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Arsenic retention in cooked rice: Effects of rice type, cooking water, and indigenous cooking methods in West Bengal, India

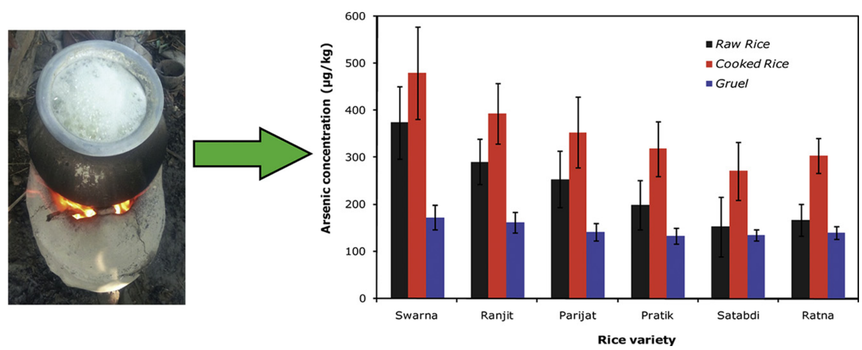
Ujjal Mandal [a], Payel Singh [a,b], Amit Kumar Kundu [a], Debashis Chatterjee [a,*], Jerome Nriagu [c], Subhamoy Bhowmick [b,*]

[a] Department of Chemistry, University of Kalyani, Kalyani, Nadia, West Bengal 741235, India
[b] Kolkata Zonal Center, CSIR-National Environmental Engineering Research Institute (NEERI), Kolkata, West Bengal 700107, India
[c] Department of Environmental Health Sciences, School of Public Health, University of Michigan, 109 Observatory Street, Ann Arbor, MI 48109-2029, USA

HIGHLIGHTS

- Paired raw and cooked rice prepared by individual households was assessed.
- Cooking with arsenic-rich groundwater elevated cooked rice arsenic concentration.
- The habit of drinking gruel heightened the arsenic risk for the local communities.
- Arsenic in raw rice and cooking water influence arsenic accumulation in cooked form.
- Use of low-arsenic water for cooking alleviates arsenic exposure from cooked rice.

GRAPHICAL ABSTRACT



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ABSTRACT

This study evaluated the concentration of arsenic in paired raw and cooked rice prepared by individual households in arsenic-endemic rural area of West Bengal. The aim was to investigate how the cooking habits of rural villagers of West Bengal might influence the arsenic content of rice meals. It was found that the use of arsenic-rich groundwater for cooking could elevate the arsenic concentration in cooked rice (up to 129% above the raw sample), thereby enhancing the vulnerability of the rural population of West Bengal to arsenic exposure through rice consumption. The risk is heightened by the habit of drinking the stewed rice water (gruel) in the local communities. The cooking method employed, rice variety, background arsenic concentration in raw rice and cooking water arsenic concentration were found to be important predisposing factors that could affect the accumulation of arsenic in cooked form. The fundamental indigenous cooking practice followed by the villagers requires use of low-arsenic water for cooking as a necessary strategy to alleviate arsenic exposure in their staple food.

1. Introduction

Human civilization has encountered the poisonous effect of arsenic for thousands of years (Nriagu, 2002; Cullen, 2008). Arsenic exposure above certain dosage can result in a wide array of health conditions which includes hematological, endocrine, cardiovascular, renal, hepatic,

* Corresponding authors.
E-mail addresses: dbchat2001@rediffmail.com (D. Chatterjee), subhamoy081984@gmail.com (S. Bhowmick).

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and dermal diseases (Rahman et al., 2009). It is now also well established that arsenic is a Class I carcinogen, manifesting itself in many types of cancers (ATSDR, 2007). Skin cancer is the most common manifestation of arsenic exposure (Ahsan et al., 2006; Yu et al., 2006; Bhowmick et al., 2014), while cancers of kidney, liver, bladder and lung have also been widely observed (Rahman et al., 2009).

In the last few decades, many articles have been published which show that millions of people worldwide are exposed to high levels of arsenic from drinking arsenic contaminated water (Nriagu et al., 2007; Ravenscroft et al., 2009 and references therein). Apart from drinking water, there has also been increasing concern over food security in terms of arsenic exposure from daily food stuff, especially rice (Mondal and Polya, 2008; Signes-Pastor et al., 2008; Chatterjee et al., 2010; Jitaru et al., 2016; Islam et al., 2017; Lee et al., 2018). Since rice has the potential to accumulate more arsenic than other food crops, rice intake has provided a facile route for arsenic exposure (Williams et al., 2007; Su et al., 2010). To add to the problem, the world's total production of rice is heavily concentrated in a few Asian countries with China, India, Indonesia, Bangladesh, Vietnam, Myanmar and Thailand, accounting for over 80% of global production (FAO, 2011). Rice grown in most of these countries is vulnerable to contamination with geogenic groundwater arsenic from irrigation processes (Ravenscroft et al., 2009). The flooding inherent in irrigation agriculture creates an anaerobic condition which increases the arsenic mobilization and bioavailability for rice uptake (Takahashi et al., 2004; Xu et al., 2008).

