

Assessing inorganic arsenic in rice and its health risk to consumers in Ho Chi Minh City, Vietnam

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Abstract

Purpose – The consumption of rice that contains high levels of inorganic arsenic may cause human health risk. This study aims to determine As species concentrations, particularly iAs, in raw rice in Ho Chi Minh (HCM) City and its health risks.

Design/methodology/approach – A total of 60 polished raw composite samples of rice were purchased from traditional markets and supermarkets in HCM City. All samples were analyzed by HPLC-ICPMS for As species determination.

Findings – Mean concentrations of inorganic arsenic in all samples, which were purchased from supermarket and traditional market, were 88.8 µg/kg and 80.6 µg/kg, respectively. Overall, inorganic arsenic level was 84.7 µg/kg and contributed the highest proportion of arsenic species in rice with 67.7%. The proportion profiles for arsenic species were: As (III) (60 %); dimethylarsinic acid (32.2 %); As (V) (7.7 %) and methylarsonic acid (0.1 %). Inorganic arsenic level in raw rice was below the recommendation of World Health Organization. Using the benchmark dose recommended by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), all exposure doses were lower than BMDL05. However, as the doses ranged from 3.0 to 8.6 of Margin of Exposure (MOE), the health risk of iAs from rice consumption remains public health concern.

Originality/value – The study results report on the surveillance data of the presence of inorganic arsenic in raw rice products, which are available in the supermarkets and traditional markets, and its health risk to consumers in a metropolitan city in Vietnam.

Keywords Inorganic arsenic, Raw rice, Health risk, Vietnam

Paper type Research paper

Introduction

Arsenic (As) occurs ubiquitously, is prevalent in the environment and can easily enter the food system through contaminated soil or water. Certainly, inorganic As species are found to be more toxic than the organic form [1, 2]. Inorganic arsenic (iAs) is classified by the International Agency for Research on Cancer (IARC) as a class 1 human carcinogen and is



associated with skin, lung, liver, kidney and bladder cancers [3]. Different arsenic (As) forms can be found in rice grains. In general, around 50% of the total As in rice grain is in the inorganic form (ranging from 10% to 90%), while the remaining fraction is dimethylarsinic acid (DMA) with trace amounts of methylarsinic acid (MMA), which are considered to be nontoxic [4]. The exposure to iAs is found to cause health risks in various endemic regions in Asia and American with the most important sources being from drinking water and contaminated food [5–7]. In recent years, several published papers have shown that rice produced in some areas was contaminated with arsenic (As), especially inorganic arsenic (iAs), which is a cause for public concern. Rice produced from arsenic-endemic areas in South and Southeast Asian countries is contaminated with iAs about 42–91% [4, 8, 9]. Hence, the consumption of rice among people living in these areas may cause a higher human health risk.

In Vietnam, the Mekong River Delta (MD) and Red River Delta are identified as severe As-contaminated regions. Previous studies have proved that the source of high iAs in MD resulted from natural sources [10–12]. The MD is a crucial rice production region of Vietnam. Thus, the problem arises when using high iAs groundwater for irrigation, iAs will be accumulated in paddy soils and, then, rice grains [13–15]. In the last decade, groundwater has become a significant water supply source in Vietnam [16, 17] and has been supplied mainly for agricultural use at about 769,619 m³/day or 40.01% of the total groundwater abstraction [18]. Huang *et al.* have indicated that the irrigation with iAs-contaminated groundwater in MD had raised the As level in field soil [19]. This may lead to a higher iAs in rice. Other studies have also estimated the As concentration in rice, but most of them estimated iAs indirectly from measured total As (tAs) by using the proportion of iAs in tAs from other studies or rice samples from other countries [20–24]. Few studies are focusing on As species, particularly iAs in rice, which is grown in the MD and their risks to people who consume rice.

Ho Chi Minh (HCM) City is the largest city in Southern Vietnam with a population of more than 8m people [25]. Rice consumed in this city is mainly from MD and some from other regions of Vietnam and countries such as Thailand, Japan and the USA [26]. With a gap about As species concentration in rice from MD and the risk of iAs in rice, this study aims to determine the As species level, particularly iAs, in raw rice, and to assess the health risk of iAs through rice consumption of people in HCM City.

Materials and methods

Sample collection and preparation of raw rice

The study was designed at the consumer end, thus, concerning the consumers' purchasing behavior, it was assumed that people would purchase rice with different brands based on price, characteristics, sales promotion and quality. According to the market share, the top five famous brands in each market were also taken into account making the selected scenario more relevant to the real situation. In total, 30 supermarkets and 30 traditional markets in HCM City were selected randomly. In each retail store of the traditional markets and supermarkets, 60 g was taken from each of the five famous rice brands. All samples were kept in plastic zip bags at room temperature before pretreatment.

During pretreatment, regarding the five famous rice brands, the amount of 60 g of each rice brand was mixed to perform a composite sample (300 g). Then, rice grains were homogenized, ground and sieved with a 0.5 mm ring by the Ultra Centrifugal Mill ZM 200 (Retsch, Inc., Haan, Germany) and then oven-dried at 105°C by Memmert Une 500 (Memmert GmbH + Co. KG, Schwabach, Germany) until a constant weight was reached. After that, the powder samples were stored in a room at 4°C.

Finally, about 1 g of the raw rice samples was analyzed by using the high-performance liquid chromatography (HPLC) with the inductively coupled plasma mass spectrometry

(ICPMS) at the Southern Food Testing Centre, Institute of Public Health at Ho Chi Minh City, Vietnam.

Arsenic determination method and calculation

Following the US FDA's method [27, 28], about 0.28 mol/L HNO₃ solution (EMSURE® Reag. Ph Eur, ISO Merck KGaA, Darmstadt, Germany) was mixed to analyze the samples of rice. Then, all samples were heated at 95°C for 90 min. As species were separated using the HPLC separation with a mobile phase of 10 mmol/L ammonium phosphate dibasic (Sigma-Aldrich, Co., St. Louis, USA) at pH 8.25 (±0.05).

The As species were identified by using a PerkinElmer Flexar™ HPLC system coupled with a PerkinElmer NexION®350X ICP-MS (PerkinElmer, Inc., Massachusetts, USA) and Hamilton® HPLC PRP-X100 (Hamilton Company, Nevada, USA). The conditions were set up with the flow rate of 1 mL/min, RF generator frequency of 40 MHz, a power output of 1350 W, argon flow rate of 15 L/min, auxiliary of 1.2 L/min, carrier of 1 L/min and nebulizer of 0.98 L/min.

