Cadmium Concentrations

All 98 samples analyzed for arsenic—including 48 local samples, 48 imported commercial samples, and 2 imported donated samples—had concentrations above the LOD (0.02 μg/g). Cadmium was not detected in all samples; 42% of samples had concentrations below the LOD (0.004 μg/g). Table 1 displays descriptive statistics for metals in all rice samples and stratified by imported and local.

When comparing local and imported rice samples, arsenic and cadmium concentrations were statistically significantly higher in the imported samples. Median concentrations were nearly two-fold higher for both arsenic and cadmium. Two imported samples (4%) and no local samples exhibited concentrations above the Codex recommended maximum concentration of 0.2 μg/g. A larger proportion of imported samples likewise had concentrations above the LOD for cadmium (64%) compared to local samples (50%). Since cadmium concentrations were overall very low within both sample types, the rest of the analyses focus on arsenic concentrations.

Figure 1 displays the distribution of arsenic concentrations with reference to select recommended limits for rice or rice products. An arsenic concentration of 0.2 μg/g in rice is the maximum level recommended by Codex. Codex Alimentarius is a collection of standards, guidelines and codes of practice adopted by the Codex Alimentarius Commission (Codex Alimentarius Commission, 2014). These standards are set in collaboration with the

Table 1. Concentrations of Arsenic and Cadmium in All Rice Samples and Stratified by Local vs. Imported

	#	% >LOD	Mean	St. Dev.	Min.	25% Percentile	50% Percentile	75% Percentile	Max.	T- test p-value [b]
Arsenic (μg/g)										
All rice samples	98	100%	0.114	0.045	0.021	0.074	0.115	0.149	0.222	
Local	48	100%	0.076	0.025	0.021	0.057	0.075	0.095	0.125	
Imported (commercial only)	48	100%	0.149	0.027	0.073	0.132	0.148	0.165	0.222	0.0001
Imported (all)*	50	100%	0.150	0.027	0.073	0.132	0.149	0.166	0.222	
Cadmium (μg/g)										
All rice samples	98	57%	0.010	0.012	<LOD	<LOD	0.004	0.009	0.056	
Local	48	50%	0.005	0.003	<LOD	<LOD	0.003	0.005	0.017	0.0031
Imported (commercial only)	48	62.5%	0.014	0.015	<LOD	<LOD	0.007	0.021	0.056	
Imported (all)[a]	50	64%	0.014	0.015	<LOD	<LOD	0.008	0.022	0.056	

[a] Two donated imported samples were collected and included in this total.
[b] For arsenic, pooled two sample t-test was performed to compare local and imported commercial samples. Wilcoxon two-sample test was used to compare cadmium.
LOD=limit of detection. LOD was 0.02 ug/g for arsenic and 0.004 ug/g for cadmium

Figure 1. Boxplots of Concentrations of Arsenic (μg/g) in the Imported (Commercial and Donated) and Local Rice Samples

Each box represents the concentrations failing within the 25th–75th percentile of all of the data in a group. The line in the middle of the box represents the median (50th percentile) value for each group. Colored lines indicate recommendation concentrations that rice samples should not exceed according to Codex (0.2 μg/g, for polished dried rice; solid red line) and the U.S. FDA for children's rice cereals (0.1 μg/g; dashed purple line).

