Research Article

EVALUATION OF FIVE WHEAT VARIETIES ON ARSENIC CONTAMINATED SOILS OF BANGLADESH

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Abstract

An experiment was conducted at Farming System Research and Development Site, Hatgobindapur, Faridpur during 2012-13 to evaluate five wheat varieties against arsenic contaminated soils and determined accumulation of arsenic in grain and straw of wheat varieties. The experiment was laid out in RCB design with six replications. BARI Gom-21, BARI Gom-23, BARI Gom-24, BARI Gom-25 and BARI Gom-26 were used as treatment variables. The arsenic content was determined by using atomic absorption spectrophotometer (AAS). Result revealed that, wheat varieties differed in their grain arsenic concentration (0.49-1.15 mg kg^{-1}). The arsenic translocation in wheat grains usually least and accumulation by different tissues followed the order root>stem>leaf>grain across the varieties. The variety BARI Gom-26 was found to accumulate least arsenic in grains followed by BARI Gom-25 and BARI Gom-24 the highest under same growing condition due to phyto-extraction or phyto-morphological potential of the varieties. Maximum grain yield (4.36 t ha^{-1}) was obtained from BARI Gom-26 followed by BARI Gom-25 and the lowest yield (3.43 t ha^{-1}) was recorded from BARI Gom-23. Therefore, BARI Gom-26 and BARI Gom-25 can successfully be grown for higher yield in arsenic contaminated soils and water of Faridpur.

Keywords: Arsenic; concentration; evaluation; irrigation; nutrient; uptake; variety

Introduction

The widespread arsenic contamination of groundwater is a well-recognized major health concern in Bangladesh, where contaminated water is used for drinking and irrigation purpose (Imamul Huq and Naidu, 2005). About 35-37 million people are exposed to arsenic contaminated well-water (smith *et al.*, 2007). A joint survey of SOES and DCH in Bangladesh indicated that 73.34 % tube-well water samples contain arsenic contamination above the WHO standard limit (0.01mg l^{-1}) and 54 districts possess this limit and 74 blocks and 2700 villages have already been identified ground water arsenic contamination above 0.05 mg l^{-1} (Chakraborti *et al.*, 2002). Out of 20 countries in different parts of the world where groundwater arsenic contamination and human suffering have been reported so far, Bangladesh appears to be the most affected followed by West Bengal, India (Sanyal, 2005). Clinical manifestations of arsenic poisoning (arsenicosis) begin with various forms of skin diseases which often deteriorates and results in damages to internal organs and ultimately to cancer and death (Hossain, 2006).

The people of Bangladesh are not only drinking arsenic contaminated water but also produce crops irrigated with this water. About 75 % of the total cropped area and 30-40 % of the net cropped area are dependent on ground-water irrigation (Dey *et al.*, 1996). Background concentrations of soil arsenic in Bangladesh are 4-8 mg kg^{-1} soil. However, in areas where irrigation is done with arsenic contaminated ground-water, soil arsenic can reach upto 58 mg kg^{-1} soil (Imamul Huq and Naidu, 2003). High arsenic concentration in soils and irrigation water is phytotoxic that adversely affect plant growth and fruit yields (Carbonell-Barrachina *et al.*, 1995), discolored and stunted roots, withered and yellow leaves, reductions in chlorophyll and protein contents and in photosynthetic capacity of plant (Marin *et al.*, 1993).

Wheat (*Triticum aestivum*) is the most important food grain and ranks first in terms of global consumption and production of food crop known as king of cereals (Costa *et al.*, 2013). In Bangladesh it is the second major cereal food grain. It occupies around 3, 58,180 hectares of land and makes up 6% of the cereal production from 9,95, 356 m tons

with an average yield of 2.78 t/ha (BBS, 2012). Consumption rate of wheat is increasing day by day due to its low production cost, good market price and nutrition value. But the availability of land for crop production has declined in recent years and this is expected to continue into the future due largely to exponential growth in human population. This is why it has become necessary to adopt intensive cultivation in order to meet the demand for more food especially in relatively fixed food grain areas. In such areas, groundwater irrigation is highly required for better crop production, particularly in post monsoon and pre-monsoon seasons when there is acute scarcity of rainfall.