A total of 60 composites of raw rice were separated into six batches for analyzing. In each batch, there were 21 samples, including ten composite samples, one method blank, one rice flour Certified Reference Material (CRM), two replications and analyses of a sample, five calibration levels, one calibration check standard and one fortified analytical portion. The CRM used was European Reference Material ERM®-BC211 (Institute for Reference Materials and Measurements of the European Commission's Joint Research Centre, Geel, Belgium) [29].

Quality assurance (QA)/quality control (QC)

The largest Analytical Solution Detection Limit (ASDL) and Analytical Solution Quantitation Limit (ASQL) were identified among four measured As species with ASDL (0.1008 µg/kg), ASQL (0.7866 µg/kg), and then, the Limit of Detection (LOD) (5.0509 µg/kg) and Limit of Quantitation (LOQ) (39.4095 µg/kg) were calculated. The results of the calibration curve of As species were 0.99 in all batches. The calibration check standards in line with the mean of iAs, DMA and MMA were 7.44, 3.0 and 3.23 %, respectively. The mean of precision of replicate analytical portions was 2.04% for iAs and 2.94% for DMA while the fortified analytical portion of all batches ranged from 11.95 to 16.07% among As species. Finally, in the ERM-BC211's results, the mean of DMA levels was 123 µg/kg and the mean of iAs was 106 µg/kg.

The level of iAs was calculated by a total of As (III) and As (V) concentrations. The level of tAs was calculated by the sum of the concentrations of As (III), As (V), DMA and MMA.

Exposure assessment and health risk assessment

An average daily dose exposure (ADD) was estimated using Eqn (1):

$$ADD_i = \frac{C_i \times IR_i \times AF \times EF \times ED_i}{BW_i \times AT_i} \quad (1)$$

where C_i is the concentration (µg kg⁻¹) of As in rice, which was taken from this study; IR_i is the daily average consumption/ingestion of rice (g/d) (Table 2); BW represents average body weight (kg) (Table 2); EF is exposure frequency (365 d year⁻¹) (the US Environmental Protection Agency (U.S.EPA) [30]); ED is exposure duration (49 years from U.S.EPA [30]); AT is the averaging exposure time for noncarcinogenic effects (49 × 365 d year⁻¹) from U.S.EPA [30]; AF is bioavailability factor ranging from 70 to 90% from FDA [31].

The information on bodyweight and rice consumption for calculating ADD was obtained from various studies in Vietnam. Based on the National Institute of Nutrition that conducted a nutrition survey in Vietnam during 2009–2010, the rice intake in all regions and the average

weight of the 2–5 age group adults aged 20–59 by gender were taken into the calculation, except for the average weight and the rice intake of other groups [32]. For children below 2 years old, their diets and consumption pattern are quite different from adults [33–35]. Thus, the risk of this age group was not assessed in this study. Overall, with the limitations of our data as well as the available evidence, the exposure dose in this study was calculated in limited age groups as detailed in Table 2.

The prediction of health risk related to iAs exposure associated with rice consumption was explained by following equations:

The Margin of Exposure (MOE) was calculated using Eqn (2)

$$\text{MOE}_i = \frac{\text{BMDL}_{05}}{\text{ADD}_i} \quad (2)$$

where ADD from Eqn (1); $\text{BMDL}_{05} = 3 \mu\text{g/kg bw/day}$ from JECFA [36]

Results

Characteristics of rice samples in supermarkets and traditional markets

All raw rice samples purchased in this study were ordinary rice, long-middle grain rice and white (polished) rice. Detailed information about these products was collected from the rice packaging and from interviewing the sellers in traditional markets. In supermarkets, rice samples were collected from 17 companies in Vietnam and one company from Thailand. About 97% of companies were located in the MD in the Southern region of Vietnam. In traditional markets, 91.3% of rice was collected from nonbranded sellers. About 77% of rice was from the MD and 17% was from an unknown location.

Level of arsenic species in rice sample

In this study, since the process capacity analysis in the laboratory was limited, only As (III), As (V), DMA and MMA were able to be determined. The concentration of AsB was not included in the study. As (III), As (V) and DMA were detected in all 60 raw rice samples and were reported in dry-weight based ($\mu\text{g/kg}$). The mean $\pm$ SD concentration of tAs and iAs were $125.5 \pm 14.7 \mu\text{g/kg}$ and $84.7 \pm 7.4 \mu\text{g/kg}$, respectively. As the MMA concentration was 98.3 % below LOD, the organic form was mainly from DMA and was found to be lower than those inorganic forms about 50%. The As (III) concentration was found to be the highest level (mean $\pm$ SD: $74.9 \pm 6.2 \mu\text{g/kg}$), followed by DMA levels (mean $\pm$ SD: $40.8 \pm 9.0 \mu\text{g/kg}$) and As (V) (mean $\pm$ SD: $9.8 \pm 3.8 \mu\text{g/kg}$). The concentration of As species in rice samples from supermarkets was significantly higher than those from traditional markets. (Table 1)

The iAs is the main component found in these samples with a mean proportion of 67.7% (ranged from 57 to 72.9%). The proportion profiles for the As species were: As (III) (60 %),

Source	Concentrations in $\mu\text{g/kg}$ (mean $\pm$ SD)					tAs*
	iAs	As(III)	As(V)	DMA	MMA	
Super market ($n = 30$)	88.8 ± 6.7^a	77.0 ± 6.2^a	11.7 ± 4.5^b	43 ± 9.6^b	0 ± 0	131.8 ± 14.1^b
Traditional market ($n = 30$)	80.6 ± 5.6	72.8 ± 5.5	7.8 ± 1.3	38.5 ± 8	0.24 ± 1.3	119.3 ± 12.6
Total ($n = 60$)	84.7 ± 7.4	74.9 ± 6.2	9.8 ± 3.8	40.8 ± 9	0.12 ± 0.92	125.5 ± 14.7

Note(s): a: significance difference in mean ($p < 0.05$) by *t*-test

b: significance difference in median ($p < 0.05$) by Mann–Whitney *U* test

*Calculated as the summation of As (III), As (V), DMA and MMA

Table 1.
As species
concentration in raw
rice in Ho Chi Minh
City ($n = 60$)

Table 2.
Individual exposure
dose of iAs from
consuming rice by age
groups and gender