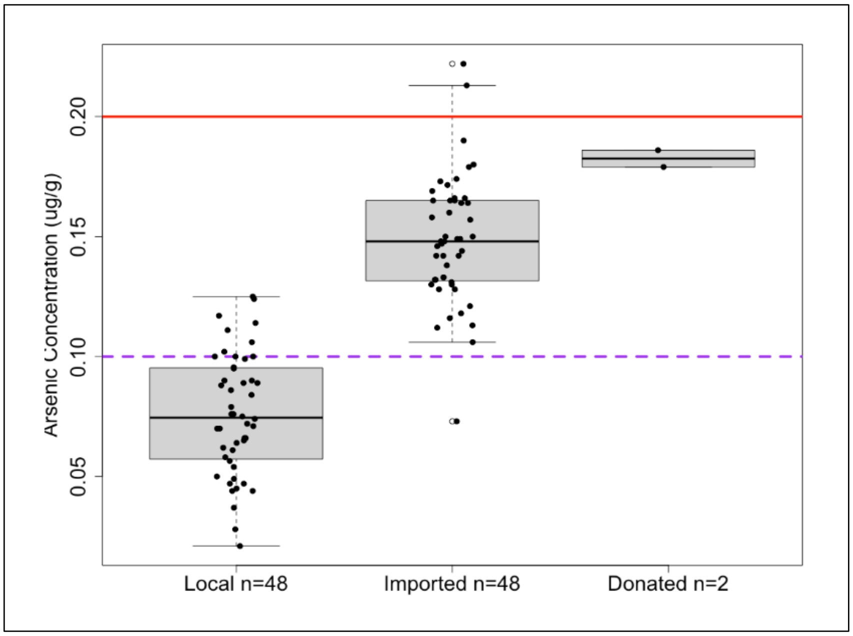
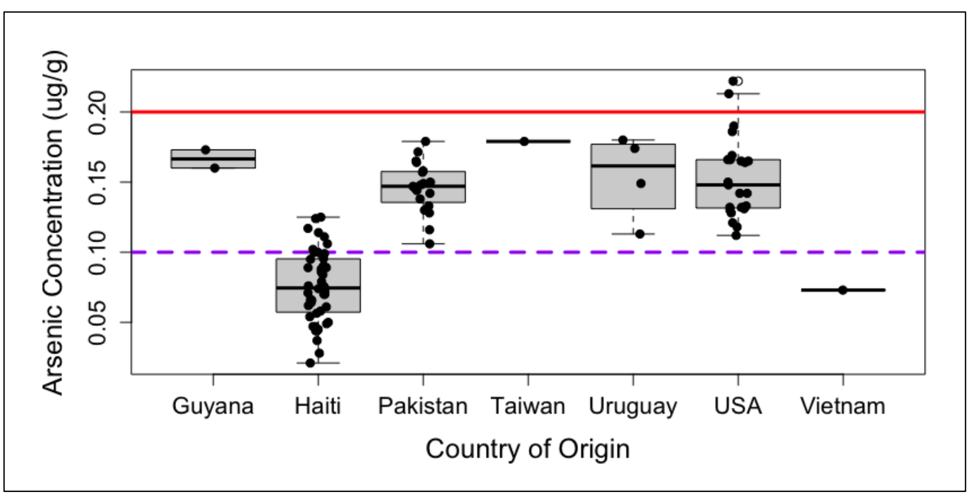


Figure 2. Concentrations of Arsenic (μg/g) in Rice Stratified by Country of Origin

Boxes represent the concentrations of the 25th–75th percentile of all of the data, with the line representing the median (50th percentile) value for each group. Lines indicate cut-offs that rice samples are recommended to stay below for human consumption according to: Codex (0.2 μg/g, for polished dried rice; solid red line) and the U.S. FDA for children's rice cereals (0.1 μg/g; dashed purple line). Taiwan and Vietnam had only one sample each, and as such the line indicates the concentration for a single sample.



Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2011). While these standards are not legally binding, they are global recommendations for protecting human health. The government agency regulating food in the U.S.—the FDA—has not set an action or recommended regulatory level for rice. However, the FDA (2020) suggests an action level of 0.1 μg/g of arsenic for infant rice cereal.

Arsenic and Cadmium Concentrations by Brand and Country of Origin—Imported

Among the imported rice samples, we conducted an exploratory analysis to compare levels by brand (Appendix Table A) and country of origin with Haitian-grown samples included (Figure 2). Numbers in some groups were very small (1–5), and meaningful statistical tests cannot be conducted to compare groups of this size. Descriptive statistics for each group can be found in the Appendix, Tables A and B.

Simulation: Arsenic Intake in Adults and Children

Rice consumption patterns in Haiti are important to consider when evaluating risk for human exposure. Thus, we simulated the amount of arsenic that Haitian citizens would consume based on observed consumption patterns of rice for both adults and young children and compared these to recommendations designed to protect health (Table 2).

