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Effect of arsenic on *Amaranthus gangeticus*

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Abstract

Groundwater arsenic contamination has become a threat to the crop production potential in the soils of vast areas of Bangladesh. Situation is grave in some districts of the country, particularly the southern part. A pot experiment was conducted to investigate the effects of arsenic treated irrigation water (0, 1, 2, 5 and 10 mgL^{-1}), where a total of ten (10) irrigations were provided thus the treatments received 0, 10, 20, 50, and 100 mg arsenic (As) pot^{-1}. Effects of applied levels of arsenic on *Amaranthus gangeticus* (Lal shak) were evaluated in terms of the growth, yield, major nutrients' content, and their translocation in the plant. As treatments significantly reduced ($p \leq 0.05$) the dry weight of shoot and root by 19.31% and 44.03% respectively. Both total and available concentrations of nitrogen (N), potassium (K) and sulfur (S) were significantly ($p \leq 0.05$) suppressed by the As treatments, while only higher three doses significantly ($p \leq 0.05$) affected both levels of concentrations of phosphorus (P), calcium (Ca) and magnesium (Mg). Translocation coefficients for soil to root for P, K, S, and Mg were significantly reduced ($p \leq 0.05$), while translocation coefficients for root to shoot were significantly increased ($p \leq 0.05$) for K and S by 5 and 10 mgL^{-1} of arsenic treatments.

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Introduction

Bangladesh, a country of agriculture, grows different types of crops and vegetables all around the year and needs irrigation in different extents. About 30 to 40 percent of the net cultivable area of our country is under irrigation and ground water is the main source (more than 60 percent) of irrigation water. But ground water in 60 out of 64 districts has been reported to be contaminated with various degrees of arsenic (As) concentration (Huq *et al.,* 2003). But its sources have not been clearly identified yet. Some researchers have reported that groundwater contamination with As is attributed to the anthropogenic sources (Anawar *et al.,* 2002). The most As contaminated part of the country lies in the southern regions covering the districts Chandpur, Comilla, Noakhali, Munshiganj, Faridpur, Madaripur, Gopalganj, Shariatpur and Satkhira. Contamination has also been found in South-west, part of North-west, North-east and North Central regions (Ahmed *et al.,* 2011). Smith *et al*. (2001) reported that in many areas of Bangladesh As concentrations in ground water were more than 50 mg L^{-1}. They also suggested that long-term use of As-contaminated irrigation water could result in As accumulation in the soil and could be absorbed by the vegetables crops. In an experiment with high-arsenic concentration in soil, As changed the concentration, accumulation and translocation of other nutrient elements in plants; vegetable plants in that soils absorbed As in toxic levels, concentrated into plant body, and ultimately affected the growth and yield after metabolism of As species by vegetables (Farid *et al*., 2003).

The most widely cultivated and the most widely consumed vegetable, *Amaranthus gangeticus* is a high nutritional value, short duration crop grown round the year in Bangladesh. Several researchers evaluated the adverse effect of As in crop field (Norra *et al*., 2005) and its accumulation by plants (Sheppard, 1992).

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Most of the vegetable growers in Bagerhat district grow *Amaranthus gangeticus* and all the people consume this more than any other leafy vegetables (BCAS, 2013). The author, under the scope of no such research conducted in the soils of this area, intends to investigate the extent of harm it can cause to the growth, yield of this vegetable and its subsequent effects on the concentration, accumulation and translocation of other nutrients as well.

Materials and methods

Soil samples were collected from areas of intensive vegetable cultivation under Bagerhat district (23^o 12″ N and 89^o 15″ E). *Amaranthus gangeticus* plants were grown in earthen pots in the field laboratory for 6 weeks (4th February to 17th March, 2013) and irrigated with water containing five different levels of arsenic: 0, 1, 2, 5 and 10 mgL^{-1} (T0, T1, T2, T3 and T4, respectively). A total of ten (10) irrigations were provided thus the treatments received 0, 10, 20, 50, and 100 mg arsenic pot^{-1}, respectively. All the treatments were replicated three times. Nitrogen, phosphorus, sulfur and zinc were applied at recommended doses (BARC, 1997). The pots were arranged in completely randomized design. Soil pH was determined electrochemically at 1:2.5 soil:water ratio by using a glass electrode pH meter as described by Jackson (1973). Electrical conductivity (EC) of the soil was measured at a soil: water ratio of 1:5 by EC meter (USSLS, 1954). Available Na^+, K^+, Ca^{2+}, and Mg^{2+} of soil samples were extracted with 1N NH_4OAc solution (pH=7.0) as described by Piper (1950) and Jackson (1962). Na^+ and K^+ were determined with the help of a flame photometer and Ca^{2+} and Mg^{2+} were determined by EDTA titration method. The properties of soil before application of treatments are presented in the Table I.

