

This is a repository copy of *Assessment of potential dietary toxicity and arsenic accumulation in two contrasting rice genotypes : effect of soil amendments*.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/143202/>

Version: Accepted Version

---

**Article:**

Irem, Samra, Islam, Ejazul, Maathuis, Franciscus Johannes Maria [orcid.org/0000-0001-6033-6428](https://orcid.org/0000-0001-6033-6428) et al. (2 more authors) (2019) Assessment of potential dietary toxicity and arsenic accumulation in two contrasting rice genotypes : effect of soil amendments. CHEMOSPHERE. pp. 104-114. ISSN 0045-6535

<https://doi.org/10.1016/j.chemosphere.2019.02.202>

---

**Reuse**

This article is distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND) licence. This licence only allows you to download this work and share it with others as long as you credit the authors, but you can't change the article in any way or use it commercially. More information and the full terms of the licence here: <https://creativecommons.org/licenses/>

**Takedown**

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing [eprints@whiterose.ac.uk](mailto:eprints@whiterose.ac.uk) including the URL of the record and the reason for the withdrawal request.

# Accepted Manuscript

Assessment of potential dietary toxicity and arsenic accumulation in two contrasting rice genotypes: Effect of soil amendments

Samra Irem, Ejazul Islam, Frans J.M. Maathuis, Nabeel Khan Niazi, Tingqiang Li



PII: S0045-6535(19)30432-1

DOI: <https://doi.org/10.1016/j.chemosphere.2019.02.202>

Reference: CHEM 23314

To appear in: *ECSN*

Received Date: 15 October 2018

Revised Date: 8 February 2019

Accepted Date: 28 February 2019

Please cite this article as: Irem, S., Islam, E., Maathuis, F.J.M., Niazi, N.K., Li, T., Assessment of potential dietary toxicity and arsenic accumulation in two contrasting rice genotypes: Effect of soil amendments, *Chemosphere* (2019), doi: <https://doi.org/10.1016/j.chemosphere.2019.02.202>.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1 **Assessment of potential dietary toxicity and arsenic accumulation in two contrasting rice**  
2 **genotypes: Effect of soil amendments**

3

4 Samra Irem<sup>a,b,c</sup>, Ejazul Islam<sup>a,b,\*</sup>, Frans JM Maathuis<sup>c</sup>, Nabeel Khan Niazi<sup>d</sup> and Tingqiang Li<sup>e</sup>.

5

6 <sup>a</sup>Soil & Environmental Biotechnology Division, National Institute for Biotechnology and  
7 Genetic Engineering (NIBGE), Faisalabad, 38000, Pakistan

8 <sup>b</sup>Pakistan Institute of Engineering and Applied Sciences (PIEAS), Islamabad, Pakistan

9 <sup>c</sup>Department of Biology, University of York, York YO10 5DD, UK

10 <sup>d</sup>Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, Faisalabad  
11 38040, Pakistan.

12 <sup>e</sup>Ministry of Education Key Laboratory of Environmental Remediation and Ecological Health,  
13 College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058,  
14 China

15

16

17 **\*Corresponding author**

18 Address: Dr. Ejazul Islam, Soil & Environmental Biotechnology Division, National Institute for  
19 Biotechnology and Genetic Engineering (NIBGE), Faisalabad, 38000, Pakistan