Environmental and health agencies including the U.S. Environmental Protection Agency (EPA, 2007), JECFA (2011), and the U.S. Agency for Toxic Substances and Disease Registry (ATSDR, 2007, 2012) set recommendations for intake of arsenic and cadmium that should not be exceeded by an individual per day. These standards were set to protect against adverse health effects that are linked to cadmium or arsenic exposure at certain doses. For example, the ATSDR reports a minimum risk level for exposure to inorganic arsenic compounds of 0.0003 mg/kg/day over the course of a year or longer, as well as minimum risk levels of 0.02 mg/kg/day and 0.01 mg/kg/day for the two most prevalent organic arsenic species found in rice—dimethylarsinic acid and methylarsonic acid, respectively (ATSDR, 2007). The standards are set based on the assumption that a person could consume that amount (or less) every day for their entire lifetime and avoid adverse health effects from the exposure.

We compared estimated levels to the lowest health standard for long-term intake of 0.3 μg arsenic/kg of body weight per day. ATSDR and EPA both set this standard to protect against non-cancer health outcomes caused by arsenic. Given usual rice consumption patterns, we estimated the intake of arsenic from both local and imported rice samples at a range of possible weights for adults and a range of rice consumption per day. We estimated intake for adults eating 1, 2, 3, or 4 cups of cooked rice per day—or 80 g, 160 g, 240 g, or 320 g of uncooked rice, respectively. Figure 3 displays results for adults. Adults of all weights consuming 3 or more cups of imported rice per day are estimated to exceed daily intake recommendations (Figure 3c and 3d).

We conducted a similar comparison for children, given their increased susceptibility to the lifelong consequences of heavy metal exposure (Figure 4). Since many Haitian children start eating rice as soon as they can eat solid food, we estimated intake for children ages 9 months to 5 years old. The majority of children consuming 1 or more cups of local or imported rice per day would be expected to exceed the limit set by ATSDR. Low-weight children with higher consumption of imported rice exceed the lifetime intake level recommended to avoid arsenic-associated cancer (Figures 4c and 4d) while children consuming local rice do not exceed this value.

Discussion

Arsenic and cadmium are metals that contaminate food and water supplies in various places throughout the world due to human activities and naturally occurring levels of these metals in certain regions. Many plants, including and especially rice, can uptake metals from the surrounding environment. Rice consumption then becomes a source of exposure for humans. We compared levels of arsenic and cadmium in 50 imported and 48 domestic rice

Table 2. Reference Values Set to Protect Adult Human Health for Arsenic

Agency	Recommendation (μg/kg bw/day)	Type of Recommendation[a]	Set to Protect Against
U.S. Agency for Toxic Substances and Disease Registry (ATSDR)	0.3	MRL	Dermal effects
U.S. Environmental Protection Agency (EPA)	0.3	RfD	Dermal and vascular effects
Joint FAO/WHO Expert Committee on Food Additives (JECFA)[b]	2.1	PTWI	Cancer

[a] MRL = chronic duration oral minimum risk level; RfD = chronic oral reference dose; PTWI = provisional tolerable weekly intake, converted to a daily intake here.
[b] The JECFA decided in 2010 that this level may not be protective enough, and the concentration will likely be lowered.