The contents of arsenic in agricultural soil irrigated with arsenic contaminated groundwater are higher than normal levels (Chen *et al.*, 2002). A significant quantity of groundwater is utilized in agricultural sector, especially for irrigating Boro (winter) rice which contributes about 50% of rice production in this country. The use of arsenic contaminated groundwater for irrigation may lead to an accumulation of arsenic in soils and subsequent entry into the food chain (Jahiruddin *et al.*, 2003). In order to evaluate arsenic toxicity, it is important to consider the range of background exposures, because arsenic occurs naturally in the environment and is transported to the food chain. Recent studies have shown that the contribution of food-chain towards arsenic pollution in human is in many folds greater than that of the drinking water (Diaz *et al.*, 2004). The uptake of arsenic by the plant tissues from soil irrigated with arsenic contaminated groundwater was significantly evaluated, particularly in edible crops (Hossain, 2006). The plant uptake level also varies with crops and the cultivars of the particular crop (Kundu *et al.*, 2012). It was also observed that the use of arsenic rich irrigation water affected plant height, crop yield and development of root growth (Hossain, 2006).

Therefore, the assessment of total arsenic contents in soils and grain crops irrigated with arsenic contaminated groundwater is a matter of health concern (Meneses *et al.*, 1999). Rice based cropping system is the predominant system in Bangladesh; however, monsoon season rice (T.aman) is not a major problem due to its rainfed cultivation (Duxbury *et al.*, 2003). On the other hand, Boro rice is cultivated mainly through groundwater irrigation through shallow tube-well, appears to be more susceptible to arsenic accumulation than wheat and barley (Su *et al.*, 2010). Wheat is widely cultivated in Bangladesh and it is a veritable alternative for wetland rice cultivation (Reddy, 2009). Its commonness is due to lesser groundwater irrigation requirement than Boro rice. In Bangladesh, wheat is mainly cultivated as rabi crop in the month of November-December with irrigation but over the past decade, arsenic contamination in groundwater irrigated soil has been reported from these areas (Hossain, 2006 and Rahman *et al.*,

2007a). So, it is necessary to evaluate the varieties which would be less efficient in uptaking arsenic from the soil and water. Considering the above fact, this investigation was undertaken to study the relative pattern of arsenic accumulation and varietal tolerance of wheat by selected cultivars under charland ecosystem of Faridpur.

Materials and Methods

The experiment was conducted at farmers' field of FSRD site, Hatgobindapur, Bangladesh Agricultural Research Institute (BARI), Faridpur during rabi 2012-13. It belongs to the Low Ganges River Floodplain Agro-ecological Zone (AEZ-12). The geographical position of this area is between 23º33′N latitude and 89º44′E longitude. The study area was contaminated with arsenic (Chakraborti *et al.*, 2002) and the level of arsenic in groundwater greatly exceeded WHO permissible limit for drinking water (0.01mgl⁻¹) and Food and Agricultural Organization permissible limit for irrigation water (0.10mgl⁻¹).

The experimental area is located in sub-tropical region characterized by high temperature and high rainfall during the monsoon/rainy season (June-October and low temperature and rainfall during post monsoon/winter (November-February). The mean minimum and maximum temperature and relative humidity ranging from 11.84-33.81ºC and 64.75-82.61%, respectively. The crop received (90.07mm) rain showers from November 2012 to March 2013. The experimental soils were mostly sandy to silt loam in texture and slightly acidic to alkaline having a pH ranged from 6.8 to 7.1. The detailed characterization of the experimental soils and irrigation water has been recorded in Table 1.

The experiment was laid out in Randomized Complete Block Design (RCBD) replicated six times having five selected cultivars of wheat, namely BARI Gom-21, BARI Gom-22, BARI Gom-24, BARI Gom-25 and BARI Gom-26. The unit plot size was 5m x 4m. The different wheat varieties were planted in the 3rd week of November with the seed rate 120 kg ha⁻¹ and maintaining row spacing of 20 cm with recommended fertilizer (FRG'2005) applied to a well pulverized soil. The whole amounts of triple super phosphate, muriate of potash, gypsum, zinc sulphate and boric acid and two thirds of urea were applied before final land preparation prior to sowing. Rest of urea was applied in two equal splits. The first split was applied at 21 days and second at 48 days after seed sowing. Irrigation was applied immediately after sowing and subsequent irrigations were performed at crown root initiation (CRI), tiller completion, late joining, flowering, milking and dough stage where arsenic contaminated shallow tube-well (STW) water was used as the source of irrigation. Weeding was done twice, one at CRI stage and another at maximum tillering stage.

