Effects of arsenic and its interaction with phosphorus on yield and arsenic accumulation in rice

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Abstract
A study was made on the effect of arsenic (As) and As × P interaction in Boro (dry season) rice. Arsenic was added to soil (having 2.6 mg/kg initial As) @ 0, 15 and 30 mg As/kg from $Na_2HAsO_4.7H_2O$ and phosphorus @ 0, 20, 40, 60 and 80 mg P/kg from KH_2PO_4. Each pot had received 100 mg/kg N, 40 mg/kg K and 25 mg/kg S from urea, muriate of potash (MoP) and gypsum, respectively. The grain yield of rice was reduced by 20.6 % for 15 mg/kg As treatment and 63.8 % due to 30 mg/kg As. Such reductions for straw yield were 21.0 and 65.2 % with these two As treatments, respectively. Arsenic concentration in grain and straw significantly increased due to arsenic application. The adverse effect of arsenic on rice was further enhanced by P addition. This reaction has an implication to P fertilizer management in rice.

Key Words
Arsenic, phosphorus, rice.

Introduction
Arsenic (As) contamination of groundwater is a severe problem in Bangladesh and this has affected at least 25 million people (Ravenscroft *et al.* 2005). Next to drinking water, rice could be a potential source of As exposure of the people living in the As affected areas of Bangladesh (Hossain *et al.* 2008, Panaullah *et al.* 2009; William *et al.* 2009). Roberts *et al.* (2007) estimated that over 1000 tons of As might be transferred to arable land each year from As contaminated groundwater irrigation, creating a potential risk for future agricultural sustainability and food security of the country. Arsenic may enter into human body directly through drinking water and indirectly through foods, chiefly rice for Bangladeshi people. Rice covers about 75% of the total cropped areas in this country. Many areas have high groundwater and soil arsenic contents which are likely to be taken up by plants through roots and transported to the aerial portion. Islam *et al.* (2005) reported 12.3 mg/kg mean As over 456 soil samples across the country. Phosphorus fertilization is common in rice cultivation which might interact with arsenic uptake since phosphate is an analogue of arsenate and compete for the same sorption sites (Qafoku *et al.* 1999). Considering the above points in view, the present study was conducted to evaluate the effect of arsenic and its interaction with P on yield loss and arsenic accumulation in rice. The experiment was conducted with varying doses of arsenic addition to soil having low arsenic content in order to understand the situation in high arsenic soil.

Materials and methods
A pot-culture experiment was set up during Boro season (January-May) of 2006 with Bangladesh Agricultural University (BAU) farm soil having low arsenic content (2.6 mg/kg) in a net-house of the Department of Soil Science of BAU, Mymensingh. Texturally the soil was silt loam with 6.7 pH, 2.28% organic carbon, 0.28% total N, 9.8 mg/kg available P, 14 mg/kg available S, 0.7 mg/kg available Zn and 0.11 mol_c/kg exchangeable K. The size of each pot was 43 cm in diameter and 40 cm in height. There were 15 treatments consisting of three doses of As (0, 15 and 30 mg/kg) and five doses of P (0, 20, 40, 60 and 80 mg/kg), their sources being $Na_2HAsO_4.7H_2O$ and KH_2PO_4, respectively. The experiment was conducted in a two factorial completely randomized design with three replications. The seedlings (cv. BRRI dhan29) were transplanted in the pots on 26 January 2006. Every pot had received 100 mg/kg N from urea, 40 mg/kg K from muriate of potash (MoP) and 25 mg/kg S from gypsum. Nitrogen was added in three splits, the first split during final land preparation and the remaining splits at 35 days and 60 days after transplanting. Intercultural operations such as weeding and irrigation were done whenever required. The crop was harvested at maturity and the data on yield and yield parameters were recorded. Plants of all three hills from each pot were measured and averaged to record the yield contributing characters. The grain and straw As content was determined after digesting the samples with HNO_3 and H_2O_2 at 120°C followed by flow injection hydride generation atomic absorption spectrophotometer (UNICAM model No. 969) with hydride generator assembly using matrix-matched standards. Nitrogen content of grain and straw was determined after digesting the samples with H_2O_2 and H_2SO_4 in presence of catalyst mixture. Phosphorus was determined

from HNO_3 and $HClO_4$ (3:1 ratio) digest following phosphomolybdate blue colour method. All the plants data were statistically analyzed following F-test and the difference between treatment means was adjudged by Duncan's Multiple Range Test.