Table I: Characteristics of soil

Properties of soil	Analysis
pH	7.93
EC	1.96
CEC ($cmol_c kg^{-1}$)	20.25
Texture	Silty Clay Loam
Organic carbon (%)	0.68
Moisture (%)	4.70
Available N ($mgkg^{-1}$)	104.50
Available P ($mgkg^{-1}$)	29.65
Available K ($mgkg^{-1}$)	27.48
Available S ($mgkg^{-1}$)	10.39
Available Ca ($mgkg^{-1}$)	290.00
Available Mg ($mgkg^{-1}$)	40.00

Agronomic parameters and nutrient content of the plant were determined by recommended methods. Translocation of nutrients from soil to root was measured by which is given below:

$$TF_{root} = \frac{C_{root}}{C_{soil}}$$

Translocation of nutrients from root to shoot was measured by which is given below:

$$TF_{shoot} = \frac{C_{shoot}}{C_{root}}$$

Where, C_{soil}, C_{shoot} and C_{root} are nutrients concentration in the soil (mg kg^{-1}), shoot (mg kg^{-1}) and root of plant (mg kg^{-1}), respectively. *TF*>1 represent that translocation of nutrients effectively was made to the root from soil and to the shoot from root (Fayiga and Ma, 2006). The level of significance of the different treatment means were calculated by Duncan's new multiple range test (DMRT) and least significant difference (LSD) techniques (Zaman *et al*., 1982).

Results and discussion

Effects of arsenic on yield and yield components

Effects of different levels of As on yield and yield parameters are summarized in Table II. The result showed that with increasing arsenic concentration in irrigation water the number of plants per pot (15), shoot length (18.14 cm), stem circumference (1.68 cm) and number of leaves per plant (8.15) decreased significantly ($p \leq 0.05$) from the control. Maximum reduction in fresh matter (26.85gm) and dry matter yield (3.05gm) was found at the highest arsenic treatment (T4) which reduced the fresh and dry mater yield by 19.48% and 19.31% respectively and biological yield by 19.42% over control. At T4 treatment fresh matter productions of root decreased by 47.32% while the dry matter decreased by 44.03%. The dry matter production of root at T3 did not show any significant change with T4. This confirms that root was affected first than shoot due to arsenic contamination. Reduction in growth and yield parameters was due to the uptake and accumulation of arsenic in plant.

Choudhury *et al*. (2008) found similar results in which they observed a decrease in the growth and yield parameters of red amaranth due to arsenic toxicity.

Table II. Yield components of *Amaranthus gangeticus* and changes of yield due to treatment

Treatment	No of Plants per pot	Shoot length (cm)	Stem circumference (cm)	No of leaves per plant	Shoot fresh matter (gm)	Shoot dry matter (gm)	Root fresh matter (gm)	Root dry matter (gm)	Yield decrease over control (%)
T0	20 a	19.53 a	1.79 a	8.83 a	33.32 a	3.78 a	8.98a	1.34a	0.00
T1	20 a	19.17 ab	1.78 b	8.75 a	32.37 b	3.68 b	9.38b	1.12b	2.85
T2	19.3 a	18.93 b	1.78 b	8.57 b	31.33 c	3.56 c	6.35c	1.08b	5.97
T3	17.7 b	18.83 b	1.75 c	8.53 b	30.07 d	3.41 d	4.30d	0.75c	9.75
T4	15 c	18.14 c	1.68 d	8.15 c	26.85 e	3.05 e	4.73e	0.75c	19.42
SE(±)	0.47	0.23	0.002	0.048	0.37	0.04	0.18	0.09	-
CV (%)	3.14	1.49	0.16	0.67	1.46	1.48	3.20	11.24	-

Means followed by different letter/s in each column are significantly different ($p \leq 0.05$) according to DMRT (SE= Standard error and CV= Coefficient of variance)

Effects of arsenic on nutrient concentrations in shoot and root

Effects of different levels of arsenic on nutrient concentrations in shoot and root summarized in Table III. The concentration of nitrogen showed a significant ($p \leq 0.05$) decrease with the increase in arsenic concentration for both root and shoot where the lowest nitrogen concentration was found at the highest arsenic treatment. The activities of nitrate reductase and nitrite reductase enzymes may be affected by arsenic toxicity which results in the lowering of nitrogen concentrations in both root and shoot. Ghosh *et al.*(2013) found severely reduced nitrate and nitrite contents in both shoot and root of wheat seedlings due to arsenic toxicity. Phosphorus concentration ranged from 5.92 to 12.18 mgg^{-1} in shoot and 4.17 to 10.37 mgg^{-1} in root (Table III) The concentration in shoot showed a decreasing trend with increasing As treatment but a significant ($p \leq 0.05$) decrease was found at T3 and T4 while, in root the concentration was significantly reduced from the control. In both cases highest level of arsenic treatment (T4) gives the lowest concentration