Table 1: The characterization of source (irrigation water) and sink (soil) of experimental site at Hatgobindapur, Faridpur during rabi 2012-13

Properties	Observations		Methodology	Citation
	Initial soil	Post-harvest soil		
P^H	6.85	6.83	Soil-water suspension (1:2.5)	Jackson (1967)
EC (dsm^{-1})	0.15	0.15	Soil-water suspension (1:2.5)	Jackson (1967)
Oxydizable organic C (g kg^{-1})	4.42	4.40	Wet digestion method	Walkley and Black (1934)
Available soil N (kg ha^{-1})	129	126	Hot alkaline permanganate	Subbaiah and Asija (1956)
Available P (µg g^{-1})	9.91	9.75	0.5M NaHCO$_3$ extraction	Olsen *et al.* (1954)
Available K (meq/100 g soil)	0.12	0.11	Neutral (N) NM$_4$OAc extraction	Brown & Wrancke (1988)
Available S (µg g^{-1})	13	12	0.15% CaCl$_2$ extraction	Page *et al.* (1982)
Total soil arsenic (mg kg^{-1})	28.60	28.87	HNO$_3$:H$_2$So$_4$:HClO$_4$ 10:1:4 (v/v)	Mclaren *et al.* (1998)
Irrigation water arsenic (mg l^{-1})	-	0.25	-	Mclaren *et al.* (1998)

Irrigation water samples have been collected from the shallow tube well pump which is used for irrigation in our study area. Prior to sample collection the pump was kept running for about 10-15 minutes to get a uniform rate of discharging water. Then the water samples were collected in plastic container and preserved with concentrated HNO$_3$. The crop was harvested at well matured stage on the 14 March 2013. At maturity stage, ten hills from each plot were sampled randomly for collection of yield contributing data. The crop was cut at the ground level. Grain and straw yield were taken from whole plot. Plant samples were taken from the field at maturity. The roots, stems, leaves and grains were collected separately and cut into small pieces. These samples were air dried and kept in the sample packet. For determination of arsenic concentration 1 g of prepared sample was taken and digested with tri-acid mixture (HNO$_3$: H2SO$_4$: HClO$_4$, v/v) until a clear solution was obtained. The total arsenic content in the solution was determined by using atomic absorption spectrophotometer (AAS), Perkin Elmer Analyst 200 coupled with Flow Injection Analysis System (FIAS 400) where the carrier solution was 10% v/v HCl following Olsen method as described by McLaren *et al.* (1998). The data were analyzed statistically with computer package programme MSTAT-C and the mean differences were adjudged by Duncan's Multiple Range Test (DMRT) at 5% level of probability (Gomez and Gomez, 1984).

Results and Discussion

Significant variations were observed in yield components of the tested wheat varieties (Table 2). The performances of wheat varieties were good because initial and post-harvest soil arsenic (28.60 to 28.87 mg kg^{-1}) were low in soil. This result indicates that under aerobic situation the presence of arsenic in soil even up to 29 mg kg^{-1} might not affect the yield of the crop. Arsenic concentrations in agricultural soils of arsenic affected areas in Bangladesh range from 20 to 90 mg/kg soil (Ullah, 1998).

Plant Height (cm)

Plant height of wheat varieties were insignificant and ranges from 96.50 cm to 99.30 cm (Table 2). Mondal *et al.* (2011) reported that plant height of tested wheat varieties were in between 92-100 cm. So, effect of arsenic on plant height was not found remarkably. Increasing arsenate in soil enhanced competition between arsenate (As V) and phosphate for sorption sites (Zhang, 2009). The phosphate level (12 µg g^{-1}) in post-harvest soil was lower than initial soil (13 µg g^{-1}) due to pH level became lower (6.8) in post-harvest soil than initial soil (6.9) that indicated arsenate (As-V) presence in soil more than arsenate (As III). Arsenic III is more toxic than As-V (Oscarson *et al.*, 1983).

Number of Effective Tillers Hill^{-1}

Number of effective tillers hill^{-1} varied significantly among the varieties. Maximum number of effective tillers hill^{-1} (3.75) was obtained from BARI Gom-26 followed by BARI Gom-25 (3.58) which was statistically similar. The lowest number of effective tillers hill^{-1} (2.68) in BARI Gom-23 which was statistically at par with BARI Gom-24 and BARI Gom-21 (Table 2). Performance of the wheat varieties was apparently good as the level of arsenic in soil was low and no adverse effect on number of effective tillers hill^{-1}. Marin *et al.* (1993) reported that improving tillering and no reduction in dry matter production when arsenic concentration was low in growth media. Irfan *et al.* (2005) stated that different varieties respond differently due to variation in their genetic makeup.