The risk posed from rice depends upon both the amount of rice consumed and the concentration of inorganic arsenic in rice grains, moderated by uptake rate in the gut (Althobiti et al., 2018). In this context, the problem is of particular concern for the people in Bengal delta plain (encompassing West Bengal, India and Bangladesh) where serious exposure can result from rice consumption (Meharg et al., 2009; Chatterjee et al., 2010; Mondal et al., 2010; Halder et al., 2013). The high rice intake for these population (up to 0.5 kg dry weight per day) along with elevated inorganic arsenic content in Bangladesh and Indian rice grains make the population particularly vulnerable to arsenic poisoning (Meharg et al., 2009; Halder et al., 2013). An investigation of arsenic exposure from drinking water versus rice intake by Halder et al. (2013) showed that for population with drinking water that has low arsenic concentration, the intake from only rice consumption can lead to an unsafe dose of exposure. The situation is further compounded as large variations in arsenic concentrations among different rice cultivars and rice genotype has been reported in the literature (Mondal and Polya, 2008; Meharg et al., 2009; Pal et al., 2009). It has been noted that arsenic content in rice grains is influenced by the grain size and color; brown colored rice and short and bold grain size have been observed to have more arsenic content compared to white rice and longer grain size rice respectively (Halder et al., 2012).

Previous studies of the risk of arsenic exposure from rice consumption have generally considered arsenic in raw (uncooked) rice. However, for proper risk estimation, it is important to consider the arsenic contamination in cooked rice, as this is the form which is ultimately consumed by the population (Jitaru et al., 2016). Studies have shown that the final concentration in cooked rice can be very different from that of the corresponding uncooked rice (Sengupta et al., 2006; Signes et al., 2008; Halder et al., 2014). The various factors that dictate the final arsenic concentration in cooked rice is still poorly understood and the various approaches for assessing the health risk from raw rice consumption may yield misleading results (Ackerman et al., 2005). With the exception of a few articles (Mondal and Polya, 2008; Ohno et al., 2009; Pal et al., 2009; Mondal et al., 2010), most of the studies have mainly mimicked the actual household cooking methods through laboratory-based cooking (Sengupta et al., 2006; Signes et al., 2008). Such evaluations may have some limitations as the indigenous cooking practice followed by the rural household can be markedly different especially in terms of the amount of cooking water used, container capacity, spices added and material and type of fuel used. Therefore investigations dealing with the indigenous cooking practice followed by the rural people along with paired raw-cooked rice analysis are essential for meaningful assessment of actual exposure risk.

In the present study, rice samples were cooked in individual households in rural Bengal following their traditional cooking methods. The aim of the study is to investigate the various independent factors such as rice varieties, cooked versus raw rice, and the arsenic content of cooking water in mediating the levels of arsenic in rice cooked according to traditional methods. Additionally, the use of arsenic-safe cooking water in decreasing arsenic content in cooked rice is explored as a strategy for reducing arsenic exposure for the local population.

2. Materials and method

2.1. Study area

The study area is located in Chaku danga village of Chakdaha block in Nadia district, West Bengal (Fig. 1). This area was previously reported to have high arsenic concentration in groundwater (Biswas et al., 2011). Agriculture is the main occupation for the people of these areas, with paddy rice and jute being the major crops that are grown. The agricultural system is highly dependent upon groundwater to meet the water requirement for irrigation of crops. The socio-economic conditions for the people are mostly below average.

A brief questionnaire survey was done in the studied area during the baseline assessment so as to get information about the household cooking practices followed, source of rice and water used for cooking, and the amount of rice cooked and consumed daily. The selection of households was guided by the following criteria: (i) should consume the widely used rice varieties (ii) income level, (iii) spatial representation to include households so as to have a wide coverage of the studied localities and, (iv) willing to permit the research staff to visit their homes while they are preparing food so as to collect paired raw and cooked rice samples as well as cooking water. The staff documented the cooking procedures and estimated the quantity of water and rice used for cooking.

2.2. Rice cooking and sample collection

For this study, rice was cooked in individual household following the traditional methods of the rural villagers. Generally, rice was washed 3–4 times with water and the washed rice was soaked in excess water for 15–20 min and finally cooked. After cooking, the excess starch water (gruel) was discarded by tilting the pan against the lid. As a control for arsenic in cooking water, Milli-Q water (18 MΩ) was taken from the laboratory to the field and was given to individual household for cooking. The entire cooking procedure as described above was done using the supplied Milli-Q water in the control experiments.

Water samples used for cooking (except the Milli-Q water) were collected from individual household in pre-washed polyethylene bottles. The water samples upon collection were acidified with ultrapure nitric acid (brought from laboratory to field) to bring the pH < 2. Raw rice samples were collected in individual plastic zipper bags labeled with characteristics code of each samples. The cooked rice samples was cooled to room temperature and was collected with marked characteristic code in individual plastic zipper bags. The starch water and rice-wash water were also collected in pre-washed polythene bottles. After returning to the laboratory, samples of cooked rice and starch water, water and rice-wash water, and raw rice were kept at −20 °C, 4 °C, and room temperature, respectively, until they were analyzed. Subsequently, the length and breadth of representative raw rice grains was measured by micrometer screw gauge and the grain size and shape of the rice grain was classified into short bold (SB), medium slender (MS) and long slender (LS), as described in Halder et al. (2012).