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ARSENIC UPTAKE BY RICE (*ORYZA SATIVA* L.) IN RELATION TO SALINITY AND CALCAREOUSNESS IN SOME SOILS OF BANGLADESH

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Abstract

A pot experiment was conducted to investigate the effect of soil salinity and calcareousness on uptake of arsenic by two varieties of rice (*Oryza sativa* L.) plant. Of the two varieties one was salinity tolerant local variety (LV) and the other was salinity non-tolerant high yielding variety (HYV). Four types of soils covering saline and calcareous belts were selected from south-western part of Bangladesh. The soils were calcareous (Sca), non-saline non-calcareous (Sn), slightly saline non-calcareous (Sss) and highly saline non-calcareous (Shs). Arsenic at the rates of 0, 0.5 and 10.0 mg/l was applied with water. Grain samples were collected at harvest and analyzed for arsenic with HG-AAS. Analysis of the grain showed higher arsenic contents for plants growing on Sca and Sss than on Sn and Shs in both LV and HYVs. Phosphorus, sulfur, sodium and calcium accumulation in grain were reduced at the high arsenic treatment. The present findings are likely to throw some insights on the relationship between arsenic dynamics and its subsequent accumulation in rice in salt affected soils where ground water arsenic contamination is reported leading to a better management strategy.

Introduction

Arsenic pollution of ground water has created a draconian situation in Bangladesh. About 29.05 million people are exposed to arsenic toxicity from drinking water.[1] The high level arsenic in ground water is geogenic in origin. Both arsenic content (0.4 - 10 mg/kg) of Bangladesh sediments and their mineralogy are typical of young alluvial and deltaic sediments that contain a wide variety of minerals reflecting their diverse source of parent material. The development of strongly reducing conditions is believed to be responsible for the release of naturally occurring arsenic from the sediment into the ground water. Strong reducing condition in the Holocene aquifers is developed from the rapid microbial consumption of dissolved oxygen by oxidation of fresh organic matter in recently buried sediments.[2] The mechanism of this release is poorly understood quantitatively but is now a general consensus that bacterial dissolution by *Geobacter* of arsenic bearing iron hydroxides (also known as hydrous ferric oxides) is the main mechanism of release.[3]

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Studies on pure systems suggest that high affinity of arsenic for oxidic surfaces may vary with pH, charge density and soil solution composition. Moreover soil texture, nature of minerals and nature of competing ions such as Cl^-, SO_4^{2-}, PO_4^{3-}, Fe^{3+}, Mn^{4+} and Ca^{2+} have strong influence on arsenic dynamics in soils.(4)

The accumulation of arsenic by edible plants is of great interest. Uptake of arsenic by plants occurs primarily through root system and the highest arsenic concentrations are reported in plant roots and tubers.(5) Rice is the main crop of Bangladesh and covers about 75% of the total cropped area. In dry season irrigation of surface soil with arsenic laden ground water from shallow aquifers add arsenic to the soil. Background level of arsenic in soils of Bangladesh varies between 4 and 8 mg/kg with an average of less than 10 mg/kg, whereas arsenic concentration can reach up to 100 mg/kg in areas irrigated with contaminated tube well water.(6,7) Arsenic loading from irrigation water for rice cultivation may exceed 5.5 kg/ha/yr in drought condition.(6) Arsenic level of rice grain varies between 0.10 and 0.95 µg/g(8) with maximum level of 2.05 µg/g.(9) It has been reported that in rice grain the arsenic concentration in most cases is <1 mg/kg and about 2 mg/kg for rice straw.(10)

Soil salinity is a major problem in the coastal areas of Bangladesh. During dry season the soil salinity can increase up to 49.5 dS/m in some areas.(11) It has been reported that over the last three decades the extent of salinity affected area increased to about 22.47%.(11) This creeping up tendency of soil salinity to the non-saline belts creates concern on better management of saline soils. In addition to salinity problem arsenic level in the ground water of these areas has been reported to be high.(12) During the dry season ground water moves upward by capillary action and leaves arsenic in the soil (Personal communication S.M. Imamul Huq 2006). Moreover, some of the coastal saline soils are calcareous in nature. So, a possible interaction between salinity and calcareousness on arsenic transfer to rice grain is very important.(13)

In this paper the effect of soil salinity and calcareousness on arsenic translocation to rice (*Oryza sativa* L.) is discussed.

