Environ Sci Pollut Res (2016) 23:4481–4488
DOI 10.1007/s11356-015-5623-z

RESEARCH ARTICLE

Arsenic speciation in rice and risk assessment of inorganic arsenic in Taiwan population

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Received: 12 May 2015 / Accepted: 15 October 2015 / Published online: 29 October 2015

Abstract This study assessed the total arsenic content and arsenic speciation in rice to determine the health risks associated with rice consumption in various age–gender subgroups in Taiwan. The average total arsenic levels in white rice and brown rice were 116.6±39.2 and 215.5±63.5 ng/g weight (n= 51 and 13), respectively. The cumulative cancer risk among males was 10.4/100,000. The highest fraction of inorganic/total arsenic content in white rice ranged from 76.9 to 88.2 % and from 81.0 to 96.5 % in brown rice. The current study found different arsenic speciation of rice in southern Taiwan, where the famous blackfoot disease has been reported compared with arsenic speciation from other Taiwan areas. Therefore, rice and other grains should be further monitored in southern Taiwan to evaluate whether arsenic contamination is well controlled in this area.

Keywords Arsenic · Inorganic arsenic · Cancer risk · Rice · Blackfoot disease · Risk assessment

Responsible editor: Philippe Garrigues

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Introduction

Arsenic naturally exists and also accumulates through industrial pollution and pesticide use (Hite 2013). Arsenic compounds are carcinogenic in humans whether received orally or by inhalation. They cause a variety of toxic effects in the gastrointestinal tract, circulatory system, skin, liver, kidney, nervous system, and heart in mice, rats, and hamsters (Brown 1994), and long-term exposure to arsenic from drinking water has been shown to have a dose–response relationship with an increased risk of diabetes mellitus and hypertension among residents of arseniasis-endemic areas in southwestern Taiwan and Bangladesh (Chen 2007). In many Asian countries, arsenic contamination has been detected in water used for drinking, irrigation, and cooking. Rice has been shown to be an indirect source of arsenic accumulation in human bodies (Rahman et al. 2008; Carbonell-Barrachina et al. 2012; Phan et al. 2014). Arsenic contamination in groundwater irrigation systems has caused serious health impact in Taiwan (Liang et al. 2011; Liao et al. 2011; Lu et al. 2011; Tseng et al. 1996), where it was referred to as blackfoot disease. Because rice is the primary staple food in Taiwan, determining the levels of arsenic, particularly in rice, is an issue of considerable importance.

Arsenic contamination of groundwater has attracted attention with regard to food safety (Ye et al. 2012), fish farming, and other applications (Hsu et al. 2012; Lin et al. 2004). Significant increases in arsenic concentration have been observed in rice grain and straw as a result of increases in arsenic content in the soil (Fu et al. 2011; Phan et al. 2013; Talukder et al. 2012). In soil-crop systems, arsenic bound with amorphous and crystalline hydrous oxides exhibit high availabilities in soils (Hsu et al. 2012), such that different arsenic speciation in groundwater can result in the transfer of arsenic through irrigated paddy fields. In contrast, another study has claimed that arsenic concentrations in rice grains are only weakly related to arsenic concentrations in the soil (Stroud et al. 2011). A combination of arsenic speciation, soil composition, and plant species may affect the uptake of arsenic (Bundschuh et al. 2012; Santra et al. 2013). Moreover, inorganic arsenic concentration can be further increased by cooking rice with arsenic-rich water (Rahman et al. 2011).

Inorganic arsenic, a human carcinogen, can be found in the environment and in various foods. Considerable quantities of arsenic are absorbed or concentrated in rice and vegetables, primarily in inorganic forms (Rahman et al. 2011).With regard to arsenic speciation, approximately 50 % of arsenic found in grains is inorganic (ranging from 10 to 90 %) (Zhu et al. 2008). Data obtained in the UK identified rice products with the highest arsenic contents (75.2–90.1 %) (Sun et al. 2009). Inorganic arsenic (arsenite and arsenate) comprise 80–91 % of the total arsenic found in rice from South Asia and Southeast Asia (Rahman et al. 2011; Smith et al. 2006), and elevated levels of inorganic arsenic in rice may be the main source of dietary inorganic arsenic.

