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# **Influence of cooking method on arsenic retention in cooked rice related to dietary exposure**

**M. Azizur Rahman<sup>1\*</sup>; H. Hasegawa<sup>1</sup>; M. Arifur Rahman<sup>2</sup>; M. Mahfuzur Rahman<sup>3</sup> and M. A.  
Majid Miah<sup>4</sup>**

<sup>1</sup>Graduate School of Natural Science & Technology, Kanazawa University, Kakuma, Kanazawa  
920-1192, Japan; <sup>2</sup>Bangladesh Centre for Advancement of Science (BCAS), Dhanmondi, Dhaka,  
Bangladesh; <sup>3</sup>Department of Botany, Jahangirnagar University, Savar, Dhaka-1342,  
Bangladesh; <sup>4</sup>Bangladesh Rice Research Institute (BRRI), Division of Soil Science, Gazipur,  
Bangladesh.

\*Corresponding author

Tel/Fax: +81-76-234-4792

E-mail: [arahman@stu.kanazawa-u.ac.jp](mailto:arahman@stu.kanazawa-u.ac.jp); [aziz\\_ju@yahoo.com](mailto:aziz_ju@yahoo.com)

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## **Abstract**

Arsenic concentration in raw rice is not only the determinant in actual dietary exposure. Though there have been many reports on arsenic content in raw rice and different tissues of rice plant, little is known about arsenic content retained in cooked rice after being cooked following the traditional cooking methods employed by the people of arsenic epidemic areas. A field level experiment was conducted in Bangladesh to investigate the influence of cooking methods on arsenic retention in cooked rice. Rice samples were collected directly from a severely arsenic affected area and also from an unaffected area, to compare the results. Rice was cooked according to the traditional methods employed by the population of subjected areas. Arsenic concentrations were  $0.40\pm 0.03$  and  $0.58\pm 0.12$  mg/kg in parboiled rice of arsenic affected area, cooked with excess water and  $1.35\pm 0.04$  and  $1.59\pm 0.07$  mg/kg in gruel for BRRI dhan28 and BRRI hybrid dhan1, respectively. In non-parboiled rice, arsenic concentrations were  $0.39\pm 0.04$  and  $0.44\pm 0.03$  mg/kg in rice cooked with excess water and  $1.62\pm 0.07$  and  $1.74\pm 0.05$  mg/kg in gruel for BRRI dhan28 and BRRI hybrid dhan1, respectively. Total arsenic content in rice, cooked with limited water (therefore gruel was absorbed completely by rice) were  $0.89\pm 0.07$  and  $1.08\pm 0.06$  mg/kg (parboiled) and  $0.75\pm 0.04$  and  $1.09\pm 0.06$  mg/kg (non-parboiled) for BRRI dhan28 and BRRI hybrid dhan1, respectively. Water used for cooking rice contained 0.13 and 0.01 mg of As/l for contaminated and non-contaminated areas, respectively. Arsenic concentrations in cooked parboiled and non-parboiled rice and gruel of non-contaminated area were significantly lower ( $p < 0.01$ ) than that of contaminated area. The results imply that cooking of arsenic contaminated rice with arsenic contaminated water increases its concentration in cooked rice.

## 1. Introduction

Arsenic contaminated groundwater is the main source of drinking water for about 90% of the total population (130 million) of Bangladesh (WHO, 2001) and an estimated 35-77 million people is exposed to arsenic contaminated drinking water (Rabbani et al., 2002) in this area. The source of arsenic in the ground water in Bangladesh remains undiscovered. However, it is believed that long term geological changes led to the release of arsenic from its core compound called arsenopyrites due to its oxidation by air reaching the underground aquifers through the tubewells conduits (Mandal et al., 1998). The other theory indicates that reduction of iron and manganese oxy-hydroxide is associated with arsenic release to groundwater (Kinniburgh and Smedley, 2001). The populations of Bangladesh have been used arsenic contaminated ground water not only for drinking purposes but also for rice cultivation, particularly during the dry season. About 33% of total arable lands of this country are under irrigation a facility (BBS, 1996), which is done mainly with underground water which become contaminated with very high level of arsenic (>50-500 ppb) (Meharg et al., 2003). Irrigation with arsenic contaminated groundwater is likely to increase its concentration in top soils of paddy fields and eventually in agricultural crops. Arsenic levels varied between 3.1 and 42.5  $\mu\text{g/g}$  in the 0-15 cm surface paddy soils and 0.058 and 1.83  $\mu\text{g/g}$  in rice grain of Bangladesh (Meharg et al., 2003). Meharg et al. (2003) reported ten-fold elevation of arsenic levels in rice grain grown in arsenic contaminated soil. They also reported variations in arsenic content for different rice varieties. Thus, though drinking water is the main source of arsenic in the environment, it is not the only source for human being. For the population living on subsistence rice diets, arsenic contaminated rice grain contributes greatly in its dietary intake (Mandal et al., 1998; Meharg, 2004). Previously, 1.83 mg of As/kg have been reported in rice grain collected from the arsenic affected areas of Bangladesh (Meharg et al., 2003). Thus, arsenic concentration in rice grain is newly uncovered disaster on a massive scale for the population of subsistence rice diet. Onken and Hossner (1995) reported that plants grown in soils treated with arsenic had higher rates of its uptake for similar rates of

growth compared to that of untreated soils. However, use of arsenic contaminated groundwater for rice cultivation could be another major route for arsenic intake in human body.

