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A Probabilistic Assessment of Human Health Risk from Arsenic-Contaminated Rice Grown Near The Mining Areas of Korea

Min-Kyoung Paik*, Won-Il Kim, Ji-Hyock Yoo, Jin-Kyoung Kim, Geon-Jae Im, and Moo-Ki Hong

Department of Crop Life Safety, National Academy of Agricultural Science, Rural Development Administration, Suwon 441-707, Korea

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ABSTRACT – Chronic exposure to Arsenic (As) causes significant human health effects including various cancers. Total As concentrations from 300 polished rice samples cultivated near the mining areas in Korea were analyzed to estimate a probabilistic assessment of human health risk from As-contaminated rice. The mean of total As concentrations in rice was 0.09 mg/kg and lognormal distribution model was set for total As concentrations. Human health risk for As in rice was estimated using gender-specific rice consumption data and average daily dose (ADD). While cancer risk (CR) and hazard quotient (HQ) were calculated using oral cancer slope factor (OCSF) and Reference dose (RfD) suggested by the U.S. EPA. Mean of CR posed by total As was 2.16 (for male) and 1.83 (for female) per 10,000. The HQ for general population from rice cultivated near the mining areas in Korea was below 1 as the 50^{th} percentile of general population. However, less than 10% of general population consuming rice cultivated near the mining areas would exceed 1.0. This result is similar with those from each gender-specific group.

Key words : arsenic, rice, mining area, probabilistic assessment

Arsenic (As) is a highly toxic and carcinogenic ubiquitous metalloid and is widely distributed in the environment through both natural and anthropogenic pathways, such as pesticide use, mining, or irrigation[1]. Chronic exposure to As causes significant human health effects including various cancers (skin, lungs, bladder and kidneys), skin disorders (hyperkeratosis and pigment changes), vascular disease and diabetes mellitus [2-5].

Arsenic is more elevated in rice than in other cereal crops such as wheat and barley[6]. Especially, rice is the primary source of inorganic As, a human carcinogen[7,8], into the human diet[9,10]. Because rice is the staple food in the Korean diet with up to 0.45 kg of rice being ingested per day by 95^{th} percentile population in Korea, consumption of As-contaminated rice may represent a significant As exposure pathway[11].

The United Kingdom has banned consumption of milk products made by rice for children under 4.5 years of age, and the European Food Safety Authority is currently reviewing rice[12]. Although international concerns about As contamination in agricultural foods have currently increased, there is no adequate standards for As particularly on agricultural commodities in Korea. On the other hand, China has set a ML of 150 μg/kg inorganic As in rice[13,14] and Australia (New Zealand) has determined As ML on cereal grains which is based on total As contents[15]. In addition, Japan has regulated the ML based on trioxide arsenite contents in agricultural commodities, which do not have legal restrictions[16]. Therefore, it is necessary to calculate the human health risk assessment from As throughout consumption of rice in order to supply a basic data useful on adequate risk management standard for As in Korea.

In this study, we investigated the concentration of total As in rice that was cultivated in the mining areas, and then estimated average daily As dose of groups divided by gender and inhabitant area-specific in Korea. To reduce the uncertainties in estimating exposure and to provide a more accurate estimate of risk, we used probabilistic estimation approach that can consider the uncertainty of output associated with the variation of input parameters in order to provide much useful information to risk[17]. And we used total As contents in rice for inorganic As contents of rice in calculating human health risk from As throughout rice consumption of Korean population, according to Williams *et al.*'s suggestion that total As must be assumed to represent the concentration of inorganic As of rice to ensure adequate protection to human health until sufficient speciation data is available for risk prediction[9].

*Correspondence to: Min-Kyoung Paik, Department of Crop Life Safety, National Academy of Agricultural Science, Rural Development Administration, Suwon 441-707, Korea
Tel: +82-31-290-0527, Fax: +82-31-290-0506
E-mail: mink1114@korea.kr

Material and Methods

Determination of Total As concentration in rice

Three hundred samples of polished rice were collected near fifty two mining areas of Korea in the year 2000. A portion (50 g) of ground rice was weighed into a crucible for dry digestion in furnace at 550°C. The digest was evaporated by adding conc. HNO_3 and were diluted to 25 ml with 0.1N HCl before analysis by inductive coupled plasma-OES (GBC Integra XMP, Melbourne, Australia).

