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ORIGINAL PAPER

Mitigation of arsenic in rice through deficit irrigation in field and use of filtered water in kitchen

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Abstract An experiment was conducted in an arsenic-affected area of West Bengal, India, with the aim of alleviating arsenic toxicity from food chain through water management in rice field and modification of cooking procedure of the same grain in kitchen. Three regimes of deficit irrigation, viz. intermittent ponding, saturation and aerobic condition were tested in field against continuous ponding, i.e. local farmers' practice. Produced grains were cooked in traditional method with both arsenic-contaminated and filtered water. Results revealed that deficit irrigation can be efficiently used to reduce the arsenic load in rice grain. Water management in field can reduce 9–21 % arsenic content in raw rice grain and can save 150–340 mm of irrigation water over traditional cultivation procedure. Furthermore, use of filtered water for cooking can alleviate up to 32 % of arsenic. The study also revealed that growing rice under deficit irrigation can also increase the water use efficiency of the crop.

Keywords Aerobic culture · Cooking procedure · Dietary exposure · Food chain · Intermittent ponding · Water management

Introduction

Arsenic poisoning from drinking of contaminated water and food stuffs has arrested significant global attention in recent times. This metalloid, commonly referred as a heavy metal, ranked first in a list of 20 hazardous substances by the Agency for Toxic Substances and Disease Registry and United States Environmental Protection Agency (Goering et al. 1999). IARC 2004 has classified its inorganic compounds as Group 1 carcinogen. In Asia, arsenic pollution scenario is most severe in Bangladesh followed by West Bengal, India. Nearly 35 % of total population (nearly 30–40 million or even more) of this East Indian state is potentially affected (Bhattacharya et al. 1996). 9.5 million people from around 39,000-square-kilometre area of Gangetic alluvial zone of West Bengal are already identified to suffer from this menace (SOESJU 2006).

Alike the whole world, water scarcity has become another concern in India (Mall et al. 2006; Rodell et al. 2009). In India, around 78 % of freshwater is consumed in agriculture alone (Kumar et al. 2005) and major part of it is used for cultivation of summer rice. Summer rice is cultivated in over 1.4 million hectare (Government of West Bengal 2008) mostly under submerged condition in West Bengal, and huge quantity of water is applied to the fields (1,300–1,500 mm) to meet the high evaporative demand. Due to drying of water resources during summer season, farmers commonly lift groundwater through tube wells to irrigate the crop. This oxidises the aquifer and in turn increases the solubility of arsenic. The soluble arsenic then comes up through irrigation water (Das et al. 1996; Mandal et al. 1996; Nickson et al. 2000). Deficit irrigation may be a solution to combat both the problems, which has been already deployed by many workers (Duxbury & Panaullah 2007; Xie and Huang 1998; Xu et al. 2008). Among various deficit irrigation regimes, only aerobic cultivation or raised bed has been commonly tested against conventional practice. Few comprehensive studies are available on other irrigation regimes.

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Although many of the works (Bhattacharya et al. 2002; Mazumder et al. 1998; Tondel et al. 1999) relied on the concentration of arsenic in drinking water to envisage the entry of arsenic into human body, food chain aspect had been neglected. Rice, being the staple food of rural population of West Bengal, has prominent presence in food chain. Moreover, it contains significant amount of arsenic and thus should be taken into consideration for calculation of exposure to arsenic (Abedin et al. 2002; Duxbury et al. 2003; Meharg and Rahman 2003; Williams et al. 2006). Some studies have also pointed out that cooking procedure has some effect on arsenic concentration in cooked rice. In majority of the studies, rice was either cooked with filtered water or the arsenic concentration of the cooking water was not mentioned (Bae et al. 2002; Mihucz et al. 2007; Sengupta et al. 2006; Smith et al. 2002). But rural people of India have limited access to purified water and are forced to use contaminated water for cooking. Therefore, it was found necessary to modify the practices both in field and kitchen level to restrict the entry of arsenic into cooked rice. The present experiment was carried out in Nadia district during 2008 and 2009 to investigate the effect of deficit irrigation in field and modification of cooking procedure at home.

Materials and methods

Study site

The chosen site was a farmer's field and his kitchen located at an arsenic-affected village (Jaguli) of Nadia district, West Bengal, during two consecutive summer seasons starting from 2008. Georeference of the field was N23°02′7.1″ and E88°35′4.8″. Several studies (Bhattacharya et al. 2009; SOESJU 2006) have confirmed the presence of arsenic in groundwater in this locality. The field is of medium land situation with an altitude of 8 m from mean sea level. Physiochemical properties of the experimental soil have been summarised in Table 1.