Recently, dietary exposure studies, that included evaluations of total arsenic in foods, have been reported for Canada (Dabeka et al., 1993), the United States (Gunderson, 1995) and Japan (Tsuda et al., 1995). The estimated daily intake of total arsenic varied substantially among the three countries from 38.6  $\mu\text{g}$  for young American males to 59.2  $\mu\text{g}$  for a similar age group of Canadian males, with much higher values being reported for Japanese females (160 to 280  $\mu\text{g}$ ) (Roychowdhury et al., 2002). In Asian arsenic endemic areas, a large proportion of the populations live on subsistence diets of rice- a cereal containing a relatively high amount of arsenic as compared to other agricultural products (Schoof et al., 1998; Schoof et al., 1999).

In the arsenic affected areas of Bangladesh, majority of the residents depend on rice for their caloric intake (about 70% of total) suggesting that rice is an important dietary source of arsenic for Bangladesh population (Bae et al., 2002). The residents of this area consume rice after being cooked traditionally with extensive water and gruel produced from rice is discarded after cooking though they also cook rice with limited water. Moreover, the residents cook rice for two times before consumption. Bae et al. (2002) reported increased arsenic concentrations in rice cooked with arsenic contaminated water. Thus, cooking rice with arsenic contaminated water may be an important source of arsenic and that the cooking process may further affect the concentration of this element in cooked rice. There have been some reports on arsenic in paddy rice related to dietary exposure (Meharg et al., 2003; Williams et al., 2005) and arsenic content in cooked rice (Schoof et al., 1999; Bae et al., 2002; Das et al., 2004; Ackerman et al., 2005). But, estimation of arsenic concentration in cooked rice of arsenic affected areas of Bangladesh, retained after being cooked traditionally, has been undiscovered. It is very important to investigate the content of arsenic in traditionally cooked rice to assess the actual dietary exposure of arsenic to the population of this arsenic epidemic area, from rice. The present study

had been undertaken to evaluate the effects of traditional cooking methods on arsenic retention in cooked rice.

## **2. Materials and methods**

### ***2.1. Sample Collection***

Three samples (1 kg) of each of the two rice (*Oryza sativa* L.) varieties (BRRI dhan28 and BRRI hybrid dhan1) were collected from three sampling points (2 m<sup>2</sup> of area). There were two locations in each of the two sampling areas. Soil samples (1 kg) were also collected from three points of 2m<sup>2</sup> areas and 10-15 cm depth of the selected plots using soil auger. Locations of the sampling areas are explained in figure 1 (arsenic contaminated) and figure 2 (arsenic non-contaminated). Samples were collected during harvest and sun dried immediately after collection, tagged properly, air tied in polyethylene bags and kept in room temperature for farther laboratory analysis.

Water samples (1 liter) were collected from shallow tubewells nearby the rice field from which irrigation has been performed. Water was sampled in polyethylene bottles from a uniform rate of discharging water, usually 10-20 minutes after pumping, which were then filtered through 0.45 Millipore filter paper. About 90 ml water was collected from each sampling points and preserved in the refrigerator at 4°C temperature with addition of 10 ml 2M hydrochloric acid.

### ***2.2. Treatment of raw rice***

In the present experiment, two standard methods were followed for cooking rice, employed commonly by the population of subjected areas. The cooking methods are explained in Figure 3.

#### ***i) Soaking***

800 gm of raw rice from both arsenic contaminated and non-contaminated areas were soaked in 1400 ml water, separately collected from the respective areas, for 36 hours at room temperature (25 to 32°C).

### ***ii) Parboiling***

Soaked raw rice was sieved by wire net (2.0 mm pore size) and water was discarded. However, the soaked raw rice was placed in a silver pot in such a way that about 25% grains remained under water in the pot. The pot was heated on an electric heater at 100°C for about 1.5 hours. The raw rice was parboiled by boiling water as well as steam generated from the water. The completion of parboiling of rice was determined by slightly opening the lemma and palea of the grain. Parboiled rice was then sieved by wire net (2.0 mm pore size) and water was discarded. The sieved parboiled rice was then sun dried to around 14% moisture content and preserved for milling.

### ***iii) Milling***

Both the parboiled and non-parboiled rice was dehulled in Satake Rice Mill. Hulls and brown rice were collected separately. The brown rice was further milled in a Satake Rice Testing Mills to remove 10% bran-polish. The bran-polish and polished/milled rice were collected separately.

### ***iii) Cooking***

In Bangladesh, most of the populations of arsenic affected areas have been used parboiled rice for cooking though in some areas, non-parboiled rice is also used. Moreover, the people of Bangladesh cook rice in different ways. Almost in all area, the populations cook rice with excess water and discard the gruel after cooking though in some area, they cook rice with limited water and no gruel remains after cooking. In this experiment both methods were taken in account.

The milled/polished rice was washed separately for three times with water collected from each of the two sampling areas. After washing, 250 ml (for cooking with excess water) and 100 ml (for cooking with limited water) of water was added to 50g of rice and boiled at 100°C temperature until the rice become soft. The cooked rice was drained on wire sieve to separate cooked rice and gruel. The cooked rice was dried in the sun and kept for analysis.

On the other hand, gruel was dried on the electric heater to almost dryness and dried in the sun.