Exposure Assessment

To estimate exposure via ingestion of As in rice grown near the mining areas in Korea, the Monte Carlo analysis was conducted using Crystal Ball® software. The following basic exposure equation was used.

$$ADD_r = \frac{C_r \times IR_r \times BF}{BW}$$

where

ADD_r = Arsenic daily dose of As from rice (mg/kg/day)

C_r = Arsenic concentration in rice (mg/kg)

IR_r = ingestion rate of rice (kg/day)

BF = relative bioavailability factor for As regarding consumption of cooked rice

BW = body weight of an exposed individual (kg)

Using the As concentrations of rice determined in this study, values below limit of detection (LOD) were assigned as one half of LOD. According to Juhasz *et al*' study, gut bioavailability of As, particularly inorganic As, in rice grain is 33 ± 3%[18]. Therefore, we used 0.33 as bioavailability factor in cooked rice in calculating exposure dose. The ADD_r was calculated using the body weight data in each group from KNHANES[11] (Table 1).

Risk characterization

The noncarcinogenic hazard quotient (HQ) and cancer risk (CR) from rice were calculated using the equations:

$CR = ADD_r \times OCSF$

$HQ = ADD_r / RfD$

where OCSF is the oral cancer slope factor and RfD is the reference dose (mg/kg/day). The parameters used in calculating the hazard quotients and cancer risks were based on standard EPA assumed values[19] (Table 1).

Results and Discussion

Arsenic levels in rice

Table 2 shows concentrations of total As in 300 rice samples obtained near the mining areas in Korea. Mean concentration of total As in rice samples was 0.09 mg/kg (6.58 mg/kg Max.) and the 95 % percentile value was 0.30 mg/kg. Lognormal distribution model for probabilistic estimation was set for total As concentrations in this study.

According to recent study of rice collected from agricultural area and marketplace of Korea, mean of total As concentration in rice were 0.09 mg/kg and 0.07 mg/kg, respectively for agricultural area and marketplace[20], which indicate that total As concentration in rice cultivated near the mining areas in Korea is similar those of rice cultivated at general agricultural land in Korea. However, Alam *et al.* reported that As concentrations of rice grain in Bangladesh ranged from 0.16 to 0.58 mg/kg (mean 0.35 mg/kg), which is largely due to As-contaminated soil and water[21]. Also, rice grown in some

Table 1. Parameters used to calculate As risk in each group

Parameter	Units	Object & Value		Description	Source	Reference
ADD_r	mg/kg/day	Calculated		Chronic arsenic daily dose	a	
IR_r	kg/day	General	0.22	Ingestion rate of rice	KNHANES(2007)[b]	11
		Male	0.24			
		Female	0.19			
BF	-	0.33		Bioavailability factor	Juhasz *et al.*(2006)	18
BW	kg	General	54.11	Body weight	KNHANS(2007)[b]	11
		Male	57.04			
		Female	51.56			
CR	-	Calculated		Calculated cancer risk	c	
HQ	-	Calculated		Calculated hazard quotient	d	
OCSF	-	1.5		Oral cancer slope factor[a]	EPA(1997)	19
RfD	mg/kg/day	0.0003		Oral reference dose value[a]	EPA(1997)	19

[a] $ADD_r = C_r \times IR_r \times BF \times 1/BW$

[b] KNHANS: Korea Health and Nutrition Examination Survey

[c] $CR = ADD_r \times OCSF$

[d] $HQ = ADD_r/RfD$

Table 2. Arsenic concentration of rice grown near the mining areas in Korea

(mg/kg)

Mean	Percentile value					Min.	Max.
	5th	25th	50th	75th	95th		
0.09	0.01	0.03	0.05	0.11	0.30	0.00	6.58

Table 3. ADD_r calculated from rice grown near the mining areas in Korea

(μg/kg/day)

