Science of the Total Environment 609 (2017) 311–318

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Effect of irrigation and genotypes towards reduction in arsenic load in rice

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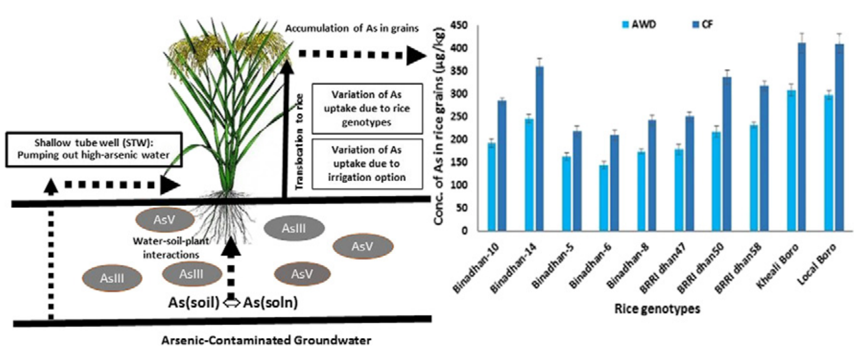
HIGHLIGHTS

- The concentrations of arsenic (As) in rice grains are cultivar dependent.
- High grain As bioaccumulation was detected in plants in areas of high soil As.
- AWD irrigation practice reduced 17% to 35% of grain As concentration.
- 7% to 38% increase in rice grain yield under AWD irrigation practice.
- Moderate to high level of As contaminated soils some varieties are quite promising.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 May 2017
Received in revised form 11 July 2017
Accepted 12 July 2017
Available online 25 July 2017

Editor: F.M. Tack

Keywords:
Arsenic
Rice genotypes
Water management
Bioaccumulation
Mitigation strategies

ABSTRACT

Arsenic (As) bioaccumulation in rice grains has been identified as a major problem in Bangladesh and many other parts of the world. Suitable rice genotypes along with proper water management practice regulating As levels in rice plants must be chosen and implemented. A field study was conducted to investigate the effect of continuous flooding (CF) and alternate wetting and drying (AWD) irrigation on the bioaccumulation of As in ten rice cultivars at three locations having different levels of soil As and irrigation water As. Results showed that As concentration in different parts of rice plants varied significantly ($P < 0.0001$) with rice genotypes and irrigation practices in the three study locations. Lower levels of As in rice were found in AWD irrigation practice compared to CF irrigation practice. Higher grain As bioaccumulation was detected in plants in areas of high soil As in combination with CF irrigation practice. Our data show that use of AWD irrigation practice with suitable genotypes led to 17 to 35% reduction in grain As level, as well as 7 to 38% increase in grain yield. Overall, this study advances our understanding that, for moderate to high levels of As contamination, the Binadhan-5, Binadhan-6, Binadhan-8, Binadhan-10 and BRRI dhan47 varieties were quite promising to mitigate As induced human health risk.
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1. Introduction

Arsenic is recognized as a toxic and carcinogenic element (Group I) which is widely distributed in the environment. Presence of As in groundwater poses a significant threat to human health. In many regions of the world including Bangladesh, shallow tube-well water in different locations is heavily contaminated with As. Apart from its domestic use about

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http://dx.doi.org/10.1016/j.scitotenv.2017.07.111
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86% of these water sources are being used for irrigation (Saha and Ali, 2007), particularly in dry seasons crops, especially Boro season rice which contributes about 60% to rice production in Bangladesh. It has been estimated that 900 to 1360 tons of As end up on arable land in south and southwest Bangladesh due to irrigation with As-contaminated groundwater annually (Ali, 2003). It is well documented that compared to the other cereal crops rice accumulates appreciable levels of As since it is grown under flooded conditions which are conducive to high bioaccumulation of As (Talukder et al., 2012; Williams et al., 2007; Xu et al., 2008). Irrigation using As-contaminated groundwater also results in significant loading of As in soil and as a consequence bioaccumulation of As in rice grains for rainy season rice can also occurred (Islam et al., 2007; Meharg and Rahman, 2003). Elevated levels of As have also been shown to lead to substantial yield losses (Khan et al., 2009; Panaullah et al., 2009).

Rice is the staple food crop of half of the world's population and it provides the main nutritional input for many countries. Therefore, rice itself is an important exposure source of As intake for humans, especially for people consuming substantial amounts of rice in their diet. Given the risk that As poses to human health, mitigation strategies are needed to reduce the transfer of As from root to rice grain to minimize the human exposure risks due to rice consumption. Under aerobic conditions the smallest As bioaccumulation was found in rice straw and grain (Li et al., 2009) but anaerobic conditions enhanced As uptake in rice plant (Talukder et al., 2012). Research showed that aerobic soil conditions resulted in a 10–fold smaller amount of As uptake among a set of several hundred global cultivars compared to a flooded field (Norton et al., 2012). Similar results were obtained from a greenhouse experiment, where maintaining soil under aerobic conditions decreased As concentration in rice grain and straw by 10 to 20-fold, and 7 to 63-fold, respectively, compared with continuous flooded rice (Li et al., 2009; Xu et al., 2008). It was also observed that intermittent flooding reduced As uptake (23% in root, 14% in shoot and 20% in leaf) at panicle initiation stage, instead of continuous flooding (Rahaman et al., 2011). In another field study in Bangladesh, a site employing intermittent irrigation showed lower grain-As content than another site under continuous flooded conditions (Stroud et al., 2011). A field study carried out at Stuttgart, Arkansas, showed that grain contained 41% less As in an intermittently flooded paddy field than in continuous flooded one (Somenahally et al., 2011). Talukder et al. (2011) found that the As concentrations in grain and straw decreased by 62% and 86%, respectively.