The sun dried samples were further dried in the oven at 95-105°C for 2 h.

### ***2.3. Sample digestion procedure***

Soil and rice samples were digested following the heating block digestion procedure with  $\text{HNO}_2 + \text{HClO}_4 + \text{H}_2\text{SO}_4$  (Standard methods for soil analysis, 1994). Five ml of concentrated  $\text{HNO}_3$  was added to 0.2 g of dry sample in each of the 250 ml quartz glass digestion tubes and allowed to stand for overnight with covering the tubes under fume hood at room temperature. In the following day, tubes with sample were placed on a heating block and the temperature rose slowly to 90°C. After cooling, 3 ml of concentrated Perchloric acid and 1 ml of concentrated sulfuric acid were added to it. Again the tubes were heated at temperature raised slowly to 160°C until the dense white fumes of  $\text{HClO}_4$  occurred and reduced to about 2 ml. Williams et al. (2005) reported no loss of arsenic when rice samples were digested at 120°C and then evaporated to dryness at 160°C. The digests were then cooled and diluted to 25 ml with distilled deionized water and filtered through filter paper (Whatman No. 42 for soil and Whatman No. 41 for other samples) into plastic bottle.

### ***2.4. Total arsenic analysis***

Total arsenic content was determined from the digests by hydride generation atomic absorption spectrophotometer (FI-HG-AAS, Perkin-Elmer AAnalyst 100 fitted with flow injection analysis system, FIAS 100). All instruments were calibrated using matrix-matched standards. In each



analytical batch at least two reagent blanks, one spike and three duplicate samples were included in the acid digests to assess the accuracy of the chemical analysis. Recovery of arsenic for the spike was  $87.23 \pm 0.2\%$  in  $1.0 \mu\text{g/g}$  of rice sample and the accuracy was  $92.3 \pm 1.5$ . The presented data have not been corrected for this recovery.

## **2.5. Chemicals**

Nitric acid ( $\text{HNO}_3$ ) (70%), Sulfuric acid ( $\text{H}_2\text{SO}_4$ ), Perchloric acid ( $\text{HClO}_4$ ) and Sodium arsenate ( $\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$ ) were purchased from Merck. Other chemicals were from AnalaR. All the reagents were of analytical grade.

## **2.6. Statistical analysis**

The experimental data were statistically analyzed. The test of significance of different parameters was computed by t-test at 0.01 levels of significance by SPSS 10.1 for windows.

# **3. Results and Discussions**

## **3.1. Arsenic content in parboiled cooked rice**

Arsenic concentrations in parboiled rice of arsenic contaminated area, cooked with excess water were  $0.40 \pm 0.03$  and  $0.58 \pm 0.12$  mg/kg dry weight ( $n=3$ ) while those of limited water were  $0.89 \pm 0.07$  and  $1.08 \pm 0.06$  mg/kg dry weight ( $n=3$ ) for BIRRI dhan28 and BIRRI hybrid dhan1, respectively. The results imply that arsenic content in rice, cooked with limited water, was significantly higher ( $p < 0.01$ ) and about 44.95% more than that cooked with excess water. Arsenic contents in rice cooked with excess water were about 6.59% less than that of raw rice (Table 1), though gruel arsenic concentration was about 57.18% higher than that of raw rice.

In parboiled rice of non-contaminated area, arsenic contents were  $0.21 \pm 0.02$  and  $0.22 \pm 0.10$  mg/kg in rice cooked with excess and  $0.24 \pm 0.03$  and  $0.26 \pm 0.08$  mg/kg in rice cooked with limited water for BIRRI dhan28 and BIRRI hybrid dhan1, respectively ( $n=3$ ). The gruel arsenic

concentrations were statistically same for BRR1 dhan28 and BRR1 hybrid dhan1 ( $0.24\pm 0.03$  and  $0.26\pm 0.08$  mg/kg, respectively).

### ***3.2. Arsenic content in non-parboiled cooked rice***

In non-parboiled rice of arsenic contaminated area, arsenic concentrations ranged between  $1.62\pm 0.07$  and  $1.74\pm 0.05$  mg/kg for gruel cooked with excess water, which differ significantly ( $p < 0.01$ ) from that of cooked rice and about 75.92% higher. Total arsenic retained in rice cooked with limited water ranged from  $0.75\pm 0.04$  to  $1.09\pm 0.06$  mg/kg ( $n=3$ ), which is 13.50 to 36.69% higher than that of in raw rice and 27.0 to 59.63% higher than that of rice cooked with excess water. Arsenic in rice (excluding gruel) cooked with excess water was  $0.39\pm 0.04$  and  $0.44\pm 0.03$  mg/kg for BRR1 dhan28 and BRR1 hybrid dhan1, respectively which were less than that of raw rice (Table 2).

Cooked rice samples of arsenic non-contaminated area contained much lower concentrations of arsenic compared to that of arsenic contaminated area (Table 2). Rice of BRR1 dhan28 and BRR1 hybrid dhan1 cooked with excess water contained  $0.17\pm 0.02$  and  $0.28\pm 0.01$  mg As/kg, respectively while that of limited water contained  $0.26\pm 0.02$  and  $0.32\pm 0.01$  mg As/kg, respectively. The increase is about 1.92 to 2.34% which is significantly higher than that of arsenic contaminated area (27.0 to 59.63%). This was because, water used for rice cooking from arsenic non-contaminated area contained very low level of arsenic (about 0.04 mg/l, lower than the recommended safe level according to Bangladesh standard) compared to that of arsenic contaminated area (0.13 mg/L, very high than the recommended safe level) and arsenic absorption/adsorption in rice from water was insignificant. However, it is evident from the above discussions that arsenic concentrations in cooked rice have been affected by cooking method when the cooking rice and water were arsenic contaminated.