Table 1 Physiochemical properties of the study soil

Property	Value
Mechanical composition	
Sand (%)	18.2
Silt (%)	49.6
Clay (%)	32.2
Bulk density (g cm^{-3})	1.57
Soil pH	6.76
Organic carbon (%)	0.56
Available nitrogen (kg ha^{-1})	120
Available phosphorus (kg ha^{-1})	57
Available potassium (kg ha^{-1})	190
Available arsenic (mg kg^{-1})	2.33
Total arsenic (mg kg^{-1})	13.92

Experimentation

Three regimes of deficit irrigation, viz. intermittent ponding (IP), saturation (SAT) and aerobic condition (AER) were tested against farmers practice, i.e. continuous ponding (CP). These four regimes were replicated five times and arranged in randomised complete block design (RCBD). Net area of each plot was 7 m × 6 m = 42 m^2. The treatments were designed to impose stress up to tillering stage (15 DAT to 45 DAT) only. Out of various growth stages of rice, flowering stage is most sensitive to water stress (O'Toole 1982; Garrity and O'Toole 1995), and thus, imposing stress in tillering stage has minimum negative effect on yield. The crop received uniform submergence, in exception to this period. During the period of treatment consideration, in CP, 5 cm of water was applied at every 3-day interval, which simulated the local farmers' practice and was considered as control. At IP, 5-cm irrigation was only administered when hairline line cracks were found. The interval was normally 6 days. In SAT, 1-cm irrigation was provided everyday to keep the soil saturated. For maintenance of AER, 1 cm of irrigation was given on alternate days to AER. The treatments were designed with the philosophy of easy applicability for the farmers. Some of the irrigations were skipped due to receipt of 84 and 68 mm of rainfall during the study period of 2008 and 2009, respectively. Plots were irrigated from a submersible pump having depth of 70 m. Arsenic level of the irrigation water was 0.163 ± 0.02 mg As L^{-1}. Two-metre-wide buffer zone was left surrounding the plots to minimise seepage from the neighbouring plots. Main and sub-channels were lined with polyethylene sheet to check the loss of irrigation water. Locally available cost-effective 62.5-micron-thick polythene sheets were used for this purpose. Bunds were reconstructed at regular interval. A locally popular rice variety Gontra Selection-3 was chosen for the study. This variety is medium statured, bold grained and of medium duration mainly suited for cultivation in medium land. Transplanting of thirty 2-day-old seedlings at 3–4 per hill was performed on February 14 and February 1 during 2008 and 2009 and harvested on May 18 and May 8, respectively. Standard package of cultivation practice including quick and eco-safe plant protection measure was followed.

Collection of plant samples

Five plant samples were collected from each plot. The plants were washed thoroughly with tap water followed by deionised water to make them free from dust and dirt. Samples were then chopped and placed in a hot air oven at 60 °C for 48 h. Dried samples were finally ground with a ball mill and composited in order to obtain the working sample.

Procedure of rice cooking and sampling

Rice obtained from different treatments was milled and cooked with excess water, and gruel was discarded. Six times water was added to rice to simulate the normal cooking procedure followed by the rural population of West Bengal. Cooking was performed in two sets. In the first set, arsenic-contaminated water (arsenic content 0.152 ± 0.02 mg As L^{-1}) was used, and in second set, filtered water collected from an activated alumina water filter (arsenic content 0.023 ± 0.003 mg As L^{-1}) was used. Due to lower maintenance of the filters, some filters were failed to eradicate arsenic from drinking water below permissible level. Water collected from five contaminated and uncontaminated sources were collected and composited for using in cooking process. After cooking, cooked rice was freeze-dried and digested for analysis of arsenic.

Digestion of grain samples

Known amount of rice grain (0.5–1 g) was taken in a 100-mL conical flask, and 10 mL tri-acid mixture (nitric acid:sulphuric acid:perchloric acid in the ratio of 10:1:4 by volume) was added to it. It was kept overnight for predigestion. Next day, digestion was done in a sand bath at a temperature of 120 °C for 2–3 h until a clear solution was obtained. The solution was then filtered with Whatman number 42 filter paper, and volume was made up to desired amount, normally 50 mL. This aliquot was transferred to plastic bottles for further use. Among various process of oxidation, tri-acid digestion was used by many workers (Krause et al. 1995; Loska and Wiechuła 2006).