Group		Mean	Percentile value					Min.	Max.
			5th	25th	50th	75th	95th		
General		0.13	0.01	0.03	0.07	0.16	0.47	0.00	4.70
Gender	Male	0.14	0.01	0.03	0.07	0.17	0.52	0.00	4.13
	Female	0.12	0.00	0.03	0.06	0.14	0.42	0.00	4.87

Table 4. Cancer risk calculated from rice grown near the mining areas in Korea

Group		Mean	Percentile value					Min.	Max.
			5th	25th	50th	75th	95th		
General		1.99E-04	8.03E-06	4.06E-05	1.03E-04	2.34E-04	7.00E-04	8.72E-09	7.05E-03
Gender	Male	2.16E-04	8.78E-06	4.37E-05	1.07E-04	2.50E-04	7.73E-04	1.74E-08	6.19E-03
	Female	1.83E-04	7.30E-06	3.81E-05	9.30E-05	2.15E-04	6.35E-04	4.14E-09	7.30E-03

regions of Bangladesh contained considerably higher As concentration in the cereal grains exceeds 1.7 mg/kg for total As concentrations[22]. According to the report of total As contents of polished grain, the median total As contents or rice from 10 countries varied 7-fold, with Egypt (0.04 mg/kg) and India (0.07 mg/kg) having the lowest As content while the U.S. (0.25 mg/kg) and France (0.28 mg/kg) had the highest content[18].

Schoof *et al.* found that rice has higher inorganic As concentrations than most other foods, and consequently, diets that rely heavily on rice may contain the most inorganic As[23]. Therefore, considering total As concentration analyzed in this study as inorganic As concentration, 11.6% (35 samples/ 300 total samples) of rice obtained near the mining areas in Korea would be illegal based on the inorganic arsenic ML of rice (0.15 mg/kg) in China.

Exposure assessment

Health risks of toxic materials, such as arsenic, are related to the absorbed dose[24]. Therefore, determination of bioavailability will reduce uncertainties in estimating exposure and provide a more accurate estimate of risk[25]. According to Juhasz *et al.*'s suggestion that As, particularly for inorganic As, from cooked rice grains is 33 ± 3%[18], we used 0.33 value as bioavailability factor in cooked rice in calculating exposure dose in this study.

ADD_r values that means chronic arsenic daily dose of As from rice were shown at Table 3. Mean ADD that was calculated from rice cultivated in mining areas for Korean general population was 0.13 μg/kg/day. The World Health Organization (WHO) suggested the arsenic maximum tolerable daily intake (MTDI) as 2 μg/kg[26]. According to the distribution data assessed probabilistically in this study, 0.15% of general population in Korea would exceed the MTDI value if assuming that total diet of general population in Korea consists mainly of rice cultivated near the mining areas in Korea. The ADD_r values at the 5th and 95th percentiles were 0.01 to 0.52 μg/kg/day for males and 0.00 to 0.42 μg/kg/day for females. Respectively, 0.13% for males and 0.12% for females exceeded the As MTDI of WHO.

Risk characterization

Cancer risk (CR) calculated using the probability approach was shown at Table 4. When calculating the arsenic CR, the oral cancer slope factor (OCSF) have been used as 1.5 mg/ kg/day, which is the value suggested by the Integrated Risk information System (IRIS)[19].

The acceptable or tolerable value of arsenic CR ranges from 10^{-6} - 10^{-4} for regulatory purposes[27]. The Mean CR value for general population calculated from rice grown near the mining areas in Korea was 1.19×10^{-4}, which means 1.19 per 10,000. About 49% of general population consuming rice cultivated near the mining areas in Korea was higher than the acceptable value in terms of CR. Means of CR were 2.16 (for male) and 1.83 (for female) per 10,000. Respectively 51.60% for Korean males and 47.02% for Korean females exceeded the acceptable value for CR, by just consuming the rice cultivated near the mining areas in Korea.