Arsenic concentrations in cooked rice of two rice varieties did not differ significantly from each other, rather the differences were observed between study areas containing different levels of

soil arsenic (Table 1 and 2). Thus, it can be suggested that arsenic concentrations in cooked rice have been influenced by the cooking method, arsenic concentrations in rice and water used for cooking. Cooking rice with excess water results in the decrease of arsenic concentration in cooked rice when gruel is discarded though arsenic concentration increased significantly when rice is cooked with limited water, whether the cooking water was arsenic contaminated or not. This is, perhaps, because some of the arsenic in cooking water is absorbed/adsorbed by the cooked rice and the water is evaporated. Arsenic concentrations in rice follows the trend: cooked rice (with limited water) > gruel > raw rice > cooked rice (with excess water) (Figure 4).

Meharg et al., (2003) also reported 1.83 mg/kg arsenic in rice grain collected from western Bangladesh. Bae et al., (2002) reported elevated concentrations of arsenic in cooked rice of arsenic affected areas of Bangladesh. They observed that when raw rice, containing 173.0 ng of As/g, is cooked with excess water (not mentioned the amount) the arsenic content in cooked rice was 10.0 to 35.0% higher than they had predicted. Roychowdhury et al. (2002) reported that mean ( $n=9$ ) arsenic concentrations in cooked rice was 378  $\mu\text{g}/\text{kg}$  whereas in raw rice, it was about 211.7  $\mu\text{g}/\text{kg}$  ( $n=8$ ). But the important finding of the present experiment is that when rice is cooked with excess water and the gruel is discarded, arsenic concentrations in cooked rice decreased. This is perhaps, because the water soluble arsenic from soft cooked rice is released in the cooking water at high temperature (100°C) and is discarded after cooking. However, it is notable that when rice is cooked with limited water and the gruel has not been discarded, arsenic concentration in cooked rice increased suggesting that arsenic from the cooking water is absorbed/adsorbed or concentrated by cooked rice. The phenomena can be explained more precisely by the hypothesis of Bae et al. (2002). If the hypothesis of Bae et al. (2002) is true, then it can be said that during cooking, water soluble arsenic is released from rice into the water and then either chelated by rice grain or concentrated by cooked rice because of evaporation. This hypothesis was also supported by Chakravarty et al. (2003), who reported about 66.6% retention of arsenic in cooked rice when rice was cooked in excess water and the gruel was

drained out, while the retention of arsenic was around 93.3% when gruel was not discarded. Huq et al. (2003) found that cooked rice contained different amounts of arsenic and they supposed the difference would be either due to the varietal differences of rice or variation in the concentrations of arsenic in cooking water. They also proposed that the method of cooking might also affect the amount of arsenic in cooked rice. The present study proved and stated that cooking method as well as the arsenic concentration in cooking water is the major parameters affecting the concentrations of arsenic in cooked rice rather than rice variety, though Meharg et al. (2003) reported variations in arsenic concentrations among different rice varieties.

In cooked rice, the source of total arsenic is the cooking rice and water (Bae et al., 2002). Thus, the percentage of water absorbed by the rice also affect the total arsenic in cooked rice, which is dependent on the type of rice and the way the rice is prepared (Ackerman et al., 2005). Duration of cooking could also affect in the arsenic concentrations in cooked rice.

There is no upper standard limit of arsenic in food for South and East Asian countries. In the United Kingdom and Australia, the maximum food hygiene standard level for the arsenic is 1.0 mg/kg (Warren et al., 2003). The present experiment showed that arsenic content in cooked rice remains much below the maximum permissible limit according to United Kingdom and Australia standard when it is cooked with excess amount of water and gruel is discarded, while it exceeded the permissible limit when cooked with limited water. As arsenic concentration in gruel was very high, there is an ample scope of arsenic deposition in cattle body as the discarded gruel has been feed the cattle.

### ***3.3. Dietary exposure of arsenic from rice***

The toxicity of an exposure is dependent both of the chemical form(s) of arsenic (Ackerman et al. 2005) and the total concentration though, traditionally, total arsenic have been used to asses the exposure from different food staffs (Bae et al., 2002; Duxbury et al., 2003; Abedin et al., 2002; Meharg et al., 2003). Very recently, Ackerman et al., (2005) investigated the total arsenic

concentrations and chemical form(s) in five different types of rice cooked in both contaminated drinking water and arsenic-free reagent water and found that the dimethylarsinic acid (DMA) and inorganic arsenic concentration ranged from 22 to 270 ng/g and from 31 to 108 ng/g of rice, respectively where the total arsenic concentration ranged from 99 to 345 ng/g. The results indicate that the percentage of dimethylarsinic acid (DMA) and inorganic arsenic in cooked rice ranged from 22.22 to 78.26 and about 31.30, respectively. Williams et al. (2005) reported  $64\pm 1\%$  ( $n=7$ ),  $80\pm 3\%$  ( $n=11$ ) and  $81\pm 4\%$  ( $n=15$ ) inorganic arsenic species in European, Bangladeshi and Indian rice, respectively. In the present experiment, total arsenic in cooked rice ranged from 0.40 to 1.08 mg/kg (parboiled) and 0.39 to 1.09 mg/kg (non-parboiled) and the inorganic arsenic species are predominant, according to the previous findings (Williams et al., 2005; Heitkemper et al., 2001; D'Amato et al., 2004), which are believed to be more toxic than methylated species (Cullen et al., 1989). Thus, dietary exposure of arsenic from cooked rice should not be ignored and obviously, rice is another significant source of arsenic for human being.

