

Arsenic accumulation in Rice

Current status and future management options

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Accumulation of arsenic (As) from soils-water system to human diets poses a serious health risk to humans, as it is considered the class I carcinogenic element. Arsenic contaminated groundwater is used not only for drinking purpose but also for crop irrigation, particularly for paddy rice, in South and South-East Asian countries. In India, arsenic contaminated groundwater has been used extensively to irrigate paddy rice, particularly during the rabi season. Rice has a higher tendency for As uptake than other cereals as it is grown in submerged soil conditions. Rice is the staple food over half of the world's population. Rice consumption represents a major route for As exposure in many countries, especially for people with a substantial proportion of rice in their daily diet. Thus, scientific management approaches combined with proper diet and creating public awareness on potential health risks resulting from exposure of As through rice, could play a key role in risk minimization.

Keywords: Arsenic, Irrigation water, Management options, Potential health risk, Rice

THE problem of arsenic (As) contamination in irrigation water and loading in edible parts is one of the most alarming factors threatens health risk for more than 150 million people all over the world live in 10 countries in South and South-east Asia: Bangladesh, Cambodia, China, India, Laos, Myanmar, Nepal, Pakistan, Taiwan and Vietnam. In different parts of the world where groundwater As contamination and human suffering exist, the magnitude is considered to be by far the highest in Bangladesh, followed by West Bengal, India. The exact sequence of geochemical reactions leading to As contamination in groundwater is still debated. Arsenic is the 20th abundant element in earth crust, and is ubiquitous in the environment. Its high toxicity and increased appearance in the biosphere have triggered public and political concern. The occurrence of high As in ground water was first reported in 1978 in West Bengal in India. The most affected areas in West Bengal are on the eastern side of the Bhagirathi

river in the districts of Maldah, Murshidabad, Nadia, North 24 Parganas and South 24 Parganas and western side of the districts of Howrah, Hooghly and Burdwan. Arsenic contaminated groundwater is used not only for drinking purpose but also for crop irrigation, particularly for the paddy rice (*Oryza sativa* L.), in south and southeastern Asian countries. In India, As contaminated groundwater has been used extensively to irrigate paddy rice, particularly during the *rabi* season.

Origins of As in groundwater in India is broadly geogenic. In Bengal Delta Plain (BDP), the sources of As may be (i) Transported by the River Ganges and its tributaries, (ii) Transported by the north Bengal tributaries of Bhagirathi and Padma and (iii) Transported with the fluvial sediments from the Himalayas, which is considered today as the most accepted hypothesis. Recently, two major hypotheses were proposed to account for such widespread As contamination in the groundwater in parts of West Bengal and Bangladesh

confined within the delta bound by the rivers Bhagirathi and Ganga-Padma. Of these two hypotheses, namely the arsenopyrite oxidation hypothesis and the ferric oxyhydroxide reduction hypothesis, the latter is more consistent with the experimental observations reported for the aquifer sediments and water of the Bengal delta basin.

Arsenic contamination in Rice

Rice is a major component of the basic diet for half the world's population. Arsenic in rice is a serious concern for about three billion people across the world who consumes rice as a staple food, and millions of them may be at risk of developing As related health problems. For them, rice is the primary source of carbohydrates, minerals, and essential vitamins. It is one of the most important food crops in terms of calorie intake and nutrition. It is recommended as a gluten-free substitute in the diet for people with celiac disease. It is frequently one of the first food

choices for infants due to its palatability and low risk of allergy. Arsenic uptake and accumulation in rice plants have raised environmental health concerns, which can have adverse impacts on the quality, security, marketability, and profitability of rice and its products. Rice has a higher tendency for As uptake than other cereals as it is grown in submerged soil conditions, where As availability is higher than under oxidizing conditions. Consequently, the reductive mobilization greatly enhances the bioavailability of As to rice, leading to higher sequestration in rice grain and straw. Rice paddy can take up to ten times more As than other commercial crops, such as maize from contaminated soils. Recently, researchers also reported that transability of As from soil to areal parts also varied among different cultivars. A number of studies have reported the grain-As content is also impacted by the combined influences of soil characteristics, environmental conditions, and crop management as well as rice varieties. Researchers focused on the effects of As contaminated soils and irrigation water on its uptake in root, shoot, husk and grain of rice and its metabolism in rice.