Materials and Methods

Soil samples were collected from Khulna and Jessore districts, south-western part of Bangladesh. Khulna lies approximately between 22°13′ and 23°20′ north latitude and 89°15′ and 89°52′ east longitude. Jessore lies between 22°47′ and 23°47′ north latitude and 89°42′ and 89°48′ east longitude. The soils belong to four representative soil series of Bangladesh.(14) According to USDA Soil Taxonony all the series belong to Typic Endoaquept subgroup.

Pot experiment: Top soils of Amjhupi and Sara series were collected from Jessore district whereas Ramgati and Barisal series were collected from Khulna district. The georeferences of the sampling sites are shown in Table 1. Amjhupi and Sara series are soils of Ganges meander floodplain and Ramgati and Barisal series are of Ganges tidal floodplain. Collected soil samples were air dried, debris removed, crushed and then sifted through a 2 mm sieve. Amjhupi was a non-calcareous non-saline (Sn), Sara - calcareous non-saline (Sca), Ramgati - slightly saline non-calcareous (Sss) and Barisal was a highly saline non-calcareous (Shs) soil. Soil pH, Ec_e and per cent clay content of collected samples are presented in Table 1.

Table 1. Some chemical properties of the soil samples.

Series	Code	Location	pH	Ec_e (dS/m)	% clay
Amjhupi	Sn	23.34088°N 89.33151°E	7.98	1.38	61.45
Sara	Sca	23.20598°N 89.17265°E	8.54	1.11	31.45
Ramgati	Sss	22.77455°N 89.53331°E	7.76	6.34	58.95
Barisal	Shs	22.64574°N 89.52265°E	7.74	14.77	56.45

The pot experiment was carried out in a net house using four kilogram air dried soil samples into each earthen pot. A salinity tolerant local variety (LV) *Ratna* and a high yielding variety (HYV) BR-26, popularly known as *Sraboni* were grown as the test varieties of rice. These varieties are cultivated in puddled waterlogged condition in monsoon season characterized by high rainfall, humidity and cloudiness. Urea, triple super phosphate (TSP), muriate of potash (MP) and zinc chloride (Zn) were applied at the rate of 120, 24, 72 and 3 kg/ha as per requirement of the soils.[15] Three levels of arsenic 0, 0.5, and 10 mg/l were applied as the arsenic treatments. Sodium arsenite ($NaAsO_2$) salt was used to prepare the treatment water. Arsenic was applied through the As-treated water throughout the growing season. Four 30-day-old-seedlings were transplanted in each pot. All treatments were repeated three times and total number of pots was 72. Pots were watered daily with arsenic laden irrigation water to keep them water logged. The plants were harvested 90 days after transplantion at grain maturity. After harvest, the grains were oven dried at 65 ± 5°C for 24 hours and ground for chemical analysis.

Analyses: The grain samples were digested with conc. HNO_3 in block digester.[16] Arsenic in water, and grain extract was estimated with HG-AAS technique and certified reference materials were used to ensure QA/QC.[17] The phosphorus in the grain sample extract was estimated colorimetrically by vanadomolybdate yellow color method, the sulfur was estimated by turbidimetric method and the sodium by flame analyzer and calcium content was determined titrimetrically.[18]

Statistics: The results of the experiment were evaluated statistically by Split-Split Plot design[19] by using MINITAB 13 package.

Results and Discussion

Arsenic translocation to grain: The concentration of arsenic (mg/kg) in rice grain was lower at control and 0.5 mg/l As treatments compared to 10.0 mg/l As in both LV and HYV (Figs. 1-2). Arsenic concentration in grain was higher in Sca than Sn at different arsenic treatments with the exception for 10 mg/l treatment in HYV. Higher salinity showed a negative effect on the arsenic accumulation in rice grain. The arsenic concentration was higher in Sss than Shs in different arsenic treatments with the exception at 10 mg/l in HYV. Although there was no general trend of difference in arsenic concentration between LV and HYV yet, HYV rice grain tended to accumulate lower arsenic than LV. So far the As accumulation in the grain is considered, the arsenic treatment ($F = 54.68^{**}$) and variety ($F = 5.52^{*}$) were found to have significant effect whereas the effect of soil (effect of salinity or calcareousness) was not significant. However, the interaction between soil × arsenic was significant ($F = 6.59^{**}$).