#### ***3.4. Arsenic intake in human body from cooked rice and drinking water: a comparative analysis***

Although many reports relied on the concentrations of arsenic in drinking water (Mazumder et al., 1998; Hopenhayn-Rich et al., 1998; Kurttio et al., 1998; Tondel et al., 1999; Bhattacharya et al., 2002; Anawar et al., 2002; Frisbie et al., 2002) as the surrogate of human exposure, potential individual consumption of water and additional exposure through food had been neglected. The biological dose indicators would neither give any information on the absolute intake level nor on the relative relevance of different arsenic sources, especially the importance of water versus food arsenic, which would be important in establishing risk assessment and in determining the priority for mitigation (Watanabe et al., 2004).

The average daily consumption of rice by an adult Bangladeshi male/female is between 400 and 650 g raw rice (Duxbury et al., 2003) and the average concentration of arsenic in raw rice was found to be  $0.57\pm 0.04$  -  $0.69\pm 0.21$  mg/kg in the present experiment. Thus, the expected daily intake of arsenic from raw rice has been estimated to be 0.25 - 0.36 mg (Table 3). However, the actual intake would be much higher than the expected value because of the use of arsenic contaminated water in rice cooking and also because of traditional cooking method. From this experiment, it was found that the cooked rice contained higher concentrations of arsenic than that of raw rice and the actual daily intake of arsenic from cooked rice was found to be 0.16 - 0.26 mg when the rice is cooked with excess arsenic contaminated water and the gruel is discarded after cooking (0.13 mg/l was the arsenic concentration in drinking and cooking water of the experimental area) though the value was be 0.36 - 0.56 mg when the rice is cooked with limited water and gruel is not discarded. This amount is much higher than that of drinking water. Infact, from these information it is crucial that the traditional cooking method of rice in arsenic epidemic areas of Bangladesh may contribute to high dietary intake of arsenic from rice grown in arsenic contaminated soil. Watanabe et al. (2004) estimated that rice grain containing 173 ng of As/g may exposed 90 and 52  $\mu\text{g}$  of arsenic/day to an adult male and female, respectively if they intake 523 and 300 g raw rice, respectively.

It is apparent that drinking water is the major source of arsenic for the population living in arsenic affected areas. People consume water in several ways. Direct water consumption (intake of water as drinking behavior) and indirect consumption (intake of water used for preparing food). WHO recommended 2 liter/day as the standard of direct water consumption by adults (Levallois et al., 1998). Water intake differs greatly from country to country and also from population to population as well as sex and age. It has been reported that Taiwanese male and female (weighting 55 and 50 kg, respectively) consume 3.5 and 2.0 liter of water/day, respectively as direct drinking (Abernathy et al., 1989; Brown et al., 1997). In tropical countries like Bangladesh and India, water consumption is normally very high. In a report on a population

of West Bengal, India, the average direct water consumption by males, females and children were described as 4, 3, and 2 liters/day, respectively (Chowdhury et al., 2000). The report also speculated that those who worked in the field drank as much as 6 liters a day. Most of the arsenic affected areas of Bangladesh are villages where people are involved in agrarian manual labor and the daily water consumption (directly) by an adult ranged between 4 and 6 liters (Alam et al., 2002). In the present report, the mean arsenic concentration in Shallow Tube Well's (STW) water of arsenic contaminated area, which has been used as drinking as well as cooking purposes, is recorded as 0.13 mg/l ( $n=6$ ). The concentration is much higher than the acceptable limit for arsenic in drinking water according to WHO standard (0.01 mg/l) and Bangladesh standard (0.05 mg/l). Thus, when the arsenic concentration in drinking water is 0.13 mg/l, as we found in the present study, a Bangladeshi adult is expected to intake 0.50 to 0.78 mg of arsenic/day only from drinking water (Table 3). Watanabe et al. (2004) also reported the total dietary intake of arsenic from direct drinking water as 0.46 mg/day. In West Bengal, India, the estimated amount of arsenic intake from direct drinking water has been reported as 1.0 mg/day (Chowdhury et al., 2001).

#### **4. Conclusion**

The present experiment suggest that, not only the As concentration in raw rice, but also the rice strain, cooking method and As concentration in cooking water influence its retention in cooked rice. Most important concern is that, gruel of both parboiled and non-parboiled rice contained very high amount of arsenic compared to cooked rice suggesting that discursion of gruel (as the local population do) decreases As concentration in cooked rice. Therefore, it is safer for the population of arsenic epidemic areas to cook rice with excess water to lessen the arsenic concentration in cooked rice rather than limited water but the discarded gruel should not feed the cattle.