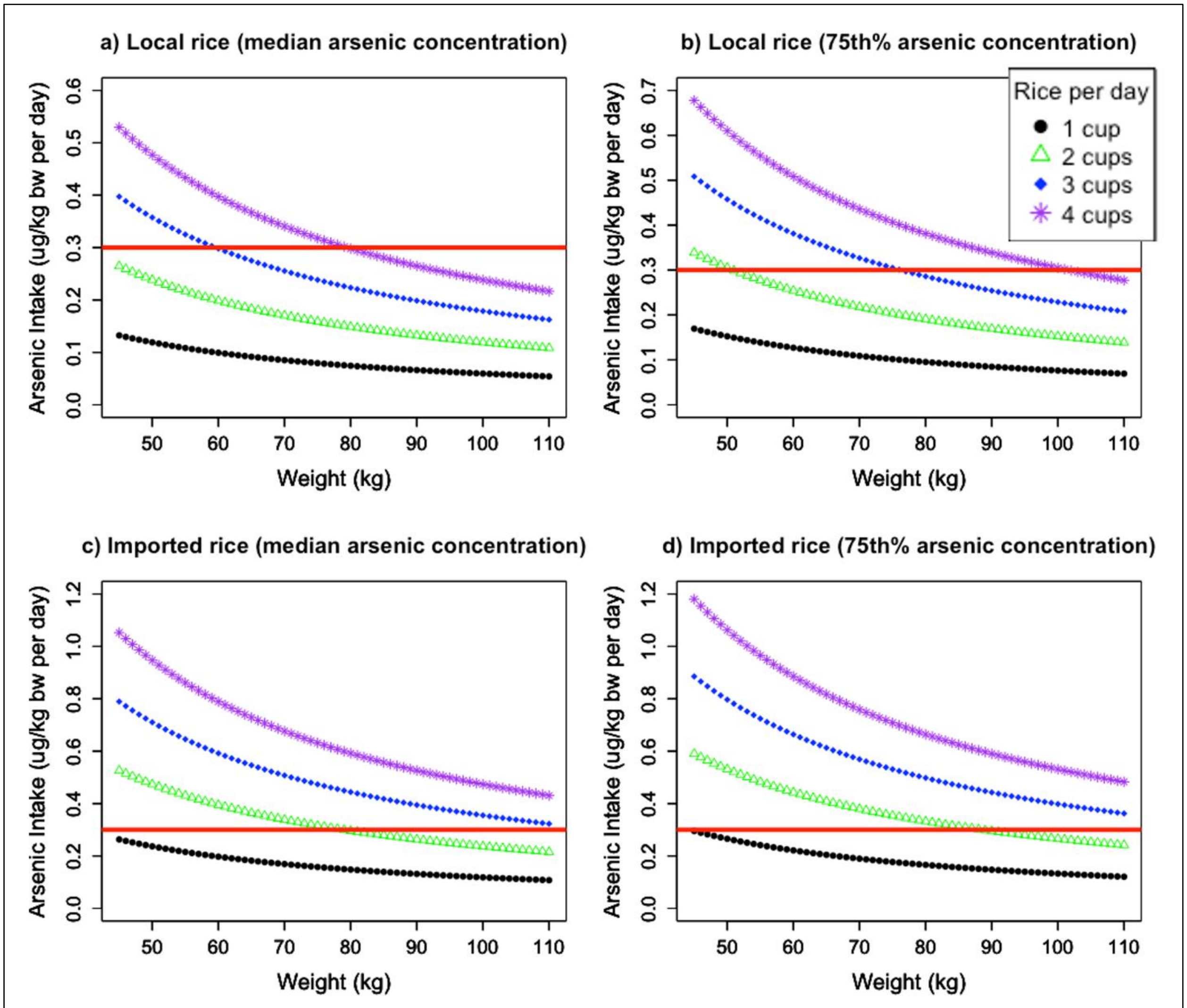
samples collected from vendor sites in the Lower Artibonite Valley of Haiti. On average, both arsenic and cadmium concentrations were twice as high in imported samples compared to those from the community food system. However, cadmium levels were extremely low in all types of rice. The arsenic levels in some of the imported rice samples exceeded science-based standards recommended by Codex and other agencies to protect human health.

When estimating arsenic intake via a simulation study based on realistic consumption patterns of rice in Haiti, children and adults at varied weights are expected to exceed standards that could lead to toxicity and adverse health outcomes when consuming imported rice. Some individuals may exceed these standards when eating local rice at high amounts as well. The frequency and quantity of rice consumption in Haiti is an important consideration when setting safety standards to protect

Figure 3. Estimated Arsenic Intake per Body Weight for Adults

We estimated the amount of arsenic ingested if individuals consumed the local rice analyzed in this study at (a) the median arsenic concentration and (b) the 75th percentile concentration. We also estimated based on consuming solely imported rice at the (c) median concentration and (d) 75th percentile quantified in the samples we collected.