Major Health Concerns

Increasing levels of As in agricultural soils from contaminated underground irrigation water, and its uptake in rice, vegetables, and other food crops have become a real health emergency in this region. A number of recent studies report that another major source of As exposure is through the regular consumption of rice cultivated and irrigated with As-contaminated groundwater.

The amount of rice consumed determines the risk of human exposure. Health concern of As in rice grains is due to the large quantity of average daily per capita consumption of rice (0.4 kg/day) in Asian countries such as Bangladesh and India (Table 1). This is the prime cause of increasing concerns regarding the As content in food, as it is associated with carcinogenicity and a number of multiple adverse health consequences.

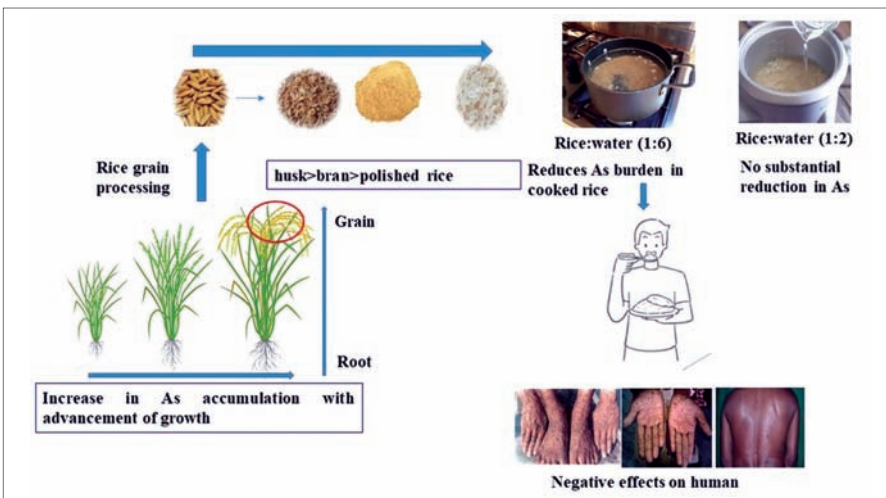


Fig. 1. Entry of arsenic from soil-water system to human through rice consumption.

There have been many studies focusing on the risk assessment of human exposure to As. Studies showed that the lifetime cancer risk (ILCR) in West Bengal, India was 7.62×10^{-4} which is many folds higher than the threshold value (10^{-4} – 10^{-6}) stipulated by United States Environmental Protection Agency (USEPA). The future prediction on As content in Bangladesh demonstrated that, the As content in rice grain will be increased upto ~0.15 to 0.25–0.58 mg kg⁻¹ by 2050 under current irrigation practices in Bangladesh. This increase in As content in rice grain subsequently enhances the human As intake by 1.5–3.8 fold through rice consumption (Fig. 1). In human, common symptoms of chronic As toxicity are pigmentation and keratosis. Apart from these symptoms, arsenicosis produces

problems such as weakness, chronic respiratory disease, peripheral neuropathy, liver fibrosis, genotoxic effects, cardiovascular diseases, peripheral vascular disease, conjunctivitis, cardiovascular diseases, gangrene and skin cancer, pre-malignant skin lesions, bladder and lung cancer. WHO confirmed the maximum permissible limit for irrigation purpose is 0.05 mg L⁻¹, for rice as 1 mg kg⁻¹, while it is 0.15 and 0.5 mg kg⁻¹ as prescribed by USDA and EU, respectively.

Management options: Way forward

The accumulation of As in a major edible crop like rice remains a serious threat to our food security. A clear understanding of the biogeochemical fate of As, as well as effective yet inexpensive soil/water treatment options, is the need of the hour. Rice

Table 1. Arsenic content (mg kg⁻¹) in popular rice varieties grown in arsenic affected areas of India and Bangladesh