Age	Gender	Wt (kg)	Rice intake (g/d)	ADD (µg/kg/d) (AF 70–90%)	MOE
2–5	Boy	16.4 [37]	204.7 [32]	0.74–0.95	3.2–4.1
	Girl	15.2 [37]		0.80–1.02	3.0–3.8
20–24	Male	54.19	330.3 [32]	0.36–0.47	6.4–8.3
	Female	45.98		0.43–0.55	5.5–7.0
25–29	Male	55.6		0.35–0.45	6.7–8.6
	Female	47.03		0.42–0.54	5.6–7.1
30–34	Male	55.68		0.35–0.45	6.7–8.6
	Female	48.15		0.41–0.52	5.8–7.3
35–39	Male	55.73		0.35–0.45	6.7–8.6
	Female	48.15		0.41–0.52	5.8–7.3
40–44	Male	55.58		0.35–0.45	6.7–8.6
	Female	49.66		0.39–0.51	5.9–7.7
45–49	Male	55.67		0.35–0.45	6.7–8.6
	Female	49.52		0.40–0.51	5.9–7.5
50–54	Male	54.94		0.36–0.46	6.5–8.3
	Female	50.72		0.39–0.50	6.0–7.7
55–59	Male	54.42		0.36–0.46	6.5–8.3
	Female	49.62		0.40–0.51	5.9–7.5

Note(s): MOE (Margin of Exposure) = $BMDL_{05}/ADD_i$; $BMDL_{05}$ = 3 µg/kg bw/day [36]

DMA (32.2 %), As (V) (7.7 %) and MMA (0.1 %). The As (III) was the main species, which ranged from 47.6 to 67.6%) of tAs while there was a small proportion of MMA. (Data was not shown)

The exposure dose and health risk associated with the consumption of rice with iAs

Given the exposure factors described in Eqn (1), the daily exposure doses of iAs from consuming rice among adults ranged from 0.35 to 0.55 µg/kg bw/day. The exposure doses among females were found to be higher than those found among males. The results also showed that the ADD among children aged 2–5 was two times higher than that in adults. All exposure doses were below the $BMDL_{05}$. The MOE for children aged between 2 and 5 years was 3.0–4.1, while the range for the adult groups was 5.5–8.6 (Table 2). The MOE of children was found to be lower than that of the adult groups.

Discussion

The results of QA and QC complied with the recommendation of the FDA’s instruction. The recovery was compared to the CRMs value of iAs at 85%. This value had fallen between 80 and 110%, which was acceptable in accordance with the Association of Official Analytical Chemists Standard Method Guidance [38]. The ERM-BC211 for As species determination was used and compared to the Certified CRM [29] and other studies [35, 39–44]. In this study, tAs was calculated as the summation of As (III), As (V), DMA and MMA; thus, the tAs levels were 239 ± 8 (µg/kg). This level was lower than those of other studies that used LC-ICP-QQQ, HG-AAS, SS-HG-CT-AAS and LC-ICPMS methods [35, 39–42]. However, it is found that this level was close to those of other studies that used the same method [43, 44]. The As (III) in this study was about 104 ± 3 (µg/kg) and those in other studies that used the same method of HPLC-IPMS ranged from 104 to 106 (µg/kg). Our results were similar to other studies with respect to the level and standard deviation of iAs levels [43, 44].

The As species in rice that other studies identified were As (III), As (V), Arsenobetaine (AsB), DMA and MMA. However, AsB, which was one of the types of organic arsenic and was the main species in fish or seafood, was found to be very low and rarely detected in rice grains [22, 45–48]. Besides, it was found that there was no significant difference between the direct

determination of tAs and the summation of As species. Agusa *et al.* calculated tAs in rice as the sum of As species including As (III), As (V), AsB, DMA and MMA [22]. Sofuoglu *et al.* also calculated tAs as the sum of As (III), As (V), DMA and MMA [49].

When comparing tAs in this study to other studies, the results were in line or higher than those found in Iran (120 µg/kg), Ghana (110 µg/kg), Japan (95 µg/kg), India (46–80 µg/kg), the Hunan Province of China (129 µg/kg) and Taiwan (116.6 µg/kg) [23, 50–53]. However, they were lower than those found in Turkey (202 µg/kg), Brazil (229 µg/kg), France (280 µg/kg), Spain (200 µg/kg), USA (250 µg/kg) and Finland (250 µg/kg) [9, 46, 47, 49]. The tAs concentrations in this study were lower than the Chinese and Hungarian tAs recommendation [54, 55]. However, the concentrations were in the global normal range (82–202 µg/kg) of rice grains as reported by Zavala and Duxbury [56] with the assumption of 10% moisture content [57].

Likewise, compared to a previous study of Vietnamese rice, the tAs concentrations were similar to those from previous studies in the local markets in Thailand, Ghana and Cambodia [21, 23, 24]. However, these results were lower than those from As-contaminated areas in Vietnam including An Giang province in the Mekong Delta and Ha Nam province in the Red River Delta [22, 58].

The high level of tAs in rice grown in the Mekong Delta and Ha Nam province may involve the contaminated groundwater used for irrigation. Farmers used a huge amount of groundwater for the irrigation of paddy rice fields due to the shortage of water during the dry season or even in monsoon season. This process would increase the As deposition in soil over time [5, 59, 60]. Pal *et al.* showed a significant correlation between the level of As in rice, irrigation water and soil [61]. Concerning the area contaminated with As, the As concentrations in the affected area of Vietnam were lower than those found in Bengal and India [61, 62]. It would be the influence of the amount of irrigation water and the duration of using groundwater, which was shorter than the duration in Bengal. By comparing the results of tAs in rice in markets in Ho Chi Minh City and contaminated areas in Vietnam as well as the earlier discussion, the raw rice distributed in the markets may come from not only the MD but also other areas.

As species concentrations in rice were compared between samples collected from supermarkets and traditional markets. Although the main products distributed in Ho Chi Minh city were not from the contaminated areas, this could be from various factors such as soils, types or cultivars. In addition, all of these samples were polished rice, the type of rice that has the lowest iAs level due to the removal of the bran. Also, Narukawa *et al.* noted that tAs and iAs decreased with the increase of the degree of polishing the rice [63].

The iAs was the main component in these rice samples; however, the concentrations of iAs were lower than the recommendation of WHO (200 µg/kg) [64]. Previous studies from various countries in the world as well as in this study showed that the iAs form was found to be the major part of As species in rice with the percentage ranging between 44 and 100% [9, 52, 65, 66]. The As species including As (III), As (V), DMA and MMA were also similar to those of other studies from Vietnam [21, 22] as well as other Asian countries [9, 21, 50, 53]. Besides, there was a wide variation of As species levels in rice since the As levels in soils and other factors could result in large coefficients in As species results [53, 67]. In this study, due to the sample preparation as a composite and replication strategy, the variations would be reduced.