The solid red line indicates the value that both the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Environmental Protection Agency (EPA) recommend humans remain below for chronic exposure to arsenic.

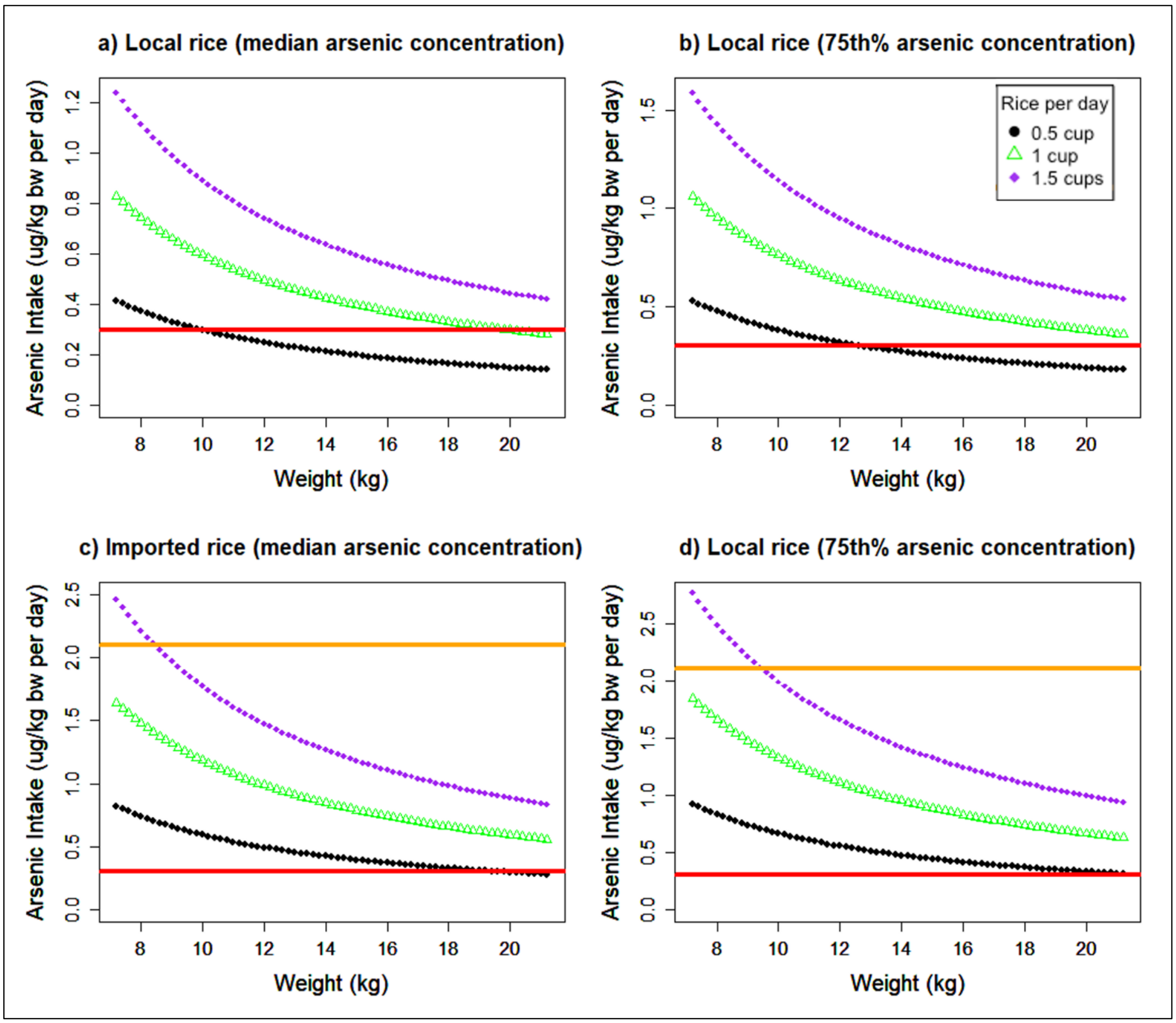


health. The likelihood and urgency of communicating the risk of exceeding maximum levels for long-term oral arsenic exposure vary around the world, based on the quantity, frequency, and origins of rice consumed by the local population and among different age groups. As of 2020, Haitians rank the fourth highest consumers of rice in the Americas with an average of 85 kg/capita/year (FAO, 2023), with most of this rice coming from the southern U.S. The results of our study point to the critical need for interventions that would promote safer consumption patterns of rice in Haiti,