In Spain, approximately 77 % of the arsenic content in pure infant rice samples was below 0.150 mg/kg (Carbonell-Barrachina et al. 2012). The mean level of arsenic in milled rice obtained from a Chinese market was 0.119 mg/kg (Qian et al. 2010). In Brazil, the mean level of total arsenic was 0.223 mg/kg (Batista et al. 2011). The cumulative cancer risk was calculated according to the dietary consumption of inorganic arsenic from a linear dose response for chronic exposure (Zhu et al. 2008). The upper range of the daily dose of arsenic by Cambodians exceeded the lower limits of the benchmark dose (BMDL) for a 0.5 % increase in the incidence of lung cancer [$BMDL_{0.5}$ was equal to 3.0-μg/day/kg body weight (BW)] (Phan et al. 2013). In Turkey, 93 % of the participants who consumed rice resulted in a cancer risk that exceeded acceptable levels (Sofuoglu et al. 2014). Rice is a staple food in Taiwan; therefore, the dietary exposure to inorganic arsenic and details of the arsenic speciation in rice are important matters. Our study focused on the associated health risk of rice consumption for various age–gender subgroups in Taiwan. The data provide a valuable reference for establishing agricultural control strategies for dealing with arsenic contamination.

Materials and methods

Rice sampling

First, we tabulated the total rice production in 18 cities and counties in Taiwan from the yearly report of the Council of Agriculture, Executive Yuan, Taiwan, 2011. Rice production in each town and village was ranked, and then, the top 1–3 in each city or county were selected for this study. Samples were purchased from the rice husking industry and from markets in towns or villages in the selected top 1–3 localities. We asked, 'Is the rice cultivated locally?', and if the answer was 'Yes,' then we used those samples in this study. Overall, 51 white rice varieties and 13 brown rice varieties produced in 18 regions around Taiwan during 2011 were studied, all of them cultivated locally. Then, a total of 15, 12, 4, and 20 samples were collected from central, eastern, northern, and southern Taiwan, respectively. This included the areas known for "blackfoot disease" in southern Taiwan. The rice samples were put in plastic bags at room temperature and homogenized separately. The homogenized rice was further sieved through a 250-μm mesh and put into a sterilized centrifugal tube for storage until analysis.

Measurement of total arsenic in rice

The rice samples were processed using the methods outlined by Huang et al. (2012). To facilitate digestion, 0.1 g of dry rice flour was weighed and placed in a 20-mL ultrahigh-purity perfluoroalkoxy (PFA) Teflon tube with 2.5 mL ultrapure nitric acid (HNO_3, analytical grade, Merck) and 0.25 mL of 30 % ultrapure hydrogen peroxide (H_2O_2, TAMAPURE-AA-100). The samples were then digested using a 1600-W microwave oven (Mars, microwave digestion system, CEM) set at 50 % power. The temperature regime was calibrated to raise the temperature to 110 °C within 10 min, to hold at 110 °C for 10 min, and then to cool to room temperature. The digestion solution was subsequently filtered using a 0.45-μm syringe-type polyvinylidene difluoride (PVDF) membrane filter with the addition of 0.2 % HNO_3 to a final volume of 10 mL. Inductively coupled plasma–mass spectroscopy (ICP-MS, PerkinElmer SCIEX ELAN DRC II, San Jose, CA, USA) was used to analyze the total arsenic concentrations.