Measurement of total arsenic in plant samples

GR-grade chemicals, class B glassware, calibrated micropipettes and double-distiled water (DDW) were used throughout the chemical analysis to maintain accuracy. Known amount of aliquot taken in a volumetric flask was acidified with 10 % v/v hydrochloric acid and reduced with 5 % potassium iodide and ascorbic acid. The mixture was kept for 45 min for completion of the reaction. Finally, it was measured for total arsenic in a Perkin Elmer AANALYST 200 Atomic Absorption Spectrophotometer (Perkin Elmer, USA) coupled with a same-make Hydride Generator (FIAS 400) in 720 nm wavelength. Measurement of arsenic was done according to Standard Methods 3114B (American Public Health Association 1995) by HG-AAS which has been recognised by United States Environment Protection Agency (USEPA) as a dependable and accurate process. In each analysis, matrix-matched standards were used for calibration. To assure the accuracy, 1568a rice flour obtained from National Institute Standards and Technology, USA, was used as standard reference material.

Computation

Irrigation water use efficiency (IWUE), i.e. the efficiency of water to produce grain has been calculated by the following equation where IWUE is irrigation use efficiency (kg m^{-3}), GY is grain yield (t ha^{-1}) and IW is amount of water irrigated (mm).

$$\mathrm{IWUE} = (\mathrm{GY}/\mathrm{IW}).$$

Yield and concentrations of arsenic values were statistically analysed for comparison of means by F test. Least significant difference (LSD) among treatment means was calculated at 5 % probability according to the method described by Gomez and Gomez 1984 where the difference was found significant. Data obtained from two consecutive years were pooled over years. All statistical analysis was done in computer with MSTATC (Massachusetts State University, USA) and Microsoft Excel 2007 (Microsoft Corporation, USA) programme.

Results and discussion

Yield and water use of the crop

Data presented in Table 2 showed that 1,200, 1,050, 990 and 860 mm of water were applied to CP, IP, SAT and AER regimes, respectively, throughout the growing season. Maximum grain yield of 6.79 t ha^{-1} was obtained from CP treatment. Reduction in irrigation by 210 and 340 mm caused a nominal 8 and 5 % compromise in grain yield under SAT and AER treatments, respectively. Interestingly, with the application of lowest amount of irrigation, considerably higher grain yield could be obtained under AER, and thus, highest irrigation IWUE was achieved. On the contrary, in spite of getting a fairly good amount of irrigation, least amount of rice grain was produced under IP and recorded lowest IWUE. Most of the water management workers (Bouman et al. 2005; Bouman and Tuong 2001; Tabbal et al. 2002) agreed that SAT and IP decrease yield. In some cases, IP increases water productivity compared with conventional flooded irrigation, but cannot help substantial decline in yield up to 30 % over CP (Tabbal et al. 2002). It is evident from Table 2 that productivity is not only depend upon the amount of irrigation but also depend upon the method of irrigation.

Table 2 Amount of irrigation, grain yield received and irrigation water use efficiency under different irrigation regimes

Treatment	Amount of irrigation applied (mm)	Saving of water over CP (mm)	Grain yield (t ha^{-1})	Irrigation water use efficiency (g m^{-3})
CP	1,200	–	6.79 a	0.559 c
IP	1,050	150	5.93 c	0.556 c
SAT	990	210	6.23 bc	0.629 b
AER	860	340	6.45 b	0.745 a
SEm±	–	**–**	**0.11**	**0.010**
LSD ($P = 0.05$)	–	**–**	**0.32**	**0.029**

Values with the same alphabet are not statistically different ($P < 0.05$)

Table 3 Aresnic content in raw grain, grain cooked with contaminated and filtered water obtained from different treatments

Treatment	Arsenic content in raw rice grain (mg kg^{-1})	Rice cooked with contaminated water (mg kg^{-1})	Rice cooked with filtered water(mg kg^{-1})
CP	0.627 a	0.445 a	0.383 a
IP	0.495 d	0.346 b	0.302 b
SAT	0.572 b	0.418 a	0.350 a
AER	0.549 c	0.368 b	0.327 b
SEm±	**0.007**	**0.016**	**0.018**
LSD ($P = 0.05$)	**0.021**	**0.049**	**0.055**

Values with the same alphabet are not statistically different ($P < 0.05$)

Arsenic content in raw rice grain

Analysis results of 1568a rice flour showed 92 % recovery from the reference material and good reliability of the analytical system.