Results

Yield

Both grain and straw yields were significantly reduced due to arsenic toxicity. The grain yields due to three arsenic treatments (0, 15 and 30 mg As/kg) were 74.17, 58.86 and 26.84 g/pot and the corresponding straw yields were 86.00, 67.94 and 29.94 g/pot, all were significantly different from one another (Table 1). Compared to the control pot, the yield reductions were 20.6 and 63.8 % in grain, and 21.0 and 65.2 % in straw, for the As_{15} and As_{30} treatments, respectively. It appeared that the toxic effect of added arsenic on grain and straw yields were deteriorated due to added P showing a negative interaction (Fig. 1). For example, the grain yields due to As_{30} treatment with different doses of P viz. P_0, P_{20}, P_{40}, P_{60}, & P_{80} were 35.55, 23.22, 19.96, 29.20 and 26.28 g per pot, respectively. The highest yield in both cases was observed with $P_{80}As_0$ treatment and the lowest yields with $P_{80}As_{30}$.

Yield contributing characters

Addition of arsenic at 30 mg/kg rate produced a highly significant toxic effect on the effective tillers/pot, filled grains panicle^{-1} and 1000-grain weight (Table 1). However, the toxic effect due to 15 mg/kg arsenic treatment was not significant. The number of effective tillers/pot for 0, 15 and 30 mg/kg arsenic treatments were 33.60, 31.33 and 23.40, respectively. The corresponding values for the number of filled grains panicle^{-1} were 96.72, 92.14 and 49.57. The 1000-grain weights for the arsenic treatments followed the order of 24.53, 24.94 and 21.11 g. There was no significant interaction of As and P on these three characters.

Table 1. Effects of arsenic and phosphorus on the yield and yield components of rice (cv. BRRI dhan29).

Treatment (As or P)	Effective tillers/pot	Filled grains/panicle	1000-grain weight (g)	Grain yield (g/pot)	Straw yield (g/pot)
As (mg/kg)					
0	33.60a	96.72a	24.53a	74.17a	86.00a
15	31.33b	92.14a	24.94a	58.86 b	67.94b
30	23.40c	49.57b	21.11b	23.81 c	29.94c
S.E. (±)	0.89	4.55	0.42	2.98	1.98
P (mg/kg)					
0	29.67	82.15	22.58	58.95	64.91
20	29.44	77.38	22.75	54.09	66.62
40	32.00	71.97	23.52	48.37	57.51
60	27.89	79.43	24.49	50.92	58.51
80	28.22	86.41	24.28	49.06	58.92
S.E. (±)	NS	NS	NS	NS	NS

In a column, the figures having same letter do not differ significantly at 5% level of probability

Arsenic and nutrient content

Arsenic concentrations of both grain and straw had increased as the dose of arsenic increased, the range being 0.214 – 0.507 mg/kg As for grain and 2.55 – 8.27 mg/kg As for straw (Table 2). The treatment with 15 mg/kg As had a grain-As concentration of 0.376 mg/kg and straw-As of 6.01 mg/kg. The As content also varied with the P doses with a result of 0.339 – 0.442 mg/kg in grain and 4.84 -7.47 mg/kg in straw. The As × P interaction was significant showing the maximum As concentration (0.75 mg/kg in grain and 10.17 mg/kg in straw) for $P_{80}As_{30}$ treatment in both grain and straw (Figure 1, straw data not shown).

Similar to arsenic, the N content in grain and straw increased with increasing addition of arsenic. The grain-N varied from 1.264 -1.520% and the straw-N from 0.572 - 0.839% (Table 2). There was a significant As × P interaction for grain-N content while the straw N-content remained unaffected.