Measurement of arsenic speciation in rice

Samples were processed using the methods outlined by Narukawa et al. (2008). Arsenic speciation included arsenite [As(III)], arsenate [As(V)], monomethylarsinic acid (MMA), and dimethylarsinic acid (DMA). Water was used as the extraction solvent; a suspension of 0.1 g dry rice flour in 10 mL water was centrifuged at 4000 rpm for 10 min, and then, the supernatant was passed through a 0.45-μm syringe-type PVDF membrane filter. The filtrate was then analyzed for arsenic speciation. The rice flour and water solutions were placed in 50-mL PFA Teflon tubes for microwave-assisted extraction under the following conditions. The temperature was increased from room temperature to 80 °C over a period of 5 min, held at 80 °C for 30 min, and then cooled to room temperature over10 min. Speciation was quantified using high-performance liquid chromatography (HPLC) connected to an ICP-MS (PerkinElmer Series 200 Pump connected to PerkinElmer ELAN DRC II). A PRP-X100 10-μm anion exchange column (250×4.1-mm ID; Hamilton, Reno, NV, USA) was used with a mobile phase of 95 % of 20 mM ammonium bicarbonate (NH_4HCO_3) and 5 % of ammonium sulfate [$(NH_4)_2SO_4$], adjusted to pH 8.3 using ammonia.

Data quality control

For the analysis of total arsenic content, an internal standard (100 μL of 10 μg/L Rh) was added to the filtered solution for quality control. The accuracy of the analytical methods and instruments were validated using certified reference material from the National Metrology Institute of Japan (NMIJ CRM 7503-a). In this study, the recovery efficiency tests for arsenic were conducted using the same sample analysis procedure although with the addition of a standard solution prior to extraction. The calculated recoveries ranged between 79 and 126 % for total arsenic, As(III), As(V), DMA, and MMA. The detection limit was determined according to a selected concentration slightly lower than the lowest concentration of the calibration curve. Measurements at this concentration were repeated seven times to estimate the standard deviation, and the detection limit was set to three times this standard deviation. The instrument detection limits were 12, 90, 140, 80, and 120 ng/L, and the method detection limits were 410, 250, 140, 80, and 1350 ng/L for total arsenic, As(III), As(V), DMA, and MMA, respectively.

Cancer risk assessment of daily rice intake for inorganic arsenic

Inorganic arsenic has been recognized as a human carcinogen by the International Agency for Research on Cancer (IARC), and it has been shown to cause cancers of the lung, urinary bladder, kidney, skin, liver, and prostate in human epidemiology studies (IARC Monographs—100C). It is also defined as a human carcinogen based on the increased lung cancer mortality and the increased mortality from multiple internal organ cancers (liver, kidney, lung, skin, and bladder) that were observed in populations consuming drinking water high in inorganic arsenic (Integrated Risk Information System, IRIS, by US Environmental Protection Agency, arsenic, inorganic (CASRN 7440-38-2)). To assess the risk of cancer in a population with a lifetime exposure to arsenic, the oral slope factor of 1.5 mg/kg/day^{-1} in skin cancer by uptake drinking water (Cohen 2006; FAO/WHO 2010) was used for calculations. The daily intake of inorganic arsenic from daily rice consumption was calculated by multiplying the concentration (ng/g) of inorganic arsenic in rice and the consumption rate (g/day) in various age groups. The formula used to determine the lifetime average daily dose (LADD) is

$$\mathrm{LADD_{ingestion}}\left(\mathrm{mg}/\mathrm{kg}/\mathrm{day}\right) = \frac{C \times \mathrm{IR_{ingestion}} \times \mathrm{AF}}{\mathrm{BW}} \times \frac{\mathrm{ED}}{\mathrm{AT}} \quad (1)$$

where C is the inorganic As concentration (μg/g) in rice, $\mathrm{IR_{ingestion}}$ is the daily consumption of rice (g/day) in each age group according to survey results related to the diet of the Taiwanese population, AF is the absorption factor (%) (100 % was used in the present study), BW is the body weight (kg) based on the average BW of Taiwanese people in each age group, ED is the exposure duration (year), and AT is the averaging time (year).

The formula used to calculate the cancer risk is

$$\mathrm{Risk} = \mathrm{LADD_{ingestion}} \times \text{oral slope factor} \quad (2)$$

where the oral slope factor is 1.5 mg/kg/day^{-1} (FAO/WHO 2010).