However, the human exposure to arsenic from cooked rice in arsenic epidemic areas like Bangladesh and west Bengal, India would be a potential source along with drinking water. Thus, importance should be given in the mitigation of arsenic not only from drinking water but also from contaminated paddy soils to reduce arsenic concentrations in rice grain.

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**Table 1:** Arsenic contents in parboiled cooked rice and gruel <sup>a</sup>

Soil of study area (Soil As in ppm)	Test crop	Arsenic contents (mg/kg)			
		Raw rice	Cooked rice (with excess water) <sup>b</sup>	Gruel (with excess water)	Cooked rice (with limited water) <sup>c</sup>
As non-contaminated (6.03±0.06)	BRR1 dhan28	0.21±0.10c	0.21±0.02c	0.27±0.05c	0.24±0.03c
	BRR1 hybrid dhan1	0.24±0.00c	0.22±0.10c	0.29±0.03c	0.26±0.08c
As contaminated (14.51±0.12)	BRR1 dhan28	0.57±0.04b	0.40±0.03b	1.35±0.04b	0.89±0.07b
	BRR1 hybrid dhan1	0.69±0.21a	0.58±0.12a	1.59±0.07a	1.08±0.06a

<sup>a</sup>The results are expressed as mean± standard deviation of three independent replicates. Values having same letter do not differ significantly from each other at 1% level according to the Duncan Multiple Range Tests (DMRT).

<sup>b</sup>50 g of milled rice was cooked with 250 ml of water and therefore, a little amount of gruel (about 100 ml) remained after cooking.

<sup>c</sup> 50 g of milled rice was cooked with 100 ml of water in such a way that no gruel remained after cooking.

**Table 2:** Arsenic content in non-parboiled cooked rice and gruel <sup>a</sup>

Soil of study area (Soil As in ppm)	Test crop	Arsenic content (mg/kg)			
		Raw rice	Cooked rice (with excess water) <sup>b</sup>	Gruel (with excess water)	Cooked rice (with limited water) <sup>c</sup>
As non-contaminated (6.03±0.06)	BRRI dhan28	0.21±0.10c	0.17±0.02c	0.34±0.06c	0.26±0.02c
	BRRI hybrid dhan1	0.24±0.00c	0.28±0.01b	0.36±0.02c	0.32±0.01c
As contaminated (14.51±0.12)	BRRI dhan28	0.57±0.04b	0.39±0.04a	1.62±0.07b	0.75±0.04b
	BRRI hybrid dhan1	0.69±0.21a	0.44±0.03a	1.74±0.05ba	1.09±0.06a

<sup>a</sup> The results are expressed as mean± standard deviation of three independent replicates. Values having same letter do not differ significantly from each other at 5% level according to the Duncan Multiple Range Tests (DMRT).

<sup>b</sup> 50 g of milled rice was cooked with 250 ml of water and therefore, a little amount of gruel (about 100 ml) remained after cooking.

<sup>c</sup> 50 g of milled rice was cooked with 100 ml of water in such a way that no gruel remained after cooking.

**Table 3:** Daily intake of arsenic in human body from drinking water and cooked rice <sup>a</sup>

Source	Daily Consumption	Arsenic concentration (ppm)	Total intake of arsenic (ppm)
Drinking water	4.0 – 6.0 L	0.13	0.50– 0.78
Raw rice (uncooked)	400 - 650 g	0.57 – 0.69	0.25 – 0.36
Rice cooked with excess water	400 - 650 g	0.39 - 0.44	0.16 – 0.26
Rice cooked with limited water	400 - 650 g	0.75 - 1.09	0.36 - 0.56

<sup>a</sup>Table represents data for the population of two arsenic affected areas of Bangladesh.