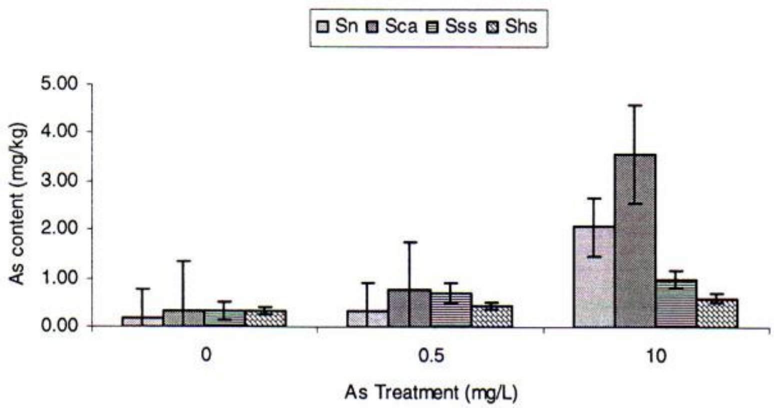

Fig. 1. Arsenic concentration (mg/kg) in rice grain of LV.

Phosphorus and sulfur translocation to grain: Phosphorus accumulation in both the LV and HYV rice grains decreased with increasing arsenic treatments. Sulfur accumulation by LV rice grains decreased with increasing arsenic treatment but HYV rice showed an opposite trend. The grains of HYV rice accumulated more P and S than LV. Phosphorus and sulfur concentration in rice grain grown on Sn was higher than Sca. The LV rice grain grown on Shs accumulated higher P and S than Sss (Figs. 3-6) whereas an opposite trend was observed for the HYV.

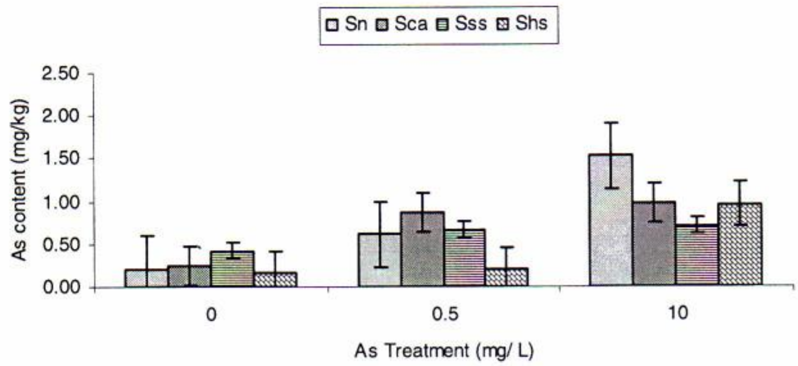

Fig. 2. Arsenic concentration (mg/kg) in rice grain of HYV.

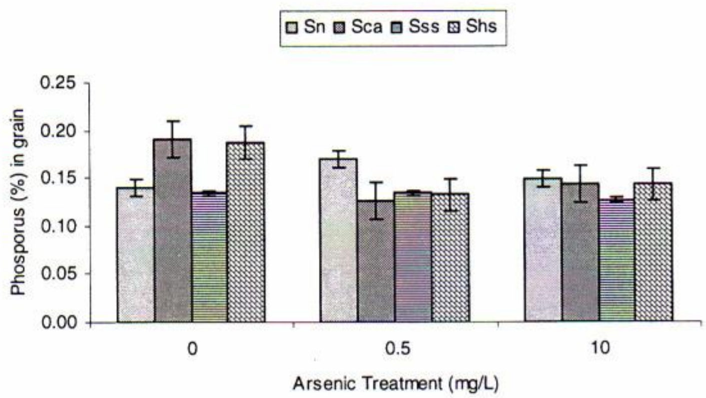

Fig. 3. Phosphorus concentration (%) in rice grain of LV.

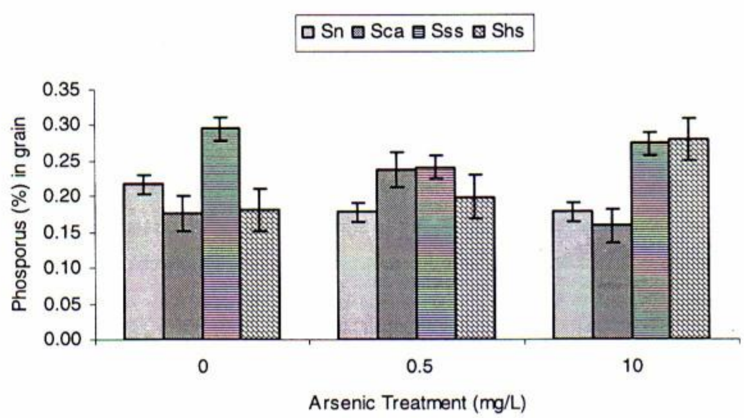

Fig. 4. Phosphorus concentration (%) in rice grain of HYV.