Non-carcinogenic risk assessment of daily rice intake for total arsenic

The formula used to calculate the average daily dose ($\mathrm{ADD_{ingestion}}$) is

$$\mathrm{ADD_{ingestion}}\left(\mu\mathrm{g}/\mathrm{kg}/\mathrm{week}\right) = \frac{C \times \mathrm{IR_{ingestion}} \times \mathrm{AF} \times 7\ \text{days}}{\mathrm{BW}} \quad (3)$$

where C is the total arsenic concentration (μg/g) in rice, $\mathrm{IR_{ingestion}}$ is the daily consumption of rice (g/day) in each age group, AF is the absorption factor (%) (100 % was adapted in the present study), and BW is the body weight (kg) based on the average BW of Taiwanese in each age group.

The hazard index (HI) was calculated as follows:

$$\mathrm{HI} = \frac{\mathrm{ADD_{ingestion}}}{\mathrm{RfD}} \quad (4)$$

where the reference dose (RfD) is 15 μg/kg/day (FAO/WHO 2010).

Results and discussion

Arsenic and its speciation in Taiwanese rice

The average total arsenic content in white rice and brown rice ranged from 116.6±39.2 to 215.5±63.5 ng/g fresh weight in Taiwan (Table 1). Among the arsenic species in white and brown rice samples, As(III) had the highest content, which

Table 1 Total arsenic (t-As) and As species concentration (ng/g fresh weight) in Taiwan commercial rice

	t-As	As(III) (ng/g)	As(V) (ng/g)	DMA (ng/g)	MMA (ng/g)
White rice (*n*=51)	116.6 (39.2)	61.6 (19.2)	4.3 (6.5)	12.1 (10.9)	2.7 (8.1)
Brown rice (*n*=13)	215.5 (63.5)	103.9 (45.0)	2.20 (1.2)	12.80 (9.8)	ND

*S*tandard deviation in parenthesis

ND means non-detectable

ranged from 61.6±19.2 to 103.9±45.0 ng/g fresh weight. DMA had the second highest content, which ranged from 12.1±10.9 to 12.8±9.8 ng/g fresh weight, followed by As(V), which ranged from 4.3±6.5 to 2.20±1.2 ng/g fresh weight. MMA was nearly undetectable in brown rice. Among the 51 samples of white rice, the total arsenic content of two samples exceeded 200 ng/g and two samples of brown rice exceeded 300 ng/g (data not shown). Significantly lower levels of total arsenic content were found in the current study (Table 2) compared to the previous study in Taiwan (average level 383 ng/g weight) (Williams et al. 2005). Our results were also lower than total arsenic contents obtained for Brazil (215–348 ng/g weight), Finland (0.11–0.65 mg/kg) (Rintala et al. 2014), USA (225–440 ng/g weight), Bangladesh (131–610 ng/g weight), the USA (0.22 mg/kg), and Thailand (0.15 mg/kg) (Adomako et al. 2011; Batista et al. 2011). The total content of organic arsenic in our study was also lower than results from other studies (Adomako et al. 2011; Batista et al. 2011; Rintala et al. 2014). However, our results were equal to or higher than those from Ghana (0.11 mg/kg) (Adomako et al. 2011), Japan (average level 95 ng/g weight), India (46–80 ng/g weight), Thailand (110 ng/g weight), and Spain (170 ng/g weight). Regarding inorganic arsenic, the levels of As(III) were higher than As(V), and DMA was the most significant species in the present study. Our results are comparable to those from another study where the percentages of arsenic species were 38.7, 39.7, 3.7, and 17.8 for DMA, As(III), MMA, and As(V), respectively (Batista et al. 2011). Therefore, in these studies, inorganic arsenic (As III and As V) and DMA were the predominant forms in the rice samples.