Figure 4. Estimated Arsenic Intake per Body Weight for Children (9 Months–5 Years)

We calculate the estimated arsenic intake (μg per kg body weight per day) for young children over a range of body weights representative of 9-month-old to 5-year-old children. We estimated the amount of arsenic ingested if children consumed the local rice analyzed in this study at (a) the median arsenic concentration and (b) the 75th percentile concentration. We also estimated based on consuming solely imported rice at the (c) median concentration and (d) 75th percentile quantified in the samples we collected.

The solid red line indicates the value that both the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) and the U.S. Environmental Protection Agency (EPA) recommend is not exceeded for chronic consumption of arsenic to protect against non-cancer health outcomes. The solid orange line is the recommended intake level the Joint FAO/WHO Expert Committee on Food Additives (JECFA) recommends not exceeding for a lifetime to avoid cancer.



such as stronger reliance on community food systems, decreasing rice intake during childhood and pregnancy, or diversifying dietary carbohydrate sources.

Arsenic and cadmium are both carcinogenic to humans and are linked to a range of toxic effects (ATSDR, 2007, 2012). Long-term exposure to inorganic arsenic is associated with skin disorders, various cancers, chronic diseases, and more. In 2019, cardiovascular disease and neoplasms ranked the leading causes of death in Haiti (Institute for Health Metrics and Evaluation [IHME], 2020). When exposure occurs during pregnancy and early life, arsenic can affect the developing brain and cause neurotoxic effects which can have detrimental impacts on cognitive and behavioral development (Gardner et al., 2013; Kippler et al., 2012). Growing evidence also indicates that in utero exposure to arsenic is associated with various types of genetic damage in newborns, increasing the risk for neoplastic disease and other health conditions later in life (Navasumrit et al., 2019). Reduction of exposure to these metals is recommended whenever possible, as higher doses may lead to greater health risks from cumulative effects. Reducing intake of arsenic or cadmium from known sources such as contaminated rice or contaminated water is beneficial. Consuming local rice instead of imported rice can reduce arsenic and cadmium intake of adults and children by half. Since local rice still contains some arsenic, consuming a varied diet of other local products with 1–2 cups of rice per day (for adults) or 0.5–1 cups per day for very young children may be beneficial.

This study had several limitations. First, by only evaluating arsenic and cadmium concentrations in rice, we may have overlooked potentially elevated levels of other toxicants. Second, our methods did not involve speciation of arsenic to evaluate levels of inorganic arsenic compounds in rice samples. By measuring only total arsenic levels, our measurements do not exactly correspond to thresholds set by Codex and the U.S. FDA, which are based on inorganic arsenic concentrations. However, because the IARC classifies both arsenic (as a single element) and inorganic arsenic compounds as carcinogenic to humans, and organic arsenic compounds also as possibly carcinogenic, we assume marginal difference when it comes to the potential health consequences of total arsenic and inorganic arsenic exposure. In addition, the simulation component of our study estimating arsenic intake per body weight for adults and children is only able to suggest a potential risk for adverse health outcomes due to long-term rice consumption of certain quantities and frequencies. This area of research would benefit from additional investigations measuring arsenic levels in biological samples collected from Haitian individuals and the epidemiological burden of arsenic-related diseases in Haiti. Last, the samples included in this study are only a snapshot of a given time in the market. Rice from local, imported, and humanitarian aid sources in Haiti is frequently in flux due to changes in supply chain reliability and access to consumers, secondary to political instability, environmental factors, and social conflict. We did not design our study to compare imported donated rice specifically to local rice, and this data will be important in future research to inform best practices for aid organizations.