Country	Rice genotypes	As content in grain	References
India	IR-36	0.41 ± 0.19	Dwivedi <i>et al.</i> (2010)
	IR-64	0.41 ± 0.02	Dwivedi <i>et al.</i> (2010)
	Gotrabhog (IET-19226)	0.52 ± 0.06	Dwivedi <i>et al.</i> (2010)
	Khitish	0.49 ± 0.001	Rahaman <i>et al.</i> , 2012
	Red minikit	0.17–0.57	Bhattacharya <i>et al.</i> (2010)
	Megi	0.11–0.43	Bhattacharya <i>et al.</i> (2010)
	Satabdi	0.180–0.310	Meharg <i>et al.</i> (2009)
	Swarna	0.44 ± 0.009	Rahaman <i>et al.</i> , 2012
	Ratna	0.55 ± 0.001	Rahaman <i>et al.</i> , 2012
Bangladesh	BRRI dhan28	0.23 ± 0.05	Rahman <i>et al.</i> (2007a)
	BRRI dhan29	0.16 ± 0.08	Khan <i>et al.</i> (2009)
	BRRI dhan35	0.20 ± 0.03	Khan <i>et al.</i> (2009)
	BRRI dhan36	0.18 ± 0.05	Khan <i>et al.</i> (2009)
	BRRI hybrid dhan1	0.14 ± 0.04	Khan <i>et al.</i> (2009)
	BRRI dhan29	0.21–0.86	Islam <i>et al.</i> , 2016
	BRRI dhan33	0.23–0.75	Islam <i>et al.</i> , 2016

cultivation requires a lot of water and groundwater serves as the main source of irrigation, particularly in *boro* cultivation (December to April). In Asia, typical amount of water needed for irrigated (*boro*) and *kharif* rice ranges 1300-1500 and 1500-2000 mm, respectively. In *kharif* season, there is a necessity for additional irrigation keeping in view of sparse distribution of rainfall. It is not economically feasible to filter a huge amount of water before applying into the field. Therefore, two options are left; either to stop *boro* cultivation or to adopt low accumulating rice genotypes for cultivation or to grow cultivars with proper management practices. Management strategies for restricting As entry in rice, thus lowering its subsequent transfer to the food chain, can be achieved by agronomic and biotechnological approaches.

The primary agronomic approach includes the supply of nutrients (e.g., iron, phosphorus, sulfur, silicon) *via* inorganic amendments. The supplied nutrients (P, Zn and Si) can compete with bioavailable As for uptake by rice. Application of Fe fertilizers restricts As entry into rice plant through the formation of Fe plaque on the root surface. Water management techniques are another option to stop As accumulation in rice. In high As polluted areas, conjunctive use of groundwater with

non-contaminated surface water/harvested rain water can restrict As supply through irrigation. Application of organic amendments like FYM, vermicompost and manure can form insoluble complexes with As and check the As entry to rice plant.

In addition to agronomic strategies, the selection of low As accumulating varieties is another possible option. Researchers showed that, rice varieties differ in As accumulation even grown under similar soil condition because of their genetic variability.

As content can further be reduced in final consumable form (cooked rice) through different processing and cooking methods. It has been observed during the processing of raw rice for human consumption, a significant amount of As get deducted through the removal of husk and bran-polish. Arsenic content in brown rice or polished rice is further reduced by wash. It has been reported that As content can reduce by 71-83% through three-time washing (Naito et al., 2015). Arsenic concentration in polish rice is further reduced during cooking with excess water. Thus, the As concentration in cooked rice is much lower than the raw rice. Thus, processing of rice and cooking method significantly contribute in lowering As load in the food chain through rice consumption. Thus,

proper selection of rice varieties, selection of better management options and processing and cooking methods can minimize the loading of As in the food chain.

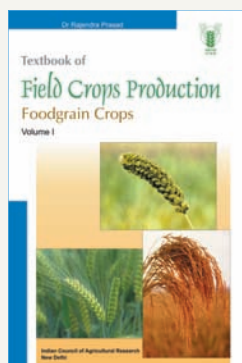
SUMMARY

Naturally occurring As has been detected in many parts of the world, and populations of south-east Asian countries are adversely affected through drinking water and food. This has resulted in a significant change in food dietary intake with Rice now being a staple food for half of the world's populations. As a consequence, consumption of inorganic As through rice poses significant health risks including cancers to humans. Paddy rice accumulates As from the soil and irrigation water and the ingestion of this As-contaminated rice acts as an exposure route to humans in any stage of life. Arsenic also has a negative effect on the growth, yield and quality of rice. Therefore, much more awareness is needed to understand the propagation of arsenic in the rice and restricting As loading in the food chain and overall, providing arsenic safe food to millions of people in the affected region regions.

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