The daily exposure doses of iAs from rice consumption were similar to those of a study in Pakistan (0.3 µg/kg bw/day), Finland (0.38–0.46 µg/kg bw/day), EU (0.22 µg/kg bw/day), Spain (0.41 µg/kg bw/day), Thailand (0.37 µg/kg bw/day) and China (0.4 µg/kg bw/day) [21, 47, 68–71]. However, the results were lower than those found in other studies in Vietnam and other countries [22, 58, 72–74], as well as being higher than those from USA (0.02 µg/kg bw/day), Turkey (0.1 µg/kg bw/day) and Iran (0.09 µg/kg bw/day) [49, 51, 75].

The difference in exposure dose among gender could be explained by a difference in body weight. Other studies showed that males consumed a higher rice intake than females in Asian countries such as Singapore, Korea, China and Cambodia [76–79]. Besides, with similar food consumption patterns among Asian countries [80, 81], the assumption of similar rice intake by gender in Vietnam could be applied. With this scenario, either the overestimate or the lower estimate for the ADD of both genders is likely to happen. A study in Taiwan that focused on the iAs risk assessment from rice consumption showed that women were exposed to iAs with a lower ADD than men [50].

The finding indicated that higher ADD among children aged 2–5 years compared with adults was similar to other countries such as Finland, Taiwan, Sweden and the USA [82]. In addition, the EU's study about As contamination in food stated that the ADD of iAs reduced with an increase in age [82]. Compared to other countries, ADD in children aged 2–5 from rice consumption in this study was higher than those in Sweden in those aged 4 years (0.185 µg/kgd) [83], in USA in those aged 0–6 (0.543 µg/kgd) [31] and Finland among the 1–6 age group (0.57–0.67 µg/kgd) [47].

The results of the exposure dose of iAs through rice consumption varied across age groups, gender and countries. This could be explained by the difference in rice intake and body weight. With the same mean of iAs level in rice, although females consumed more iAs than males in this study, the females could get a lower level of ADD than males due to their lower amount of rice intake. The children consumed higher ADD than adults due to the higher ratio of rice intake/bodyweight. From the perspective of countries, the iAs level in this study was lower than or equal to other countries but the exposure dose was relatively equal to or higher than those populations due to high rice intake per capita among the population [21, 47, 49, 51, 68–71, 75].

The results of the MOE are also similar to other studies [47, 84, 85] and were found to be lower than that in a study in Belgium where people consumed less rice and followed different consumption patterns [86]. At present, there are no international guidelines for MOE criteria. However, if the MOE is higher, then the public health concern is lower. In a worst-case scenario, consumption of rice contaminated with iAs, which is higher than BMDL₀₅, may lead to a 0.5% increased incidence of lung and bladder cancers.

Besides, studies about iAs in food showed that although rice is the major food of iAs exposure, other food also contributed the amount of iAs into humans [8, 69–71, 85]. Thus, the actual risk of iAs intake from all food might be higher in this population. This study focused on the health risk of iAs from rice consumption only; thus, lower estimation is likely to occur. Further study on inorganic As in other food items should be considered for characterizing the significant sources of exposure.

The limitation of this study is that the origin of the rice cannot be traced back due to the complicated production system. This does not reflect the variation of geography as well as the cultivar and the farm. Another uncertainty is the lack of rice consumption level specific to the study area. The data related to rice intake including age and gender groups were taken from the National Survey and other studies. Another factor is the bioavailability of As with a wide range of 55–71% [87] and 70–90% [88]. With respect to the worst-scenario approach of risk assessment, the range of 70–90% of bioavailability was used for assessing the risk. The overestimated risk would be generated.

Conclusions

The results of this study show that most people in HCM City consumed rice with the mean of iAs in raw rice 84.7 µg/kg in dry weight. The As speciation results indicate that an iAs form in rice and their distribution were similar to other Asian rice profiles. Although the iAs concentrations found in rice grains being sold in the local market in HCM City are

likely to be safe for consumers according to WHO recommendation, based on JECFA's criteria for chronic and cancer risk, the health risk could not be excluded. A risk communication of iAs in rice needs to be raised for public health awareness about the high exposure from rice consumption and chronic iAs disease. People should change their routine preparation and rice cooking methods. More importantly, people should promptly view the new information on how to reduce contamination, for instance, following appropriate washing procedures, choosing the rice already approved by the health sectors, avoiding using arsenic-contaminated water for irrigation or having a balanced and varied diet.

A monitoring program for iAs contamination in other food items should be considered. Although the use of groundwater is occasional, the risk of accumulated iAs in rice and foods grown in contaminated areas would occur over a long-term period, especially among young children. Besides, the Mekong delta, although an important region for rice production in Vietnam, is thought to be an As-contaminated area. Thus, a monitoring system for As in rice, the original production of rice, As in groundwater as well as As in soil over time should be established. In addition, rice consumption should be investigated for specific regions, gender and age groups for a more accurate risk assessment. Finally, further study on dietary intake of iAs should be carried out as the overall risk of iAs from foods in HCM City would benefit from further research.

References

1. Meharg AA, Hartley-Whitaker J. Arsenic uptake and metabolism in arsenic resistant and nonresistant plant species. *New Phytol.* 2002; 154(1): 29-43. doi: [10.1046/j.1469-8137.2002.00363.x](https://doi.org/10.1046/j.1469-8137.2002.00363.x).
2. Ng JC. Environmental contamination of arsenic and its toxicological impact on humans. *Environ Chem.* 2005; 2(3): 146-60. doi: [10.1071/EN05062](https://doi.org/10.1071/EN05062).
3. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, International Agency for Research on Cancer. A review of human carcinogens: part C: arsenic, metals, fibres and dusts. Lyon: IARC; 2012.
4. Zhu YG, Williams PN, Meharg AA. Exposure to inorganic arsenic from rice: a global health issue? *Environ Pollut.* 2008 Jul; 154(2): 169-71. doi: [10.1016/j.envpol.2008.03.015](https://doi.org/10.1016/j.envpol.2008.03.015).
5. Brammer H, Ravenscroft P. Arsenic in groundwater: a threat to sustainable agriculture in South and South-east Asia. *Environ Int.* 2009 Apr; 35(3): 647-54. doi: [10.1016/j.envint.2008.10.004](https://doi.org/10.1016/j.envint.2008.10.004).
6. Rasheed H, Slack R, Kay P. Human health risk assessment for arsenic: a critical review. *Crit Rev Environ Sci Technol.* 2016; 46(1920): 1529-83. doi: [10.1080/10643389.2016.1245551](https://doi.org/10.1080/10643389.2016.1245551).
7. Berg M, Stengel C, Pham TK, Pham HV, Sampson ML, Leng M, *et al.* Magnitude of arsenic pollution in the Mekong and Red River deltas—Cambodia and Vietnam. *Sci Total Environ.* 2007 Jan; 372(23): 413-25. doi: [10.1016/j.scitotenv.2006.09.010](https://doi.org/10.1016/j.scitotenv.2006.09.010).
8. Mondal D, Polya DA. Rice is a major exposure route for arsenic in Chakdaha block, Nadia district, West Bengal, India: a probabilistic risk assessment. *Appl Geochem.* 2008 Nov; 23(11): 2987-98. doi: [10.1016/j.apgeochem.2008.06.025](https://doi.org/10.1016/j.apgeochem.2008.06.025).
9. Meharg AA, Williams PN, Adomako E, Lawgali YY, Deacon C, Villada A, *et al.* Geographical variation in total and inorganic arsenic content of polished (white) rice. *Environ Sci Technol.* 2009 Mar; 43(5): 1612-7. doi: [10.1021/es802612a](https://doi.org/10.1021/es802612a).
10. Nguyen KP, Itoi R. Source and release mechanism of arsenic in aquifers of the Mekong Delta, Vietnam. *J Contam Hydrol.* 2009 Jan; 103(12): 58-69. doi: [10.1016/j.jconhyd.2008.09.005](https://doi.org/10.1016/j.jconhyd.2008.09.005).
11. Winkel LH, Pham TK, Vi ML, Stengel C, Amini M, Nguyen TH, *et al.* Arsenic pollution of groundwater in Vietnam exacerbated by deep aquifer exploitation for more than a century. *Proc Natl Acad Sci U S A.* 2011 Jan; 108(4): 1246-51. doi: [10.1073/pnas.1011915108](https://doi.org/10.1073/pnas.1011915108).