Table III. Nutrient contents in shoot and root

Arsenic Treatment	N (mgg^{-1})		P (mgg^{-1})		K(mgg^{-1})		S (mgg^{-1})		Ca (mgg^{-1})		Mg (mgg^{-1})	
	Root	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*
T0	8.28a	8.45a	10.37a	12.18a	39.84a	51.27a	16.54a	16.41a	14.17a	22.92a	9.50a	12.25a
T1	8.08b	8.06b	9.53b	12.01a	37.72b	47.81b	15.04b	15.27b	12.50b	22.08a	9.00a	8.50b
T2	7.89c	8.00b	8.01c	11.33ab	34.53c	46.22b	11.34c	13.65c	11.25c	20.42b	8.25a	7.25b
T3	7.75d	7.54c	6.37d	9.19b	28.16d	39.84c	7.57d	9.68d	9.17d	17.92c	5.00b	4.75c
T4	7.09e	7.18d	4.17e	5.92c	19.92e	34.00d	4.00e	7.22e	8.75d	14.58d	1.50c	1.75d
SE (±)	0.039	0.036	0.336	1.01	0.87	1.15	0.54	0.36	0.37	0.745	0.59	0.85
C V(%)	0.61	0.57	5.36	12.28	3.34	3.22	6.03	3.50	4.09	4.66	10.89	15.11

Means followed by different letter/s in each column are significantly different ($p \leq 0.05$) according to DMRT
(SE= Standard error and CV= Coefficient of variance)

of phosphorus. Competitive effect between arsenate (AsO^{3-}) and phosphate (PO_4^{3-}) ion may suppress the phosphate uptake by the plant resulting in the reduced accumulation of phosphate in shoot and root. Chen *et al*. (2002) reported that arsenic compete with phosphate for uptake by plants and suppress the phosphate-arsenate uptake system resulting in a lower accumulation of phosphate. The effect of arsenic on potassium content is shown in Table III. The values of potassium significantly ($p \leq 0.05$) decreased both in shoot and root with increasing arsenic concentration except in T1 and T2. In both cases the highest content of potassium was found in T0 (51.27 mgg^{-1} in shoot and 39.84 mgg^{-1} in root) and lowest content was found in T4 treatment (34.00 mgg^{-1} in shoot and 19.92 mgg^{-1} in root) The decrease in K content may be due to the potassium ion may form complexes with the anionic form of arsenic and thus decrease the availability of potassium into plants. Quanji *et al*. (2008) observed a significant decrease in potassium content due to arsenic treatment in both shoots and roots of wheat under hydroponic system. On the other hand, Roy *et al.* (2012) found greater concentration of potassium in shoot of green *Amaranthus* and red *Amaranthus* than root due to arsenic treatment. Sulfur concentration in both shoot and root showed significant ($p \leq 0.05$) differences among the treatments and it varied from 7.2 to 16.41mgg^{-1} in shoot and 4 to 16.5 $mgg^{-1}$for root (Table III). In both cases T4 gives the lowest concentration than control. The decrease in sulfur concentration in plants may be due to the antagonistic relationship between the anionic forms of sulfate and arsenate. Quanji *et al*. (2008) found a significant reduction in sulfur in both shoots and roots of wheat under hydroponic system. The concentration of calcium in shoot and root varied from 14.58 to 22.92 mgg^{-1} and 8.75 to 14.17 mgg^{-1} respectively (Table III). The data of calcium in shoot showed significant ($p \leq 0.05$) differences among the treatments except T0 and T1. While, in root, a significant difference in Ca concentration was observed in lower concentration of arsenic but at higher doses it did not show significant difference. This means that root did not suffer at higher level of arsenic than shoot. The lower concentration of calcium in shoot and root may be due to the precipitation of Ca with arsenate to form insoluble compounds in soil. Bothe *et al*. (1999) found reduction of the mobility of dissolved calcium with the formation of low solubility calcium arsenate. Magnesium concentration in shoot and root showed a significant ($p \leq 0.05$) decrease due to increasing arsenic content which ranges from 1.75 to 12.25 mgg^{-1} in shoot and from 1.50 to 9.50 mgg^{-1} in root. In both shoot and root, arsenic at lower concentration (T1 and T2) did not affect the uptake of Mg (Table 3) which confirms a reverse trend with the uptake of Ca ion by the plant. At lower concentration arsenic might play an additive role for what Mg uptake did not hinder. Klei *et al*. (1997) reported that in hydroponic system, addition of arsenic significantly increased the concentration of Mg in shoots of bean plants. But at higher concentration of arsenic, Mg get precipitated with arsenate ion which lowered its solubility as well as uptake by the plant. Voigt *et al.* (1996) observed similar result.