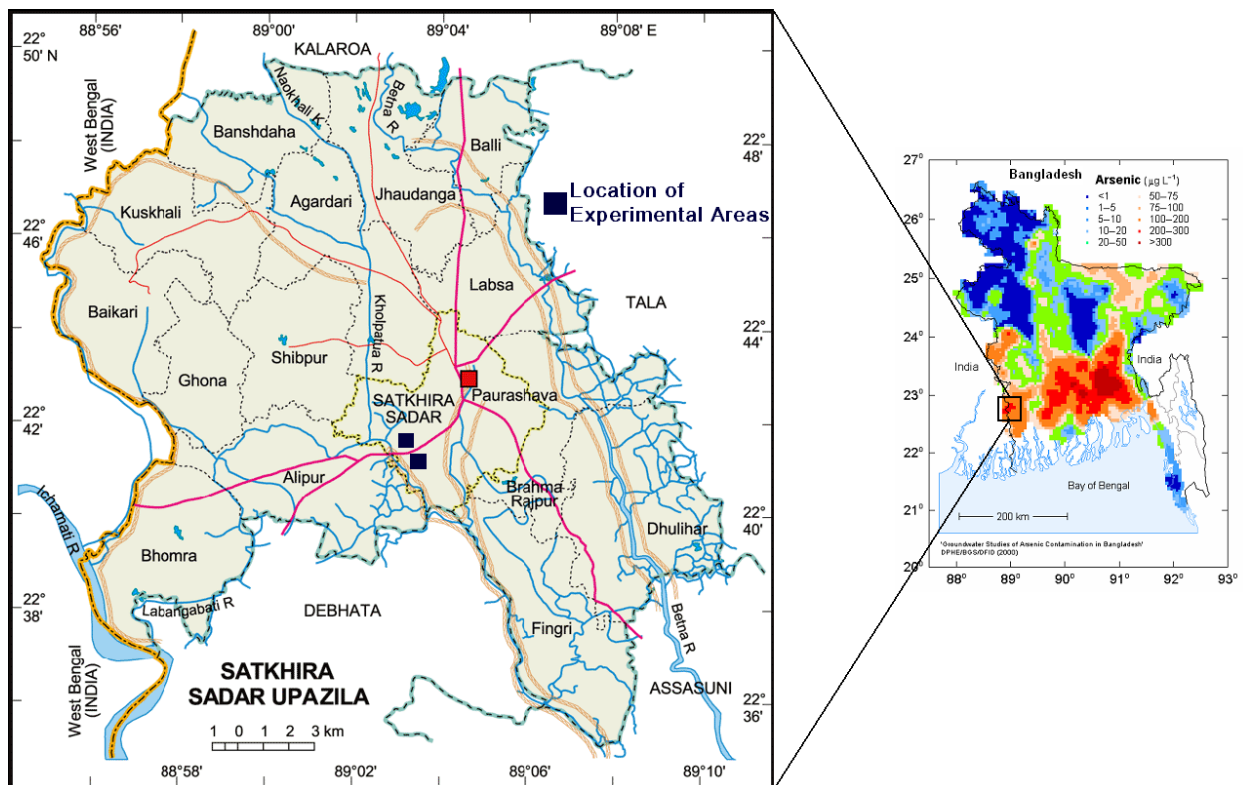


Figure 1: Site map of sampling locations; Itagasa and Guddirdangi village of Satkhira sador thana in Satkhira district, Bangladesh is on of the severely arsenic contaminated areas. The sampling area was located at 22°40'- 22 ° 42' altitudes and 89°02'- 89°04' longitude.



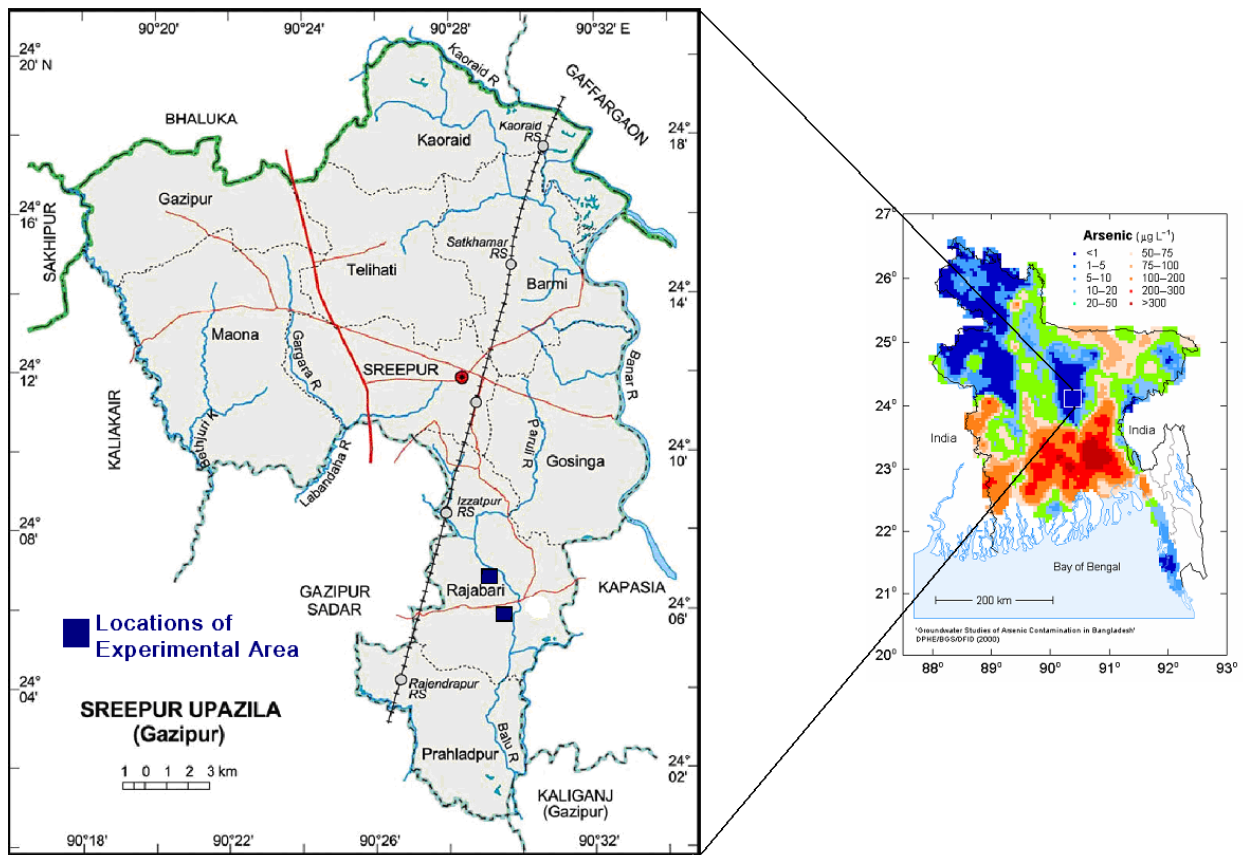


Figure 2: Site map of sampling locations; Nilatiki village of Rajabari union of Sreepur thana in Gazipur district, Bangladesh is safe from groundwater arsenic contamination. The sampling area was located at  $24^{\circ}04'$ -  $22^{\circ}06'$  altitudes and  $90^{\circ}30'$ -  $90^{\circ}32'$  longitude.