Fractions of inorganic and organic arsenic in Taiwanese rice samples

In white rice obtained from various locations in Taiwan (Table 3), the highest fraction for inorganic/organic arsenic was obtained from eastern Taiwan (88.2:11.8) and the lowest was from southern Taiwan (76.9:23.1). For brown rice, the highest fraction was obtained from eastern Taiwan (96.5:3.5) and the lowest was from southern Taiwan (81.0:19.0). Brown rice was shown to possess a higher percentage of inorganic arsenic compared with white rice. The samples in southern Taiwan showed a marginally significant difference to those from other locations (Kruskal-Wallis test, p=0.06; data not shown). This suggests that the samples obtained in southern Taiwan, where the famous blackfoot disease has been reported, may have different arsenic species compared with those from other locations in Taiwan. Rahman et al. (2006) claimed that the cooking process increased the concentration of arsenic, particularly rice boiled in water from arsenic-contaminated areas (O'Neill et al. 2013). Nonetheless, it has been demonstrated that arsenite can be removed via washing and cooking processes (Mihucz et al. 2007). Up to 57 % of the arsenic can be removed from rice using the traditional rice cooking methods of the Indian subcontinent (wash until clear, cook rice in water at a ratio of 1:6, and discard excess water). Approximately half of the arsenic can be lost in the wash water and half in the discarded water (Sengupta et al. 2006). We estimated the daily intake of arsenic in rice consumption without cooking, which represents an external dose; however, the internal dose could be less than the external dose if the cooking process is considered. Therefore, the result could be an underestimation because the internal dose from rice consumption was not verified.

Relationship between inorganic and organic arsenic

We examined the relationship between total and inorganic arsenic contents in rice (Fig. 1). The median association was determined between total and inorganic arsenic (R^2=0.330, p<0.0001). A few of the samples from southern Taiwan presented high total arsenic contents with low inorganic arsenic contents. This is a clear indication that the organic/inorganic arsenic fraction in southern Taiwan, the area with blackfoot disease, differs from samples from other locations (Table 3).

Daily intake of inorganic arsenic and exposure risk assessment from rice consumption

The cumulative risk of Taiwanese people developing cancer by ingesting inorganic arsenic through the daily consumption of rice is presented in Table 4. In each age group, the highest ADD was obtained for the population under 6 years old (male 1.36–1.59×10^{-5} and female 1.03–1.33×10^{-5}). The cumulative LADD and cancer risk, respectively, were 6.90×10^{-5} and 1.04×10^{-4} among males and 5.25×$10^{-5}$and 7.87×10^{-5}

Table 2 Total As and As species concentration (ng/g fresh weight) in rice from other countries

Countries	Rice	AsB	As^{3+}	As^{5+}	DMA	MMA	t-As	References
Taiwan	White rice	–	247 (110–510)	–	37 (30–50)	32 (15–60)	383 (190–760)	Williams et al. 2005
China	White rice	–	114 (51–302)	40 (24–86)	40 (9–147)	1.3 (7–13)	230 (19–586)	Zhu et al. 2008
	Brown rice	–	210	–	90	10	360	Meharg et al. 2008
Japan	White rice	–	71	13	11	0	95	Narukawa et al. 2008
Brazil	White rice	–	78 (40–156)	34 (16–62)	93 (39–258)	8 (0–29)	223 (109–376)	Batista et al. 2011
	Boiling white rice	–	87 (45–127)	43 (24–60)	65 (17–139)	10 (0–51)	215 (108–367)	
	Brown rice	–	146 (139–151)	42 (37–51)	127 (70–206)	11 (0–18)	348 (271–428)	
USA	White rice	–	76 (20–100)	42 (32–51)	77 (50–260)	<limit of detection (LOD)	277 (170–400)	Williams et al. 2005
	White rice	–	92 (79–101)	–	137 (141–136)	–	329 (308–350)	Zhu et al. 2008
	White rice	–	110	–	155 (40–302)	<LOD	280	Meharg et al. 2008
	Brown rice	–	105 (60–140)	–	90 (10–150)	<LOD	225 (110–340)	Williams et al. 2005
	Brown rice	–	170	–	–	10	440	Meharg et al. 2008
Canada	Wild rice	–	45 (10–80)	–	10	<LOD	65 (20–110)	Williams et al. 2005
Indian	White rice	–	27 (20–40)	–	66	0.7	46 (30–50)	Williams et al. 2005
	Brown rice	–	40	–	<LOD	<LOD	70	Williams et al. 2005
	Red rice	–	50	–	10	<LOD	80	Williams et al. 2005
Indian/ Bangladesh	Rice	4 (2–11)	240 (110–341)	40 (0–137)	5 (1–16)	1 (0–4)	354 (143–637)	Sanz et al. 2007
Bangladesh	Rice	–	83 (10–210)	–	19 (0–50)	–	131 (30–300)	Williams et al. 2005
	Brown rice	–	280	–	170	10	610	Meharg et al. 2008
Thailand	Light yellow rice	–	80	–	60	<LOD	110	Williams et al. 2005
Spain	Spain rice	–	80	–	50	<LOD	170	Williams et al. 2005