Sodium and calcium translocation to grain: Arsenic treatment caused a decreased accumulation of sodium and calcium contents in the grains of both the varieties of rice. Sodium and calcium contents in LV rice grain were generally higher as compared to HYV rice. It was observed that Na and Ca contents were higher in rice grain grown on Sca than Sn. Sodium accumulation was higher in rice grain grown on Shs than Sss whereas Ca accumulation was higher in Sss than Shs (Table 2).

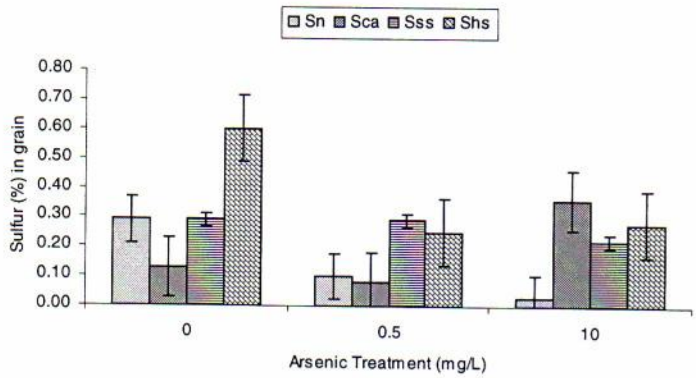

Fig. 5. Sulfur concentration (%) in rice grain of LV.

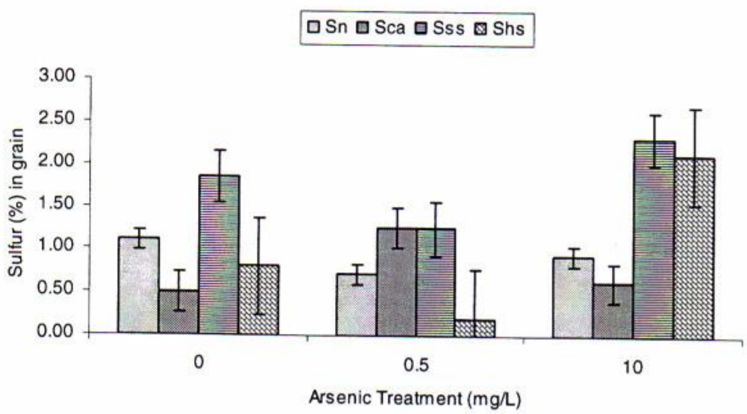

Fig. 6. Sulfur concentration (%) in rice grain of HYV.

The sampling area comprises a relatively smooth, nearly level to gently undulating landscape of both Ganges meander and tidal floodplain ridges, inter ridge depression and basins. The entire area is underlain by recent alluvium. Deposits of various ages reflect important changes in river courses that have taken place within the last thousand years.(14) The basin depression areas in tidal floodplain are not completely protected from the tidal flooding. The soils are mostly saline. It is reported that in tidal saline soils Na^+, Ca^{2+}, Mg^{2+} and K^+ ions are dominant cations whereas SO_4^{2-} and Cl^- are dominant anions.(11)

Calcareousness of soil seemed to have a positive effect on arsenic accumulation in plants. In As treated soils, salinity appeared to have restricted the As accumulation. The higher the salinity, lower was the As accumulation in plants. This phenomenon was observed for the local variety. On the other hand, the HYV behaved differently. This variety accumulated lesser amount of As compared to the LV at any treatment. Moreover, at high As contamination, it appeared that salinity had synergistic effect in As accumulation in HYV.

Table 2. Sodium and calcium contents in LV and HYV rice grain.