12. Erban LE, Gorelick SM, Zebker HA, Fendorf S. Release of arsenic to deep groundwater in the Mekong Delta, Vietnam, linked to pumping-induced land subsidence. *Proc Natl Acad Sci U S A*. 2013 Aug; 110(34): 13751-6. doi: [10.1073/pnas.1300503110](https://doi.org/10.1073/pnas.1300503110).
13. Meharg AA, Rahman MM. Arsenic contamination of Bangladesh paddy field soils: implications for rice contribution to arsenic consumption. *Environ Sci Technol*. 2003 Jan; 37(2): 229-34. doi: [10.1021/es0259842](https://doi.org/10.1021/es0259842).
14. Khan MA, Islam MR, Panaullah GM, Duxbury JM, Jahiruddin M, Loeppert RH. Accumulation of arsenic in soil and rice under wetland condition in Bangladesh. *Plant Soil*. 2010 Aug; 333(12): 263-74. doi: [10.1007/s11104-010-0340-3](https://doi.org/10.1007/s11104-010-0340-3).
15. Dittmar J, Voegelin A, Maurer F, Roberts LC, Hug SJ, Saha GC, *et al*. Arsenic in soil and irrigation water affects arsenic uptake by rice: complementary insights from field and pot studies. *Environ Sci Technol*. 2010 Dec; 44(23): 8842-8. doi: [10.1021/es101962d](https://doi.org/10.1021/es101962d).
16. International Union for Conservation of Nature [IUCN]. Groundwater in the Mekong delta. IUCN; 2011.
17. Renaud FG, Künzer C. The Mekong delta system: interdisciplinary analyses of a River Delta. Dordrecht: Springer; 2012.
18. Ha K, Ngoc NTM, Lee E, Jayakumar R. Current status and issues of groundwater in the Mekong River basin. Bangkok: UNESCO Bangkok Office; 2015.
19. Huang Y, Miyauchi K, Endo G, Don LD, Manh NC, Inoue C. Arsenic contamination of groundwater and agricultural soil irrigated with the groundwater in Mekong Delta, Vietnam. *Environmental Earth Sciences*. 2016 May; 75(9): ARTN 757. doi: [10.1007/s12665-016-5535-3](https://doi.org/10.1007/s12665-016-5535-3).
20. Phuong TD, Chuong PV, Khiem DT, Kokot S. Elemental content of Vietnamese rice. Part 1. Sampling, analysis and comparison with previous studies. *Analyst*. 1999 Apr; 124(4): 553-60. doi: [10.1039/a808796b](https://doi.org/10.1039/a808796b).
21. Nookabkaew S, Rangkadilok N, Mahidol C, Promsuk G, Satayavivad J. Determination of arsenic species in rice from Thailand and other Asian countries using simple extraction and HPLC-ICP-MS analysis. *J Agric Food Chem*. 2013 Jul; 61(28): 6991-8. doi: [10.1021/jf4014873](https://doi.org/10.1021/jf4014873).
22. Agusa T, Kunito T, Minh TB, Kim Trang PT, Iwata H, Viet PH, *et al*. Relationship of urinary arsenic metabolites to intake estimates in residents of the Red River Delta, Vietnam. *Environ Pollut*. 2009 Feb; 157(2): 396-403. doi: [10.1016/j.envpol.2008.09.043](https://doi.org/10.1016/j.envpol.2008.09.043).
23. Adomako EE, Williams PN, Deacon C, Meharg AA. Inorganic arsenic and trace elements in Ghanaian grain staples. *Environ Pollut*. 2011 Oct; 159(10): 2435-42. doi: [10.1016/j.envpol.2011.06.031](https://doi.org/10.1016/j.envpol.2011.06.031).
24. Gilbert PJ, Polya DA, Cooke DA. Arsenic hazard in Cambodian rice from a market-based survey with a case study of Preak Russey village, Kandal Province. *Environ Geochem Health*. 2015 Aug; 37(4): 757-66. doi: [10.1007/s10653-015-9696-x](https://doi.org/10.1007/s10653-015-9696-x).
25. The situation of economic and social in December 2016. [cited 2017 Jan 25]. Available from: http://www.pso.hochiminhcity.gov.vn/c/document_library/get_file?uuid=fcdce0c6-c8bb-4687-81e0-a1567671a494&groupId=18.
26. Vietnam Trade Promotion Agency Export Promotion Center. Report on Vietnamese rice sector. [cited 2017 Jan 25]. Available from: https://www.aseankorea.org/aseanZone/downloadFile2.asp?boa_filenum=1595.
27. U.S. Food and Drug Administration [FDA]. Elemental analysis manual for food and related products - arsenic Speciation in rice and rice products using high performance liquid chromatography-inductively coupled plasma-mass spectrometric determination. [cited 2018 Jul 18]. Available from: <http://www.fda.gov/downloads/Food/FoodScienceResearch/LaboratoryMethods/UCM479987.pdf>.
28. U.S. Food and Drug Administration [FDA]. Elemental analysis manual for food and related products - Reference materials. [cited 2018 Jul 18]. Available from: <https://www.fda.gov/downloads/Food/FoodScienceResearch/LaboratoryMethods/UCM421144.pdf>.