among females. Higher cumulative cancer risks were observed for males than for females. Meanwhile, the hazard index was less than 1 for all populations (Table 5). The mean and 95th percentile of exposures to inorganic arsenic in Hong Kong calculated using 600 composite samples were 0.22 and 0.38 μg/kg BW/day with cereals and cereal products

Table 3 Ratio of inorganic/organic As in white rice and brown rice (%)

Rice species	White rice				Brown rice		
Area	Midst (n=15)	East (n=12)	North (n=4)	South (n=7)	Midst (n=2)	East (n=4)	North (n=7)
Organic-As (%)	12.2	11.8	17.2	23.1	3.5	7.0	19.0
Inorganic-As (%)	87.8	88.2	82.8	76.9	96.5	93.0	81.0

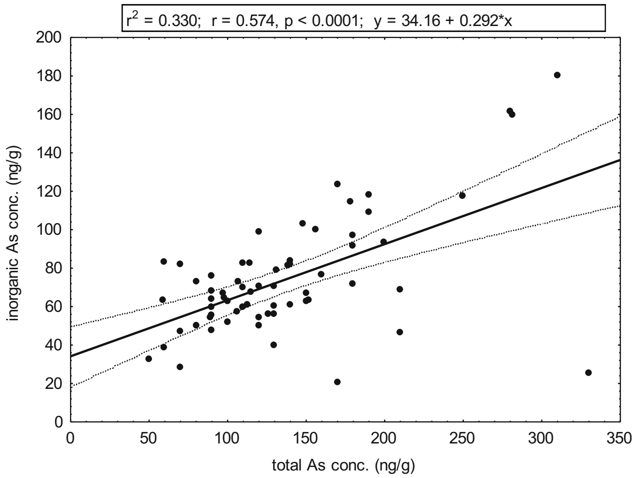

Fig. 1 Ratio of inorganic/organic As in white rice (**a**) and brown rice (**b**) (%)

(particularly rice) contributing 53.5 % of the total exposure (Wong et al. 2013). In Finland, the estimated inorganic arsenic intake from long-grain rice and rice-based baby foods were close to the lowest $BMDL_{0.1}$ value of 0.3 μg/kg BW/day set by European Food Safety Authority (EFSA) for every age group (Rintala et al. 2014). In Cambodia, the upper end of the daily dose of inorganic arsenic intake from daily food consumption ranged from 0.089 to 8.386 μg/kg BW/day, which was higher than the lower limits of the benchmark dose for a 0.5 % increase in the incidence of lung cancer ($BMDL_{0.5}$ is equal to 3.0 μg/kg BW/day) (Phan et al. 2014; Phan et al. 2013). In various regions of Brazil, the daily intake of inorganic arsenic due to rice consumption was estimated at 10 % of the provisional tolerable daily intake (PTDI) (150 μg/day) with daily ingestion of 88 g of rice (Batista et al. 2011). In Bangladesh, the daily dose was 0.15± 0.11 mg/day (range 0.043–0.49) from water, cooked rice, solid food, and cereals. The primary contributor to total arsenic intake was cooked rice (56 %) (Ohno et al. 2007). Other studies have reported results, in which total arsenic ADI was 1176 μg/day (range 419 to 2053 μg/day) with 14 % attributed to inorganic arsenic from cooked rice in Bangladesh households (Smith et al. 2006), 560 and 393 μg/day for adults and children, respectively (Santra et al. 2013). The intake of arsenic through rice as a food source was 0.20–0.35 mg/day per adult (Azizur Rahman et al. 2008). In the Chinese population, the daily intake of inorganic arsenic was approximately 42 μg/day, with rice as the largest contributor of inorganic arsenic, accounting for approximately 60 % of the total arsenic (Li et al. 2011). Our study calculated an average daily intake of 0.079 to 0.104 μg/kg BW/day in Taiwan. The results showed that arsenic content in rice did not vary a great deal but daily intake varied considerably due to differences in consumption habits. In the adult Chinese population, the incremental lifetime risk of cancer from food intake was 106 per 100,000 (Li et al. 2011). In a gold/silver mining area, the rate was shown to be 1 per 1000, which far exceeds the acceptable risk of 1 per 10,000 that was established for regulatory purposes (Lee et al. 2008). All of these findings were higher than that in the present study (female 7.9 per 100,000 and male 10.4 per 100,000). Meanwhile, the non-cancer health hazard index for the daily intake of rice showed that the toxic risk due to arsenic was 7.8 times greater than the reference dosage (Lee et al. 2008),