Arsenic treatments (mg/l)	Sn	Sca	Sss	Shs
	Sodium content (%) in LV rice grain			
0	0.08	0.16	0.10	0.11
0.5	0.06	0.10	0.07	0.09
10	0.14	0.11	0.09	0.12
	Sodium content (%) in HYV rice grain			
0	0.10	0.12	0.09	0.08
0.5	0.08	0.10	0.11	0.09
10	0.06	0.05	0.06	0.09
	Calcium content (%) in LV rice grain			
0	0.67	0.79	0.77	0.57
0.5	0.28	0.50	0.35	0.46
10	0.43	0.59	0.53	0.44
	Calcium content (%) in HYV rice grain			
0	0.39	0.38	0.51	0.24
0.5	0.40	0.44	0.51	0.28
10	0.26	0.31	0.38	0.19

Thoresby and Thornton[(20)] described the uptake of arsenic by various plant species and its translocation to different parts of plants. With increasing soil arsenic, the highest arsenic concentration was always recorded in old leaves and in roots. Das *et al.*[(21)] reported that arsenic content in rice grain was 0.14 mg/kg. Concentrations of arsenic in rice grain did not exceed the food hygiene concentration limit of 1.0 mg of As/kg dry weight.[(22)] Abedin *et al.*[(23)] have reported that with 8 mg/l arsenate, grain arsenic concentration reached a maximum of about 0.6 mg/kg. However, at lower levels of exposure (0.25, 0.50. 1.0, 2.0 and 4.0 mg/l), grain arsenic did not differ greatly from the zero exposure concentration, which was about 0.2 mg/l.[(24)] This is a situation that prevails under Bangladesh situation. In the present investigation grain arsenic content in most of the cases was found below 1 mg/kg. This result corroborates with the findings of Abedin *et al.*[(23)], Islam *et al.*[(25)] and Imamul Huq and

Naidu.[17] Arsenic content in rice grain grown on calcareous soil was in general higher compared to the grains obtained from other soils. This could be due to the fact that under such a situation As became more bioavailable as P is likely to be precipitated under high soil pH[26] as well as the antagonism between soil P and soil-As.[27] On the other hand, Sadiq[28] reported that the carbonate minerals can sorb arsenic in calcareous soils thereby reducing its subsequent uptake by plants. Present observation does not corroborate to this observation. The high clay percentage in Sn may be the reason for lower arsenic transfer to rice plants. Imamul Huq *et al.*[6] reported that retention of arsenic from soil solution was greater in higher clay containing soils. The reason for higher As content in the grains from Sss compared to Shs could be due to the difference in salt concentration of the two soils. The dominant anions in saline soil are SO_4^{2-}, Cl^-, and HCO_3^-.[11] The toxic effects of arsenic appear to be reduced by the presence of sulfur, chloride and bicarbonate.[27] This could be the reason for lesser accumulation of As in the grains from highly saline soils. In the present study it was observed that higher arsenic treatment, though statistically not significant, depressed phosphorus content in grains. This phenomenon has been observed by others too.[23, 29] Arsenate and phosphate compete for the same surface sites, with a moderate preference for arsenate adsorption.[30] Presence of sulfate has not been found to influence arsenate adsorption but has resulted in a considerable reduction in arsenite adsorption below pH 7.0.[30] However, it has also been reported that the toxic effects of arsenic appear to be diminished by the presence of sulfur.[29, 31] In the present case, a reverse phenomenon was observed. Application of As reduced sulfur accumulation in LV but showed an increasing trend in case of HYV. It needs to be mentioned here that the As applied in the present experiment was in the arsenite form. Arsenic has been found to be antagonistic with both calcium and magnesium uptake. Wallace *et al.*[32] showed that with increasing arsenic concentration calcium content decreased in all plant parts of bush bean. Antagonistic effect of arsenic on magnesium has been reported by Yamare.[33] Islam[34] observed arsenic (40 mg/kg) caused reduction in calcium content of straws and grains of rice varieties. The rice variety had a significant effect on arsenic, phosphorus, sulfur, and sodium and calcium uptake. The variation of arsenic uptake in different rice varieties has also been reported by Williams *et al.*[8] The LV is known to be a salt tolerant variety. This salt tolerant characteristics could have contributed to its high As tolerance too. However, further detailed study in this regard is necessary.

Conclusion

Calcareousness of soil accentuated arsenic accumulation in rice grain irrespective of variety. Salinity seemed to have a negative effect on As accumulation in the rice grains. The arsenic concentration in rice grain was lower than the dietary threshold of 1 mg/kg in most cases. Arsenic treatments depressed phosphorus, sulfur, sodium and calcium contents in rice grain indicating the fact that presence of As might also affect the nutritional quality of rice grains without any apparent yield decrease.

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