Length of Spike

Length of spike across the varieties was significantly affected by 5% level of probability it was ranged from 14.27 to 19.21cm (Table 2). Maximum length of spike (19.21 cm) was recorded from BARI Gom-26 which was statistically at par with BARI Gom-25. The shortest spike length (14.27 cm) was recorded in BARI Gom-24 which was statistically similar with BARI Gom-21 and BARI Gom-23, respectively. The results indicated that there was genotypic differences in length of spike might be due to genetic makeup of the varieties which was reported by Irfan *et al.* (2005).

Number of Kernels Spike^{-1}

Number of kernels spike^{-1} was significantly influenced by the varieties and it was ranged from 33.22 to 41.28 (Table 2). Significantly the maximum number of kernels spike^{-1} (41.28) was recorded in BARI Gom-26 and the less value of (33.22) was noted in BARI Gom-23 which was statistically identical with BARI Gom-21. Number of kernels spike^{-1} 41.24 and 38.94 were recorded from BARI Gom-24 and BARI Gom-25 which were statistically similar. This variation was found due to their genetic makeup. Performance of the tested wheat varieties were good due to upland situation toxic affect of arsenic was lower than submerged rice cultivation. Similar results were reported by Al-Musa *et al.* (2012).

Thousand Grains Weight

Effect of cultivars on thousand kernels weight was highly significant across the varieties (Table 2). Maximum thousand kernels weight (51.14 g) produced by BARI Gom-25 which was statistically similar with BARI Gom-26. This might be due to the balance accumulation of different nutrient elements in the grain. The less thousand grains weight (36.92 g) was found in BARI Gom-23 followed by BARI Gom-21(40.26 g) and BARI Gom-24(40.99 g). Frans *et al.* (1998) reported that grain having increased level of which decreased 1000- kernels weight. These results are in agreement with the present findings.

Arsenic Accumulation Pattern

The arsenic concentration in the different tissues of the wheat plants showed that the highest accumulation was observed in roots compared to other plant parts (Fig. 1). Arsenic accumulation in wheat kernels was lesser than any other tissues remained in an order of root> stem> leaf> kernel across varieties. In a similar study, significantly least uptake and translocation of this toxic metalloid in the wheat kernel compared with the wheat root and shoot have been reported by Pigna *et al.* (2010). In rice plants, Abedin *et al.* (2002) also observed that a very large amount of arsenic retained in root compared to its content in straw and grain and followed in order of root> stem> leaf> grain (Smith *et al.* 2007). Reports of Rahman *et al.* (2007b) and Bhattacharya *et al.* (2010) also supported these results. Such findings are quite consistent with general observations that arsenic concentration was found to vary between different tissues. Zhang *et al.* (2009) reported that arsenic concentration in roots was about 10 times higher than in straw. These results suggested that arsenic distribution to the upper plant parts is lower than ground parts might be due to its lower mobility. In general, distribution of arsenic in plant parts was in the order: below ground parts>aerial parts (Sanyal 2005).
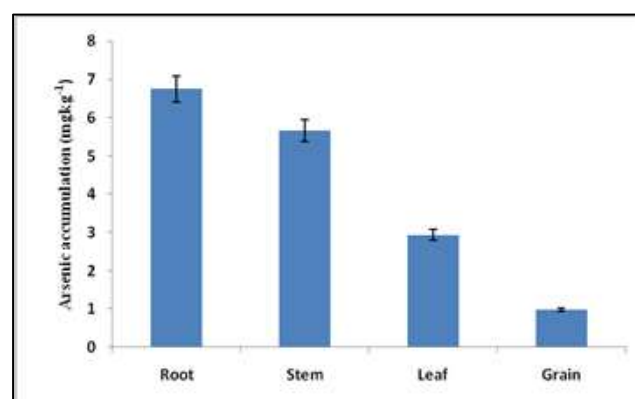

Fig. 1: Arsenic accumulation pattern of wheat varieties (average value of all varieties)

Table 2: Yield contributing characters of different wheat varieties at FSRD site Hatgobindapur, Faridpur during 2012-13