Lowest amount of arsenic was found in rice grain produced under IP treatment followed by AER > SAT > CP (Table 3). Alternate wetting and drying under IP effectively reduced the arsenic content in rice grain (0.50 mg kg^{-1}), which is 24 % less than the farmers practice (0.62 mg kg^{-1}). Keeping the field almost dry under AER and moderately moist under SAT caused 10 and 14 % more arsenic accumulation over IP, respectively. Several workers also have observed that arsenic concentrations in rice grain were markedly higher in the flooded treatments than in the aerobic ones (Duxbury and Panaullah 2007; Lauren and Duxbury 2006; Xu et al. 2008). Sanyal 1999 pointed out that biological availability of arsenic in soil increases on reduction of As(V) to As(III)

	Grain yield (t ha^{-1})	Rice cooked with filtered water(mg kg^{-1})
CP	6.79	0.627
IP	5.93	0.495
SAT	6.23	0.572
AER	6.45	0.549

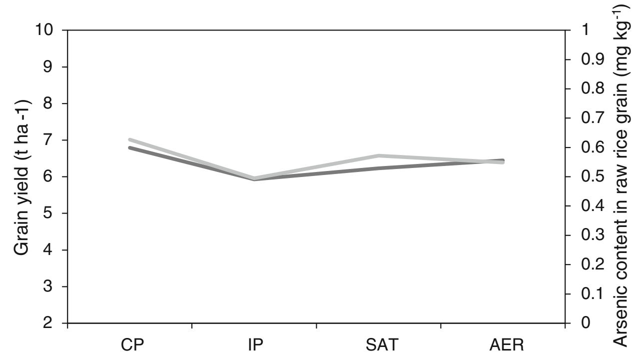

Fig. 1 Comparison between yield and arsenic content in rice grain produced under different treatments

which is facilitated in reduced flooded soil microenvironment, leading to fall in Eh. McGeehan et al. 1998 also found that flooding–drying treatments increased the short-range-order Fe fraction and most likely increased the surface area and number of potential arsenic sorption sites.

Figure 1 revealed that under IP treatment, both grain yield and arsenic content in raw rice grain are at their minimum level. Lower arsenic in grain is good from health perspective, but lower yield may not be acceptable to the farmers. A good compromise between the two can be obtained under AER.

Effect of cooking water on arsenic content in cooked rice

Filtered water obtained from an activated alumina home filter contained 85 % less arsenic than contaminated one. Cooking of rice in contaminated water resulted in more arsenic in cooked rice compared to filtered water (Table 3). Concentration ranged between 0.346 and 0.445 mg kg^{-1} with contaminated water, whereas it decreased to 0.302–0.383 mg kg^{-1} with filtered water. Some of the workers (Bae et al. 2002; Roychowdhury et al. 2002) have reported elevated concentration of arsenic in cooked rice than their raw counterpart. But interestingly, our study revealed that when rice is cooked with excess water and gruel was decanted, arsenic content in cooked rice decreased irrespective of source of cooking water. (Rahman et al. 2006) also have reported similar phenomenon. This is, perhaps, because a portion of water-soluble arsenic is released at high temperature from rice grains into cooking water which was discarded later in the form of gruel. It was found that 67–73 % of arsenic of raw rice grain was retained in cooked rice boiled with contaminated, whereas the retention was slightly decreased (59–61 %) when filtered water was used. Chakravarty et al. 2003 also reported 66.6 % retention when gruel was drained out. Significant variation was found among arsenic concentration of cooked rice produced under different irrigation regimes. Least arsenic was found in case of IP followed by AER. Although lower amount of water was used under SAT treatment, it was found comparatively less efficient irrigation regime to decrease the arsenic load in cooked rice.

Conclusion

From the findings of the study, it can be concluded that deficit irrigation can be used efficiently to reduce the arsenic load in rice grain. AER and intermittent ponding can reduce grain arsenic (12.4–21 %) with a saving of 340 and 150 mm of irrigation water, respectively, despite little yield loss (5–12.6 %) over farmers' practice. Use of filtered water further lessened the arsenic content in diet. Thirty-two percentage alleviation of arsenic was found possible when the grain produced under IP treatment was cooked with filtered water. In the case of AER, 26 % decrease was possible.

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Conflict of interest None.

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