The overwhelming presence of foreign—and particularly U.S.-grown—rice in Haiti is grounded in a history of policy reforms intended to allow heavily subsidized U.S. rice to flood the market (Moore & Koski-Karell, 2022). This study raises a serious concern that rice producers included in this study may be exporting a potentially hazardous food product to Haiti and other countries reliant upon U.S. rice. Because rice has gained such important cultural and dietary significance in Haiti, many individuals risk adverse health effects secondary to lifelong exposure to elevated levels of arsenic in imported rice. The combination of structural factors, such as market liberalization and the accretion of arsenic in a highly vulnerable, resource limited, and racially marginalized population demonstrates elements of environmental racism and what Rob Nixon (2011) describes as "slow violence" occurring over many years and generations. The flooding of U.S. rice into Haiti is not only economically violent for Haitian peyizan who struggle to sell their local product, but also violent toward the long-term health of Haitian consumers. By maintaining a system dependent almost exclusively on U.S. rice, Haiti is importing a substantial amount of risk.

Like many other low- and middle-income countries, Haiti has been unable to develop a coherent national food safety management system. U.S. rice corporations are not the first to export potentially hazardous products to nations with weaker regulatory infrastructure (Cross & Winslett, 1987). The results of this study underscore a pressing need to strengthen the efficacy of food safety regulations and interventions in Haiti, as well as international food safety practices in exporting nations, particularly the United States. The implications of chronic arsenic exposure for public health extend also to Haiti's economy. Emerging research is shedding light on the economic costs of unsafe food due to "productivity losses" resulting from foodborne disease, including the presence of heavy metals (Jaffee et al., 2019). Our data have the potential to not only shape new policies to protect Haiti's population, but also equip Haitian consumers with the knowledge to make informed purchases when possible and advocate for improved food safety.

Conclusion

In comparing samples of rice available for consumption in Haiti, imported rice had an average level of arsenic twice that of locally grown product, with some imported sources exceeding international limits recommended to protect human health from arsenic exposure. These data suggest that the current consumption pattern of imported rice over the long-term or during early life may be contributing to the burden of neoplastic, cardiovascular, and other diseases. Our study contributes to a growing body of literature evaluating the levels and implications of arsenic in rice and is the first of its kind in Haiti. More recently, greater attention is being paid to lifetime health risks related to flows of arsenic through the international food trade (Nunes et al., 2022), as well as the cognitive and behavior consequences of early life exposure worldwide (Tolins et al., 2014). Measuring the concentration of heavy metals in various rice products circulating in Haiti sets the stage for further research assessing arsenic levels in Haitian consumers, the likelihood of adverse health effects linked to chronic arsenic exposure, and potential changes in policy, market patterns, and local agricultural investment. It also prompts inquiry into ethical concerns about food safety research in resource limited settings already facing extreme food shortages. If these data influence Haitians' consumption patterns toward purchasing more domestic rice, for example, Haiti's beleaguered rice sector may not be able to keep up with demand for a safer product. Also worthy of investigation are the U.S. rice corporations facilitating the export of food with elevated levels of arsenic to Haiti and elsewhere. The implications of our research—and the call for its expansion—extend to populations worldwide where the distribution of rice may incur an uneven distribution of risk.

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Appendix

Table A. Concentrations of Arsenic (μg/g) in Imported Rice Samples by Brand

	#	Mean	St. Dev.
Brand 1	5	0.128	0.020
Brand 2	8	0.156	0.017
Brand 3	10	0.148	0.021
Brand 4	1	0.222	
Brand 5	5	0.148	0.006
Brand 6	7	0.156	0.033
Brand 7	1	0.179	
Brand 8	1	0.073	
Brand 9	1	0.144	
Brand 10	4	0.154	0.030
Brand 11	1	0.130	
Brand 12	2	0.167	0.009
Brand 13	1	0.186	
Brand 14	3	0.138	0.024

Table B. Concentrations of Arsenic (μg/g) in Rice Samples by Country of Origin

	#	Mean	St. Dev.
Haiti	48	0.076	0.025
Guyana	2	0.167	0.009
Pakistan	19	0.146	0.018
Taiwan	1	0.179	
USA	23	0.153	0.029
Uruguay	4	0.154	0.030
Vietnam	1	0.073	