29. Boertz J, Emteborg H, Charoud-Got J, Snell J, Held A, Emons H. Certification Report: the certification of the mass fractions of total arsenic, dimethylarsinic acid and the sum of arsenite and arsenate in rice. Luxembourg: Publications Office of the European Union; 2013.
30. U.S. Environmental Protection Agency [EPA]. Guidance on selecting age groups for monitoring and assessing childhood exposures to environmental contaminants. [cited 2018 Jul 18]. Available from: <https://www.epa.gov/sites/production/files/2013-09/documents/agegroups.pdf>.
31. U.S. Food and Drug Administration [FDA]. Arsenic in rice and rice products risk assessment report. FDA; 2016.
32. National Institute of Nutrition, UNICEF-Viet Nam. A review of the nutrition situation in Vietnam 2009-2010. Ha Noi: Medical Publishing House; 2011. Available from: http://www.unicef.org/vietnam/vi/A_Review_of_NU-SITAN_2009-2010.pdf.
33. Burlo F, Ramirez-Gandolfo A, Signes-Pastor AJ, Haris PI, Carbonell-Barrachina AA. Arsenic contents in Spanish infant rice, pureed infant foods, and rice. *J Food Sci*. 2012 Jan; 77(1): T15-9. doi: [10.1111/j.1750-3841.2011.02502.x](https://doi.org/10.1111/j.1750-3841.2011.02502.x).
34. Shibata T, Meng C, Umoren J, West H. Risk assessment of arsenic in rice cereal and other dietary sources for infants and toddlers in the U.S. *Int J Environ Res Public Health*. 2016 Mar; 13(4): 361. doi: [10.3390/ijerph13040361](https://doi.org/10.3390/ijerph13040361).
35. Tanabe CK, Ebeler SE, Nelson J. Fast analysis of arsenic species in infant rice cereals using LC-ICP-QQQ. [cited 2018 Jul 18]. Available from: https://www.agilent.com/cs/library/applications/5991-9488EN_as_baby_rice_lc-icp-qqq_application.pdf.
36. Joint FAO/WHO Expert Committee on Food Additives [JECFA]. Safety evaluation of certain contaminants in food. Geneva: WHO; 2011.
37. Le Nguyen BK, Le Thi H, Nguyen Do VA, Tran Thuy N, Nguyen Huu C, Thanh Do T, *et al*. Double burden of undernutrition and overnutrition in Vietnam in 2011: results of the SEANUTS study in 0.5-11-year-old children. *Br J Nutr*. 2013 Sep; 110(Suppl 3): S45-56. doi: [10.1017/S0007114513002080](https://doi.org/10.1017/S0007114513002080).
38. Association of Official Analytical Chemists [AOAC]. Appendix F: guidelines for standard method performance requirements. [cited 2018 Jul 18]. Available from: http://www.eoma.aoc.org/app_f.pdf.
39. Huber CS, Vale MGR, Dessuy MB, Svoboda M, Musil S, Dedina J. Sample preparation for arsenic speciation analysis in baby food by generation of substituted arsines with atomic absorption spectrometry detection. *Talanta*. 2017 Dec; 175: 406-12. doi: [10.1016/j.talanta.2017.07.055](https://doi.org/10.1016/j.talanta.2017.07.055).
40. Zmozinski AV, Llorente-Mirandes T, Lopez-Sanchez JF, da Silva MM. Establishment of a method for determination of arsenic species in seafood by LC-ICP-MS. *Food Chem*. 2015 Apr; 173: 1073-82. doi: [10.1016/j.foodchem.2014.10.102](https://doi.org/10.1016/j.foodchem.2014.10.102).
41. Llorente-Mirandes T, Barbero M, Rubio R, Lopez-Sanchez JF. Occurrence of inorganic arsenic in edible Shiitake (*Lentinula edodes*) products. *Food Chem*. 2014 Sep; 158: 207-15. doi: [10.1016/j.foodchem.2014.02.081](https://doi.org/10.1016/j.foodchem.2014.02.081).
42. Cerveira C, Pozebon D, de Moraes DP, de Fraga JCS. Speciation of inorganic arsenic in rice using hydride generation atomic absorption spectrometry (HG-AAS). *Anal Methods*. 2015; 7(11): 4528-34. doi: [10.1039/c5ay00563a](https://doi.org/10.1039/c5ay00563a).
43. Nachman KE, Love DC, Baron PA, Nigra AE, Murko M, Raber G, *et al*. Nitarsone, Inorganic arsenic, and other arsenic species in Turkey meat: exposure and risk assessment based on a 2014 U.S. Market Basket Sample. *Environ Health Perspect*. 2017 Mar; 125(3): 363-9. doi: [10.1289/EHP225](https://doi.org/10.1289/EHP225).
44. Maher W, Foster S, Krikowa F, Donner E, Lombi E. Measurement of inorganic arsenic species in rice after nitric acid extraction by HPLC-ICPMS: verification using XANES. *Environ Sci Technol*. 2013 Jun; 47(11): 5821-7. doi: [10.1021/es304299v](https://doi.org/10.1021/es304299v).
45. Signes-Pastor AJ, Carey M, Carbonell-Barrachina AA, Moreno-Jimenez E, Green AJ, Meharg AA. Geographical variation in inorganic arsenic in paddy field samples and commercial rice