Variety	Plant height (cm)	Effective tillers hill^{-1} (N)	Spike length (cm)	Kernels spike^{-1} (N)	1000 kernels wt. (g)
BARI Gom-21	97.00	2.90bc	14.52c	33.56b	40.26bc
BARI Gom-23	99.30	2.68c	15.02bc	33.22b	36.92c
BARI Gom-24	98.80	2.80c	14.27c	41.24a	40.99bc
BARI Gom-25	97.64	3.58a	18.20a	38.94ab	51.24a
BARI Gom-26	96.50	3.75a	19.21a	41.28a	49.98ab
CV (%)	4.94	7.63	5.57	6.39	6.49

In a column, figures having common letter(s) do not differ significantly at 5% level by DMRT

Arsenic Accumulation in Wheat Varieties

At maturity of wheat, arsenic accumulation by different plant tissues significantly varied across the tested varieties (Table 3). Arsenic concentration in wheat roots ranged from 7.08-9.72 mg kg^{-1} and the highest arsenic concentration in roots was in the variety BARI Gom-21 followed by BARI Gom-23 and BARI Gom-24. With regard to wheat stem, arsenic concentration ranged between 4.49-7.37 mg kg^{-1} and accumulation pattern showed similar trends with the roots. Across tested varieties, arsenic concentration in wheat leaves ranged from 2.60-3.23 mg kg^{-1} and significantly least arsenic concentration was in the variety BARI Gom-25 but the value was not statistically different from other varieties except BARI Gom-21. Finally, wheat kernels accumulate significantly least amount of arsenic and it ranged between 0.49-1.15 mg kg^{-1}. BARI Gom-24 had the highest concentration of arsenic which was statistically similar with BARI Gom-21 and BARI Gom-23. The least accumulation of this toxic metalloid was in the cultivar BARI Gom-25 followed by BARI Gom-26 with maximum yielding capacity. Arsenic accumulation and uptake in wheat tissues significantly varied over the tested varieties. In rice plant similar results are also reported by Meharg and Rahman (2003) who stated that arsenic uptake and accumulation in rice plant from irrigation water and contaminated soil might depend on cultivars. Selected cultivars accumulated significantly different proportions of arsenic in grain and straw among which arsenic recovery was maximum in grains of BARI Gom-24 and in straw of BARI Gom-21. On the other hand, BARI Gom-26 showed the least arsenic recovery by its grains which was statistically at par with BARI Gom-25.

Table 3: Arsenic accumulation in wheat biomass at FSRD site Hatgobindapur, Faridpur during rabi 2012-13

Varieties	Arsenic concentration (mg kg^{-1})				
	Root	Stem	Leaf	Grain	Total
BARI Gom-21	9.72a	7.37a	3.23a	1.08a	21.40
BARI Gom-23	9.01ab	5.68bc	2.96b	0.98a	18.63
BARI Gom-24	8.91ab	5.59c	3.06b	1.15a	18.71
BARI Gom-25	7.95bc	5.16cd	2.60b	0.49c	16.20
BARIGom-26	7.08c	4.49d	2.86b	0.62b	15.05
CV%	7.55	7.60	5.36	3.19	-

In a column, figures having common letter(s) do not differ significantly at 5% level by DMRT

Yield and Arsenic Uptake

Grain and straw yields of wheat differed significantly across the varieties (Table 4). The selected cultivars produced significantly different yields among which the highest grain yield was obtained from BARI Gom-25 which was statistically similar with other varieties except BARI Gom-23. With regard to straw yield, similar trend was also observed among the varieties. On the other hand, significantly least grain and straw yields were observed in BARI Gom-23. The arsenic uptake by grain and straw of the selected cultivars were presented in Table 4. The uptake through straw observed were many folds greater than the grain over the cultivars. BARI Gom-26 accumulated least amount of arsenic in grains with maximum yielding capacity whereas BARI Gom-23 had moderate concentration of arsenic in its grain and produced least grain yield. On the other hand, BARI Gom-24 had higher arsenic concentration with higher yield while BARI Gom-21 showed highest recovery of this toxic metalloid with higher yielding capacity. These results indicate that BARI Gom-21 might have higher arsenic accumulation ability and are more tolerant to arsenic phyto-toxicity than other varieties. BARI Gom-25 and BARI Gom-26 having higher production ability with least accumulation of arsenic in its edible parts. Kundu *et al.* (2012) reported that arsenic concentration appearing toxicity widely varied with plant genotypes probably due to varietal differences in arsenic translocation and phyto-extraction or phyto-morphological potential of the varieties.