Phosphorus content of rice grain also increased with arsenic doses but the reverse was true for straw-P content (Table 2). Thus, the highest grain-P concentration (0.41%) was recorded by the 30 mg/kg As treatment while for the straw-P (0.107%) the highest record was obtained with the As control. The As × P interaction was found significant with the maximum grain-P concentration (0.437%) in $P_{80}As_{30}$ and the maximum straw-P content (0.151%) in $P_{20}As_0$ treatments

Table 2. Effects of arsenic and phosphorus on the As, N and P concentrations in rice (cv. BRRI dhan29).

Treatment	N conc. (%)		P conc. (%)		As conc. (mg/kg)	
(As or P)	Grain	Straw	Grain	Straw	Grain	Straw
As (mg/kg)						
0	1.264c	0.572b	0.301c	0.107a	0.214c	2.55c
15	1.441b	0.800a	0.345b	0.076b	0.376b	6.01b
30	1.520a	0.839a	0.410a	0.085b	0.507a	8.27a
S.E. (±)	0.012	0.027	0.009	0.005	0.012	0.20
P (mg/kg)						
0	1.291c	0.796a	0.291c	0.065c	0.433ab	5.03b
20	1.284c	0.588b	0.353b	0.071c	0.352c	5.27b
40	1.524b	0.773a	0.339bc	0.094b	0.442a	4.84b
60	1.298c	0.844a	0.367ab	0.118a	0.339c	5.46b
80	1.644a	0.684ab	0.410a	0.099b	0.369abc	7.47a
S.E. (±)	0.016	0.035	0.011	0.006	0.016	0.26

In a column, the figures having same letter do not differ significantly at 5% level of probability

The study reveals that the grain yield was drastically reduced due to arsenic addition and it was associated with reduction in tillers and grain set. The toxic effect of arsenic was further deteriorated due to P supplement to soil (Fig. 1). This result can be interpreted in that added phosphate displaced sorbed arsenate from exchange sites, and therefore, increased the concentration of arsenic in the rhizosphere soil solution for subsequent uptake by rice roots.

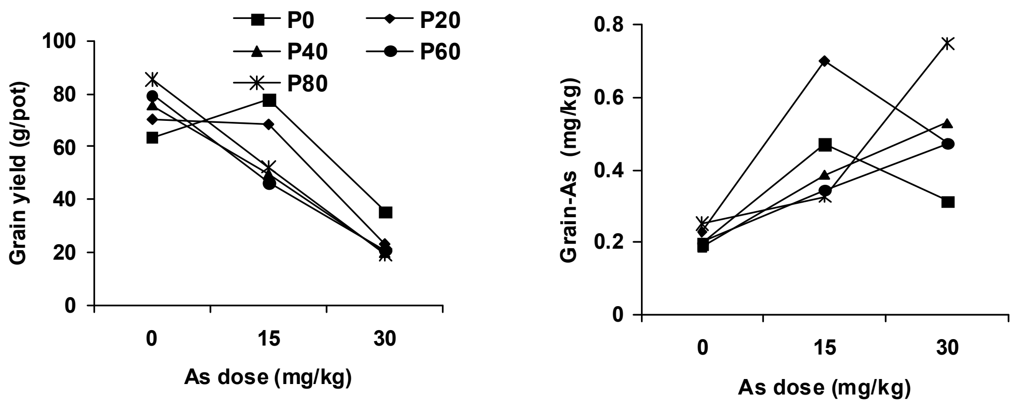

Figure 1. Interaction effect of arsenic and phosphorus on the yield and arsenic concentrations of rice.

Conclusion

The addition of arsenic markedly increased the arsenic concentration of grain and straw, with a concomitant reduction in grain and straw yields of rice. The situation was further deteriorated due to P application to soil, probably due to displacement of arsenic from adsorption sites in the bulk soil, with an increased concentration of arsenic in the rhizosphere soil solution for subsequent uptake by rice roots. Rice straw can be a potential exposure of arsenic to cattle.

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