- from the Iberian Peninsula. *Food Chem.* 2016 Jul; 202: 356-63. doi: [10.1016/j.foodchem.2016.01.117](https://doi.org/10.1016/j.foodchem.2016.01.117).
46. Batista BL, Souza JM, De Souza SS, Barbosa F Jr. Speciation of arsenic in rice and estimation of daily intake of different arsenic species by Brazilians through rice consumption. *J Hazard Mater.* 2011 Jul; 191(13): 342-8. doi: [10.1016/j.jhazmat.2011.04.087](https://doi.org/10.1016/j.jhazmat.2011.04.087).
47. Rintala EM, Ekholm P, Koivisto P, Peltonen K, Venalainen ER. The intake of inorganic arsenic from long grain rice and rice-based baby food in Finland - low safety margin warrants follow up. *Food Chem.* 2014 May; 150: 199-205. doi: [10.1016/j.foodchem.2013.10.155](https://doi.org/10.1016/j.foodchem.2013.10.155).
48. Sanz E, Munoz-Olivas R, Camara C, Sengupta MK, Ahamed S. Arsenic speciation in rice, straw, soil, hair and nails samples from the arsenic-affected areas of Middle and Lower Ganga plain. *J Environ Sci Health A Tox Hazard Subst Environ Eng.* 2007 Oct; 42(12): 1695-705. doi: [10.1080/10934520701564178](https://doi.org/10.1080/10934520701564178).
49. Sofuoglu SC, Guzelkaya H, Akgul O, Kavcar P, Kurucaovali F, Sofuoglu A. Speciated arsenic concentrations, exposure, and associated health risks for rice and bulgur. *Food Chem Toxicol.* 2014 Feb; 64: 184-91. doi: [10.1016/j.fct.2013.11.029](https://doi.org/10.1016/j.fct.2013.11.029).
50. Chen HL, Lee CC, Huang WJ, Huang HT, Wu YC, Hsu YC, *et al.* Arsenic speciation in rice and risk assessment of inorganic arsenic in Taiwan population. *Environ Sci Pollut Res Int.* 2016 Mar; 23(5): 4481-8. doi: [10.1007/s11356-015-5623-z](https://doi.org/10.1007/s11356-015-5623-z).
51. Cano-Lamadrid M, Munera-Picazo S, Burlo F, Hojjati M, Carbonell-Barrachina AA. Total and inorganic arsenic in Iranian rice. *J Food Sci.* 2015 May; 80(5): T1129-35. doi: [10.1111/1750-3841.12849](https://doi.org/10.1111/1750-3841.12849).
52. Williams PN, Price AH, Raab A, Hossain SA, Feldmann J, Meharg AA. Variation in arsenic speciation and concentration in paddy rice related to dietary exposure. *Environ Sci Technol.* 2005 Aug; 39(15): 5531-40. doi: [10.1021/es0502324](https://doi.org/10.1021/es0502324).
53. Ma L, Wang L, Jia Y, Yang Z. Arsenic speciation in locally grown rice grains from Hunan Province, China: spatial distribution and potential health risk. *Sci Total Environ.* 2016 Jul; 557-558: 438-44. doi: [10.1016/j.scitotenv.2016.03.051](https://doi.org/10.1016/j.scitotenv.2016.03.051).
54. Qian YZ, Chen C, Zhang Q, Li Y, Chen ZJ, Li M. Concentrations of cadmium, lead, mercury and arsenic in Chinese market milled rice and associated population health risk. *Food Control.* 2010 Dec; 21(12): 1757-63. doi: [10.1016/j.foodcont.2010.08.005](https://doi.org/10.1016/j.foodcont.2010.08.005).
55. Mihucz VG, Tatar E, Virag I, Zang C, Jao Y, Zaray G. Arsenic removal from rice by washing and cooking with water. *Food Chem.* 2007; 105(4): 1718-25. doi: [10.1016/j.foodchem.2007.04.057](https://doi.org/10.1016/j.foodchem.2007.04.057).
56. Zavala YJ, Duxbury JM. Arsenic in rice: I. Estimating normal levels of total arsenic in rice grain. *Environ Sci Technol.* 2008 May; 42(10): 3856-60. doi: [10.1021/es702747y](https://doi.org/10.1021/es702747y).
57. Williams PN, Raab A, Feldmann J, Meharg AA. Market basket survey shows elevated levels of as in South Central U.S. processed rice compared to California: consequences for human dietary exposure. *Environ Sci Technol.* 2007 Apr; 41(7): 2178-83. doi: [10.1021/es061489k](https://doi.org/10.1021/es061489k).
58. Hanh HT, Kim KW, Bang S, Hoa NM. Community exposure to arsenic in the Mekong river delta, Southern Vietnam. *J Environ Monit.* 2011 Jul; 13(7): 2025-32. doi: [10.1039/c1em10037h](https://doi.org/10.1039/c1em10037h).
59. Roberts LC, Hug SJ, Dittmar J, Voegelin A, Saha GC, Ali MA, *et al.* Spatial distribution and temporal variability of arsenic in irrigated rice fields in Bangladesh. 1. Irrigation water. *Environ Sci Technol.* 2007 Sep; 41(17): 5960-6. doi: [10.1021/es070298u](https://doi.org/10.1021/es070298u).
60. Dittmar J, Voegelin A, Roberts LC, Hug SJ, Saha GC, Ali MA, *et al.* Spatial distribution and temporal variability of arsenic in irrigated rice fields in Bangladesh. 2. Paddy soil. *Environ Sci Technol.* 2007 Sep; 41(17): 5967-72. doi: [10.1021/es0702972](https://doi.org/10.1021/es0702972).
61. Pal A, Chowdhury UK, Mondal D, Das B, Nayak B, Ghosh A, *et al.* Arsenic burden from cooked rice in the populations of arsenic affected and nonaffected areas and Kolkata City in West-Bengal, India. *Environ Sci Technol.* 2009 May; 43(9): 3349-55. doi: [10.1021/es803414j](https://doi.org/10.1021/es803414j).