Table 4 Cumulative cancer risk of inorganic As from daily rice in Taiwan

Age group	Sex	LADD (mg/kg/day)	Cancer risk
0–3	Male	1.59×10^{-5}	2.39×10^{-5}
	Female	1.33×10^{-5}	2.00×10^{-5}
3–6	Male	1.36×10^{-5}	2.04×10^{-5}
	Female	1.03×10^{-5}	1.55×10^{-5}
6–12	Male	$9.79E\times10^{-6}$	1.47×10^{-5}
	Female	8.26×10^{-6}	1.24×10^{-5}
12–16	Male	7.63×10^{-6}	1.14×10^{-5}
	Female	5.05×10^{-6}	7.58×10^{-6}
16–18	Male	7.36×10^{-6}	1.10×10^{-5}
	Female	3.90×10^{-6}	5.85×10^{-6}
19–65	Male	6.83×10^{-6}	1.02×10^{-5}
	Female	4.96×10^{-6}	7.44×10^{-6}
>=65	Male	7.92×10^{-6}	1.19×10^{-5}
	Female	6.65×10^{-6}	9.98×10^{-6}
Total	Male	6.90×10^{-5}	1.04×10^{-4}
	Female	5.25×10^{-5}	7.87×10^{-5}

Table 5 Hazard index (HI) of daily intake for inorganic arsenic from rice in Taiwan

Age group	Sex	Average age	HI
0–3	Male	1.55	0.34
	Female	1.68	0.28
3–6	Male	5.1	0.29
	Female	5.06	0.22
6–12	Male	8.96	0.21
	Female	9	0.18
12–16	Male	13.39	0.16
	Female	13.3	0.11
16–18	Male	17	0.16
	Female	17	0.08
19–65	Male	43.66	0.15
	Female	43.29	0.11
>=65	Male	74.08	0.17
	Female	73.28	0.14

which was clearly higher than the findings in the present study (hazard index all less than 1 for each age group).

Conclusions

The average total arsenic levels in this study were 116.6 and 215.5 mg/kg in white rice and brown rice (n=51 and 13), respectively, and the average inorganic arsenic in white rice and brown rice were 65.9 and 106.1 mg/kg, respectively. Our estimation of inorganic arsenic intake from rice consumption indicated that the lifetime daily intake among Taiwanese was one of three of the lowest $BMDL_{0.1}$ value (0.3 μg/kg BW/day) set by EFSA. The cumulative cancer risk in males was 10.4 per 100,000. According to the current data, the intake of inorganic arsenic from rice was not as serious as those in other countries. However, to provide a complete risk assessment of all foodstuffs, the intake of arsenic from other grains should also be evaluated simultaneously in the future.

Acknowledgments We are in great debt to our colleagues at Department of Industrial Safety and Health, Hungkuang University, and the Research Center of Environmental Trace Toxic Substances, National Cheng Kung University Medical College for their analytical assistance. This study was supported by grants from Food and Drug Administration, Ministry of Health and Welfare.

Conflict of interest All authors have no conflict of interest.

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