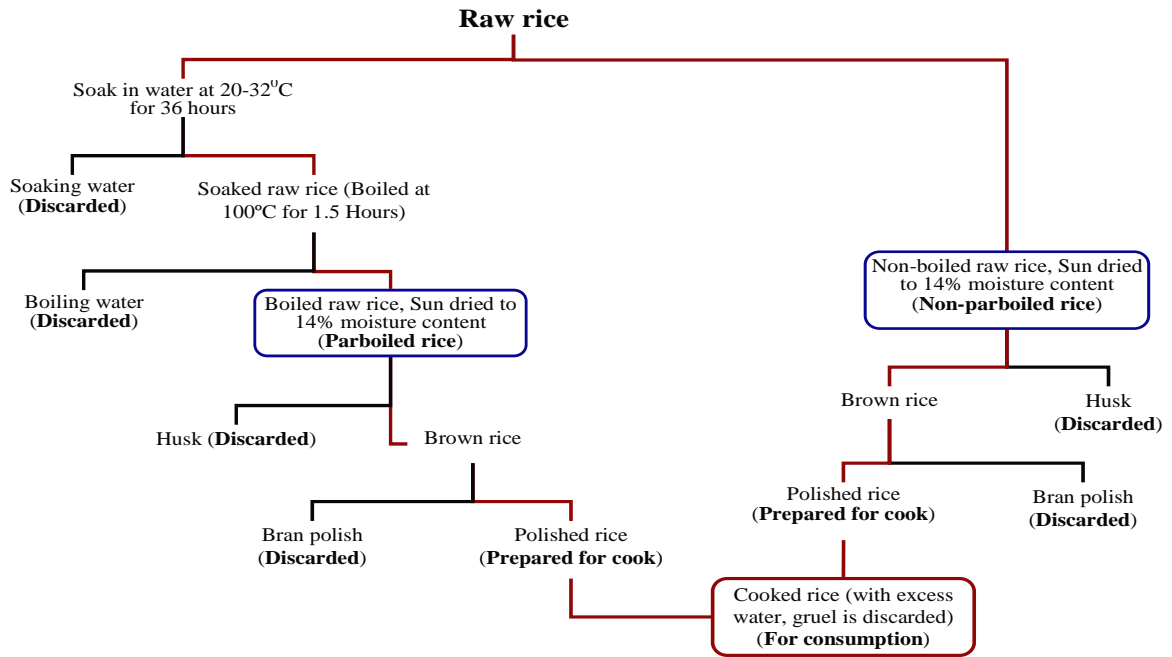


Figure 3: Flow diagram showed the sequential steps followed by the population of Bangladesh in cooking rice. They usually follow two types of polished rice, 1) parboiled and 2) non-parboiled, for cooking which are processed in two different ways shown above.

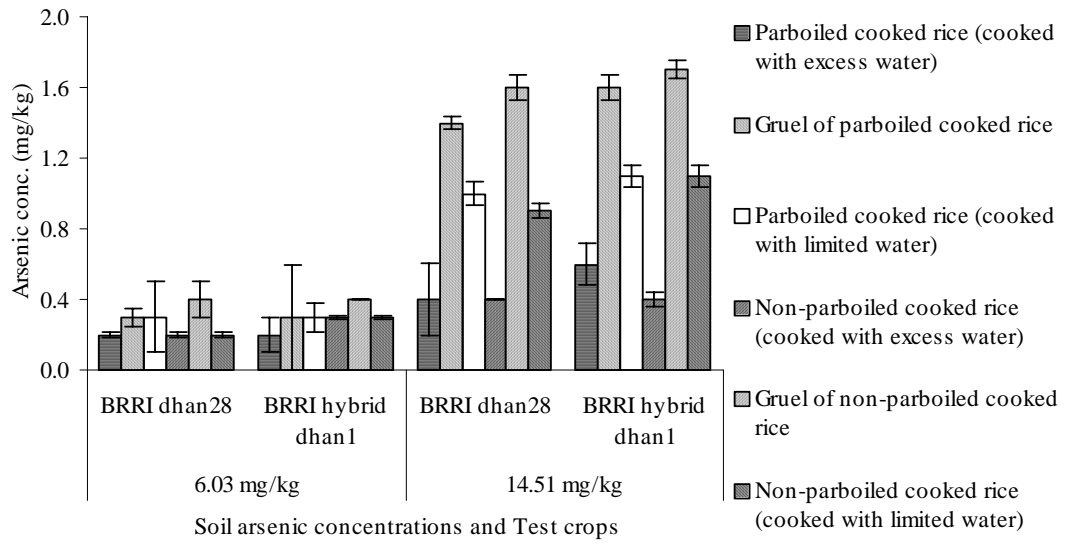


Figure 4: Arsenic concentrations in cooked rice and gruel of arsenic contaminated and non-contaminated areas. Error bars represent  $\pm$ SD ( $n=3$ ).