Table 4: Yield and arsenic uptake by different wheat varieties at FSRD site Hatgobindapur, Faridpur during rabi 2012-13

Varieties	Yield (t.ha^{-1})		Arsenic uptake (g.ha^{-1})		
	Grain	Straw	Grain	Straw	Total
BARI Gom-21	3.85ab	4.75ab	4.16a	50.35a	54.51a
BARI Gom-23	3.43b	4.30b	3.36b	37.15c	40.51b
BARI Gom-24	3.98ab	4.73ab	4.58a	40.82bc	45.40ab
BARI Gom-25	4.17ab	4.98ab	2.70c	38.64c	41.34b
BARIGom-26	4.36a	5.10a	2.04d	37.49c	39.53b
CV%	6.67	6.52	5.60	5.19	7.38

In a column, figures having common letter(s) do not differ significantly at 5% level by DMRT

Arsenic Distribution between Straw and Grain

Distribution of arsenic between straw and grains was evaluated in two ways: percentage of the total arsenic uptake that was distributed to straw and grains (Fig. 2) and the uptake ratio of straw to grain (Fig. 3). The average uptake by straw showed 9-19 times greater than grain uptake, regardless of the tested varieties among which cultivar BARI Gom-26 (19 folds) and BARI Gom-25 (14 folds) were statistically identical and recorded the maximum values. Among the varieties, BARI Gom-26 and BARI Gom-25 contributed the highest ratio which means least translocation of arsenic through grains. The significantly least straw: grain ratio with higher translocation of arsenic in grains was observed under BARI Gom-24 followed by BARI Gom-23 and BARI Gom-21. Arsenic translocation in grains varied significantly across the varieties and followed the trend of BARI Gom-

26>BARI Gom-25>BARI Gom-23>BARI Gom-21>BARI Gom-24.
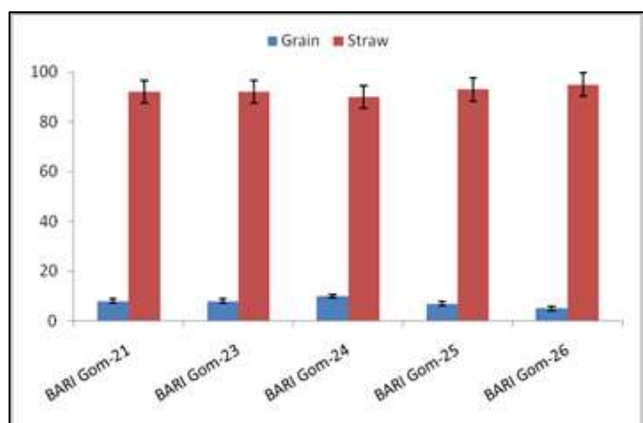
Fig. 2: Arsenic uptake percentage of straw and grains by different wheat varieties
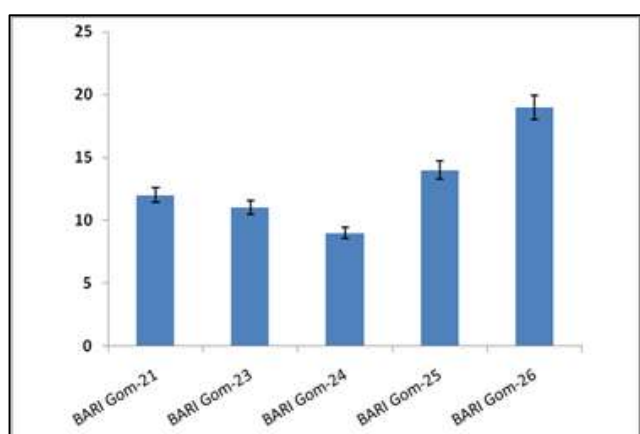
Fig. 3: Arsenic uptake ratio of straw and grains by different wheat varieties

Conclusion

It is concluded that arsenic contaminated soils and water greatly influenced the different growth and yield parameters of five wheat varieties. BARI Gom-26 and BARI Gom-25 showed better performance or seem to tolerant against arsenic contaminated soils and water among the tested varieties. Arsenic accumulation varied among the varieties and plant parts which follows the order of root> straw>grain. The yield reduction order among the varieties were as follows BARI Gom-26>BARI Gom-25>BARI Gom-24> BARI Gom-21> BARI Gom-23 but arsenic uptake in grain was found different such as BARI Gom-24>BARI Gom-21>BARI Gom-23>BARI Gom-25>BARI Gom-26. Therefore, BARI Gom-26 and BARI Gom-25 can successfully be grown for higher yield in arsenic contaminated soils and water of Faridpur.

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