In order to quantify non-carcinogenic risk, the hazard

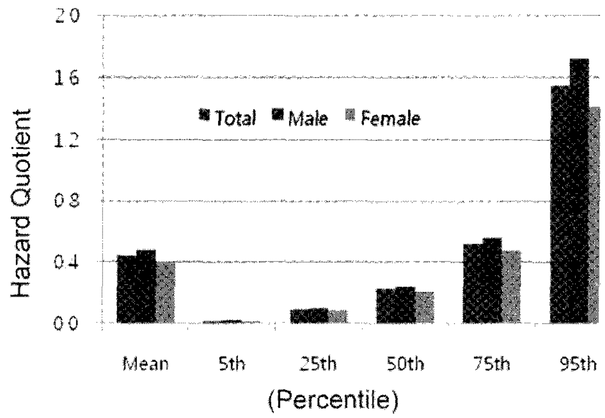

Fig. 1. Hazard Quotient calculated from rice grown near the mining areas in Korea.

quotient (HQ) was estimated by using ADD_r calculated in this study and reference dose (RfD) suggested by IRIS[19]. The HQ values calculated in this study were shown at Fig. 1. The mean of HQ from rice cultivated near the mining areas in Korea was higher than the HQ standard (1.0) recommended by the EPA[27], which means that if the HQ exceed 1.0, it may imply that toxicity can be caused by As. All mean hazard quotients of each group based on gender were below 1.0. According to the distribution data assessed probabilistically in this study, less than 10% of the general population consuming rice cultivated in the mining areas in Korea would exceed 1.0. The HQ values ranged from 0.02 to 1.55 for males and from 0.02 to 1.41 females (at the 5^{th} and 95^{th} percentiles). Respectively 10.95% for males and 9.08% for females would exceed 1.0 if they are exposured by just consuming the rice cultivated near the mining areas in Korea.

These results in this study showed that female have less susceptibility to the adverse health effects of chronic As exposure than male. This is similar with Wang *et al.*' report that showed increased prevalence for females to develop diabetes in the arsenic-endemic area in Taiwan[28]. Wang *et al.* concluded that the difference between male and female can be attributed to difference in lifestyle that can affect the accuracy of risk assessment such as poverty level or exposure via food between male and female. However, we calculated the HQ or CR values by using body weights and exposure dose via consumption of rice for each group, not considering the lifestyle such as poverty level. Therefore, we concluded that differences of risk assessment calculated between male and female in this study may be to mainly differences of body weights and ingestion rate of rice between male and female.

There are a lot of difficulties making the uncertainties in assessing the human health risk from food. First, the IRIS does not provide RfDs for the individual As species compounds, despite the difference of toxicity among each As species compounds[19]. Second, as Codex alimentarius commission said, there is no suitable analytical methods of As species in food[29]. Estimation by using total As concentrations do not indicate the true potential risk from As exposure and may cause overestimates the associated risk.

요 약

만성으로 비소에 노출될 경우 암을 비롯하여 인체에 심각한 악영향이 나타날 수 있다. 본 연구에서는 우리나라의 광산인근에서 재배된 벼의 백미시료 300점에 함유된 총 비소를 분석하고, 이 백미 시료만을 섭취했을 경우의 인체위험도를 확률적 접근법을 이용하여 평가하였다. 300점의 백미에 함유된 총 비소의 함량은 0.09 mg/kg으로 lognormal 분포형태를 나타내었다. 우리나라 전체인구와 성별로 나눠이 백미시료만을 섭취했을 경우 1일 총비소 노출량을 평가하였으며, EPA의 발암력과 기준참고치를 근거로 발암위해와 비발암위해를 정량화하였다. 광산인근 백미 섭취를 통한 발암위해의 평균은 만명기준 남성 2.16명, 여성 1.83으로 나타났으며, 전체국민의 비발암위해는 50% percentile에서 1.0 이하로 나타났다. 광산인근 백미만을 섭취하는 경우 전체 인근의 10% 미만이 비발암위해를 보이는 것으로 나타났다. 그러나, 이는 우리나라 광산인근에서 재배된 300점 백미시료에 대한 자료를 근거로 도출된 결과로서 우리나라 모든 광산인근 지역의 백미를 대표할 수 없는 한계가 존재한다.

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