62. Rahman MA, Hasegawa H. High levels of inorganic arsenic in rice in areas where arsenic-contaminated water is used for irrigation and cooking. *Sci Total Environ*. 2011 Oct; 409(22): 4645-55. doi: [10.1016/j.scitotenv.2011.07.068](https://doi.org/10.1016/j.scitotenv.2011.07.068).
63. Narukawa T, Hioki A, Chiba K. Speciation and monitoring test for inorganic arsenic in white rice flour. *J Agric Food Chem*. 2012 Feb; 60(4): 1122-7. doi: [10.1021/jf204240p](https://doi.org/10.1021/jf204240p).
64. FAO/WHO. UN strengthens regulations on lead in infant formula and arsenic in rice. [cited 2018 Jul 18]. Available from: <http://www.fao.org/news/story/en/item/238802/icode/>.
65. Ohno K, Yanase T, Matsuo Y, Kimura T, Rahman MH, Magara Y, *et al*. Arsenic intake via water and food by a population living in an arsenic-affected area of Bangladesh. *Sci Total Environ*. 2007 Aug; 381(13): 68-76. doi: [10.1016/j.scitotenv.2007.03.019](https://doi.org/10.1016/j.scitotenv.2007.03.019).
66. Kim JY, Kim WI, Kunhikrishnan A, Kang DW, Kim DH, Lee YJ, *et al*. Determination of arsenic species in rice grains using HPLC-ICP-MS. *Food Sci Biotechnol*. 2013 Dec; 22(6): 1509-13. doi: [10.1007/s10068-013-0245-z](https://doi.org/10.1007/s10068-013-0245-z).
67. Naito S, Matsumoto E, Shindoh K, Nishimura T. Effects of polishing, cooking, and storing on total arsenic and arsenic species concentrations in rice cultivated in Japan. *Food Chem*. 2015 Feb; 168: 294-301. doi: [10.1016/j.foodchem.2014.07.060](https://doi.org/10.1016/j.foodchem.2014.07.060).
68. Rasheed H, Kay P, Slack R, Gong YY. Arsenic species in wheat, raw and cooked rice: exposure and associated health implications. *Sci Total Environ*. 2018 Sep; 634: 366-73. doi: [10.1016/j.scitotenv.2018.03.339](https://doi.org/10.1016/j.scitotenv.2018.03.339).
69. European Food Safety Authority. Dietary exposure to inorganic arsenic in the European population. *EFSA Journal*. 2014; 12(3): 3597. doi: [10.2903/j.efsa.2014.3597](https://doi.org/10.2903/j.efsa.2014.3597).
70. Fontcuberta M, Calderon J, Villalbi JR, Centrich F, Portana S, Espelb A, *et al*. Total and inorganic arsenic in marketed food and associated health risks for the Catalan (Spain) population. *J Agric Food Chem*. 2011 Sep; 59(18): 10013-22. doi: [10.1021/jf2013502](https://doi.org/10.1021/jf2013502).
71. Li G, Sun GX, Williams PN, Nunes L, Zhu YG. Inorganic arsenic in Chinese food and its cancer risk. *Environ Int*. 2011 Oct; 37(7): 1219-25. doi: [10.1016/j.envint.2011.05.007](https://doi.org/10.1016/j.envint.2011.05.007).
72. Phan K, Sthiannopkao S, Heng S, Phan S, Huoy L, Wong MH, *et al*. Arsenic contamination in the food chain and its risk assessment of populations residing in the Mekong River basin of Cambodia. *Journal of Hazardous Materials*. 2013 Nov; 262: 1064-71. doi: [10.1016/j.jhazmat.2012.07.005](https://doi.org/10.1016/j.jhazmat.2012.07.005).
73. Smith NM, Lee R, Heitkemper DT, DeNicola Cafferky K, Haque A, Henderson AK. Inorganic arsenic in cooked rice and vegetables from Bangladeshi households. *Sci Total Environ*. 2006 Nov; 370(23): 294-301. doi: [10.1016/j.scitotenv.2006.06.010](https://doi.org/10.1016/j.scitotenv.2006.06.010).
74. Halder D, Biswas A, Slejkovec Z, Chatterjee D, Nriagu J, Jacks G, *et al*. Arsenic species in raw and cooked rice: implications for human health in rural Bengal. *Sci Total Environ*. 2014 Nov; 497-498: 200-8. doi: [10.1016/j.scitotenv.2014.07.075](https://doi.org/10.1016/j.scitotenv.2014.07.075).
75. Mantha M, Yeary E, Trent J, Creed PA, Kubachka K, Hanley T, *et al*. Estimating inorganic arsenic exposure from U.S. Rice and total water intakes. *Environ Health Perspect*. 2017 May; 125(5): 057005. doi: [10.1289/EHP418](https://doi.org/10.1289/EHP418).
76. Health Promotion Board. Report of the national nutrition survey 2010. Singapore: Health Promotion Board; 2010.
77. Ahn Y, Park SJ, Kwack HK, Kim MK, Ko KP, Kim SS. Rice-eating pattern and the risk of metabolic syndrome especially waist circumference in Korean Genome and Epidemiology Study (KoGES). *BMC Publ. Health*. 2013 Jan; 13: 61. doi: [10.1186/1471-2458-13-61](https://doi.org/10.1186/1471-2458-13-61).
78. Yuan YQ, Li F, Meng P, You J, Wu M, Li SG, *et al*. Gender difference on the association between dietary patterns and obesity in Chinese middle-aged and elderly populations. *Nutrients*. 2016 Jul; 8(8): 448. doi: [10.3390/nu8080448](https://doi.org/10.3390/nu8080448).
79. Phan K, Phan S, Heng S, Huoy L, Kim KW. Assessing arsenic intake from groundwater and rice by residents in Prey Veng province, Cambodia. *Environ Pollut*. 2014 Feb; 185: 84-9. doi: [10.1016/j.envpol.2013.10.022](https://doi.org/10.1016/j.envpol.2013.10.022).

-
80. Food and Agriculture Organization of the United Nations [FAO]. FAO Regional Conference for Asia and the Pacific: 34th Session: State of food and agriculture in Asia and the Pacific Region, including future prospects and emerging issues, 9-13 April 2018; Nadi, Fiji.
 81. Food and Agriculture Organization of the United Nations [FAO]. Regional overview of food security and nutrition: Asia and the Pacific. Bangkok: FAO; 2017.
 82. EFSA Panel on Contaminants in the Food Chain. Scientific opinion on arsenic in food. EFSA Journal. 2009; 7(10): 1351. doi: [10.2903/j.efsa.2009.1351](https://doi.org/10.2903/j.efsa.2009.1351).
 83. Sand S, Concha G, Öhrvik V, Abramsson L. Inorganic arsenic in rice and rice products on the Swedish market 2015. Part 2 - risk assessment. Livsmedelsverkets National Food Agency; 2016.
 84. Torres-Escribano S, Leal M, Velez D, Montoro R. Total and inorganic arsenic concentrations in rice sold in Spain, effect of cooking, and risk assessments. Environ Sci Technol. 2008 May; 42(10): 3867-72. doi: [10.1021/es071516m](https://doi.org/10.1021/es071516m).
 85. Chung SW, Lam CH, Chan BT. Total and inorganic arsenic in foods of the first Hong Kong total diet study. Food Addit Contam Part A Chem Anal Control Expo Risk Assess. 2014 Apr; 31(4): 650-7. doi: [10.1080/19440049.2013.877162](https://doi.org/10.1080/19440049.2013.877162).
 86. Ruttens A, Cheyns K, Blanpain AC, De Temmerman L, Waegeneers N. Arsenic speciation in food in Belgium. Part 2: cereals and cereal products. Food Chem Toxicol. 2018 Aug; 118: 32-41. doi: [10.1016/j.fct.2018.04.040](https://doi.org/10.1016/j.fct.2018.04.040).
 87. Li HB, Li J, Zhao D, Li C, Wang XJ, Sun HJ, *et al*. Arsenic relative bioavailability in rice using a mouse arsenic urinary excretion bioassay and its application to assess human health risk. Environ Sci Technol. 2017 Apr; 51(8): 4689-96. doi: [10.1021/acs.est.7b00495](https://doi.org/10.1021/acs.est.7b00495).
 88. Juhasz AL, Smith E, Weber J, Rees M, Rofe A, Kuchel T, *et al*. In vivo assessment of arsenic bioavailability in rice and its significance for human health risk assessment. Environ Health Perspect. 2006 Dec; 114(12): 1826-31. doi: [10.1289/ehp.9322](https://doi.org/10.1289/ehp.9322).

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