Water management and rice cultivars dramatically affect the concentration of As in rice grains and therefore, the combination of water management and use of cultivars that are low As accumulators can reduce As in rice grains. Some research has reported that the use of different water management practice may help reduce bioaccumulation of As in rice (Hu et al., 2013; Liao et al., 2016; Newbigging et al., 2015; Zhang et al., 2015). Using a rice cultivar that thrives under low moisture content may also reduce the amount of As in a paddy field from irrigation of As-contaminated groundwater. Few studies have reported the differences in rice genotypes in As bioaccumulation from As-contaminated soils and irrigation water (Hu et al., 2013; Liao et al., 2016; Zhang et al., 2015). Selecting appropriate water management practices and suitable rice genotypes is likely to reduce As uptake and enhance food security by improving greater productivity. A few published articles have reported on the use of different water management practices in combination with rice genotypes; they can reduce the levels of As in rice. Most studies, however, were based on pot experiments under controlled environments or greenhouse conditions. There is a need to investigate As bioaccumulation under field conditions using commonly grown rice genotypes to determine the level of this bioaccumulation. In this study, we investigated water management options and rice genotypes in three different As graded field sites in Bangladesh to determine: (1) the influence of water management on minimizing As bioaccumulation; (2) genotypic performance to reduce As bioaccumulation in rice; and (3) select rice genotypes that accumulate low As with suitable irrigation practices to grow in As affected areas in Bangladesh.

2. Materials and methods

2.1. Experimental sites

Three levels of As-contaminated farmers' rice paddy fields were selected for this study; firstly, one in Domrakandi, Faridpur Sadar, Faridpur (23°34′39.9″N 89°48′16.2″E), a district in central Bangladesh; secondly, one in Damkura, Paba, Rajshahi (24°23′11.9″N 88°32′23.4″E), located in north-western Bangladesh; and thirdly, one at the experimental farm of Bangladesh Agricultural University (BAU), Mymensingh (24°43′11.3″N 90°25′35.7″E), a district of central Bangladesh. The study sites have a subtropical monsoon climate with a cool and dry winter. For the Faridpur site the average soil As content is 15.7 mg/kg. In Rajshahi site the average soil As content is 4.7 mg/kg while at Mymensingh site with low soil As 2.7 mg/kg.

2.2. Soil and irrigation water sampling and its characterizations

Ten soil samples were collected from each field at 5 m intervals along the transect from the irrigation tube well water inlet. Soil was sampled to 0–15 cm depth using an auger. Three replicate soils were collected along the transect, air dried and then crushed to pass through a 2 mm stainless steel sieve and stored in plastic bags for further studies. The physico-chemical properties of the study soil are presented in Table 1. At all sites, shallow tube-well water was directly released into the field under study via an earthen channel from the tube-well. Tube-well water was collected from all field sites. Water samples were filtered using a 0.45 μm filter paper and acidified to 2% nitric acid and stored in 50 mL water sampling polypropylene bottles. Analysis of As was conducted using ICP-MS. The irrigation water As in the three field sites amounted to 255.4 μg/kg (Faridpur), 87.2 μg/kg (Rajshahi) and 2.4 μg/kg (Mymensingh), respectively.

2.3. Treatments and irrigation water management

The experiment consisted of a set of the 10 most commonly grown rice genotypes (local, high yielding and aromatic) from Bangladesh. The characteristics of selected rice genotypes are presented in Table 2. The seedlings of each rice genotype were raised in seed beds. The main field was ploughed thoroughly and flooded for the purpose of puddling before the rice seedlings were transplanted. Thirty-five day-old healthy seedlings were transplanted in the main field in January 2014. The experiment was conducted in a randomized complete block design with four replicates. After transplanting all the plots were retained with continuous standing water (5 cm) for 20 days. Then two water management options, i.e. CF and AWD were implemented. For the CF scenario, 5 cm standing water was maintained while the AWD treatment involved 5 cm water was added and allowed to dry until water drop below 15 cm depth in perforated plastic pipe. Water was

Table 1
Physico-chemical properties of initial soils from three experimental sites.

Soil properties	Average value		
	Faridpur	Rajshahi	Mymensingh
Physical properties			
Sand (%)	31.4	12.4	10.7
Silt (%)	30.3	30.1	58.5
Clay (%)	38.3	57.5	30.8
Soil texture class	Clay loam	Clay	Silty clay loam
Chemical properties			
Soil pH (soil: water = 1:10)	7.6	7.6	6.1
EC (ds/m)	1729.7	1782.0	1646.3
CEC (meq 100/g)	9.9	11.4	10.1
Nitrogen (%)	0.1	0.2	0.2
Carbon (%)	2.0	2.4	2.3
Total As (mg/kg)	15.7	4.7	2.7

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