Effects of arsenic on translocation factor (TF) of nutrients from soil to root and root to shoot

The effect of arsenic on translocation factor (TF) of different nutrients is for both root and shoot of *Amaranthus gangeticus* is shown in table IV. The translocation of nutrients significantly reduced with increasing arsenic treatments from soil to root and that from root to shoot (Table IV). Increasing As concentration significantly ($p \leq 0.05$) varied in their efficacy in reducing translocation. The translocation of nitrogen showed similar decreasing trend both in root and in shoot. Jha and Dubey (2004) observed similar findings working with rice plant. In their experiment, they reported that nitrogen is generally taken up through an active transport system which is an ATP dependent process. As toxicity might have caused a reduction in ATP pool which resulted into a reduction in the ability of the *Amaranthus gangeticus* to translocate nitrogen from soil to root as well as from root to shoot. For phosphorus, translocation factor indicates that translocation from soil to root was comparatively higher than that from root to shoot. Increasing As concentrations significantly varied in reducing the translocation to root while translocations of P to shoot were unaffected. Reduction of P translocation in *Amaranthus gangeticus* may be due to the antagonistic effect between As and P translocation. Reduction of P uptake in rice because of antagonistic effect between As and P was reported by Mehrag and Macnair (1990). Translocation of K from soil to root declined with increasing As concentration orderly. Highest translocations of K from root to shoot was obtained with no-As while that declined significantly with As treated plants. Provided that increasing As concentrations produced insignificant differences in translocation of K. Wallace *et al.* (1980) reported to find a depression of K concentration in roots of bush bean plants due to arsenic in the nutrient solution.

Lower concentration of As did not affect translocation of S but higher doses significantly affected ($p \leq 0.05$) from soil to root while translocation from root to shoot was unaffected even with higher concentration of As (Table IV). The translocation phenomenon for the first case may be due to competition of sulphate and arsenate ion in the soil solution. Merry *et al.* (1986) in their experiment obtained similar results and reasoned that S and As exists in soil solution in similar ionic forms (e.g. sulfate and arsenate) and there should be a competition between these two ions.

Increasing As concentration did not affect translocation of Ca from soil to root and similar trend was obtained also for the case of root to shoot translocation. The similarity in response of translocation against lower doses of As may be due to the fact that the concentrations applied were close to one another and below threshold concentration for soil. However, the highest As concentration significantly differed from zero-As (control). Results of Ca translocation in this experiment partially complies with that of Wallace *et al.* (1980) findings, where they obtained a depression of Ca concentration in leaves and roots of bush bean plants against increasing As concentration.

Results obtained for translocation of Mg revealed that lower two doses of As did not affect but higher two concentrations (50 and 100 mg L^{-1}) significantly differed in affecting translocation of Mg from soil to root. Mg Translocation from root to shoot was unaffected by the applied levels of As (Table IV), which may be due to selective translocation. Shaibur (2009) found a significant negative effect on the concentration of Mg both in shoots and roots of barley plants due to increasing As concentrations.

Table IV. Translocation factor of nutrients from soil to root and from root to shoot

Arsenic Treatment	N		P		K		S		Ca		Mg	
	Root	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*	*Root*	*Shoot*
T0	3.86a	1.02a	5.56a	1.46a	2.18a	1.71a	8.94a	1.83a	0.27a	1.96a	0.41a	1.33a
T1	3.56b	1.01a	5.22ab	1.42a	2.10a	1.42b	8.91a	1.28b	0.25ab	1.93a	0.38a	1.29a
T2	3.10c	0.97b	4.69b	1.41a	1.95b	1.34b	7.37b	1.20bc	0.25ab	1.82ab	0.38a	0.96a
T3	2.92d	0.95b	4.14c	1.26a	1.68c	1.28b	6.26c	1.02bc	0.24ab	1.76ab	0.20b	0.95a
T4	2.78e	0.10c	3.55d	1.17a	1.25d	1.26b	4.20d	0.99c	0.23b	1.62b	0.13c	0.88a
SE (±)	0.065	0.01	0.25	0.17	0.05	0.07	0.40	0.12	0.01	0.29	0.03	0.24
C V(%)	2.46	1.02	6.48	15.16	6.48	6.08	6.91	11.53	5.88	6.36	10.79	27.64

Means followed by different letter/s in each column are significantly different ($p \leq 0.05$) according to DMRT (SE= Standard error and CV= Coefficient of variance)

Conclusion

As a consequence of arsenic contamination, fresh and dry matter production of the *Amaranthus gangeticus* decreased at higher concentration of arsenic while root dry matter was affected by lower arsenic concentration. The contents and accumulation of N, P, K, S, Ca and Mg in the shoots and roots of plant show the variations in elemental concentrations due to increasing arsenic concentration.

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