20 E-mail: [ejazulislam75@yahoo.com](mailto:ejazulislam75@yahoo.com)

21 Tel.: +92 41 920136-20; Fax: +92 41 9201322

22

23

24

25 **Abstract**

26 High concentration of arsenic (As) in rice is a serious problem worldwide. Pot experiments were  
27 conducted to assess the potential dietary toxicity of arsenic and effect of various soil  
28 amendments on arsenic accumulation in rice grains. Two basmati rice genotypes were used to  
29 conduct pot experiments using various levels of arsenic (10, 25, 50 and 100 mg kg<sup>-1</sup> soil). In  
30 addition, plants were exposed to soil collected from a well documented arsenic contaminated  
31 site. Contrasting results for growth, yield and grain arsenic concentration were obtained for  
32 basmati-385 (Bas-385), exhibiting tolerance (56% yield improvement at 10 mg As kg<sup>-1</sup>), while  
33 genotype BR-1 showed 18% yield decline under same conditions. Furthermore, application of  
34 soil amendments such as iron (Fe), phosphate (PO<sub>4</sub>) and farmyard manure (FYM) at 50 mg kg<sup>-1</sup>,  
35 80 kg ha<sup>-1</sup> and 10 t ha<sup>-1</sup>, respectively improved the plant height and biomass in both genotypes.  
36 Accumulation of arsenic in rice grain followed a linear trend in BR-1 whereas a parabolic  
37 relationship was observed in Bas-385. Both genotypes exhibited a positive response to iron  
38 sulfate amendment with significant reduction in grain arsenic concentrations. Regression  
39 analysis gave soil arsenic threshold values of 12 mg kg<sup>-1</sup> in Bas-385 and 10 mg kg<sup>-1</sup> in BR-1 for  
40 potential dietary toxicity. This study suggests that genotype Bas-385 can be used for safe rice  
41 production in areas with soil arsenic contamination up to 12 mg kg<sup>-1</sup> and that appropriate dose of  
42 iron sulfate for soil amendment can be used effectively to reduce translocation of arsenic to rice  
43 grain.

44  
45 **Keywords:** Arsenic; iron sulfate; potential dietary toxicity; rice; soil amendments; soil arsenic  
46 thresholds.

47

## 48 1. Introduction

49 Arsenic (As) is a naturally occurring metalloid in the Earth's crust and predominantly  
50 occurs bound to iron oxides. However depending on geology, pH, redox status and microbial  
51 processes, it can exist in two oxidation states as arsenate (AsV) and arsenite (AsIII) (Li et al.,  
52 2017; Beiyuan et al., 2017a, Kumarathilaka et al., 2018a). Besides its natural occurrence in soil  
53 and water, arsenic contamination is increasing due to its use in pesticides and various industries,  
54 for example the production of precious trace elements. Extensive use of arsenic based pesticides  
55 caused accumulation of over 120 mg kg<sup>-1</sup> in topsoil of cotton cultivation areas where arsenic was  
56 used as a defoliant (Smith et al., 1998; Niazi et al., 2011).

57 The presence of arsenic in soil and irrigation water can affect the growth and yield of  
58 crops, posing threats to human health as well as global food security. Soils of various regions  
59 have substantially high concentrations of arsenic in the form of minerals that may become  
60 available due to alkaline and redox conditions, contaminating water and crops thus leading to a  
61 serious environmental hazard (Beiyuan et al., 2017b). Arsenic is a known Class-1 human  
62 carcinogen, and exposure to it can result in skin and various other types of cancers and health  
63 disorders (Kumarathilaka et al., 2018a).

64 In the Sindh province of Pakistan, groundwater arsenic concentration has reached 1100  
65 µg L<sup>-1</sup> against the World Health Organization (WHO) permissible limit of 10 µg L<sup>-1</sup> for drinking  
66 water. Moreover, about 36% of the population in the Punjab province of Pakistan and 20% of the  
67 population in the Sindh province is exposed to arsenic contamination above the prescribed limits  
68 of WHO (Shahid et al., 2018). In many cases the same water is used for irrigation purposes,  
69 causing elevated levels of arsenic in the surface soils and crops.

70 Human exposure to arsenic occurs through contaminated water and food supply, the later  
71 is particularly problematic in Asia where rice is used as major food since this plant species is  
72 known to accumulate relatively high arsenic due to the reducing conditions in paddy soils (Briat  
73 2010, Kumarathilaka et al., 2018b). Contaminated food ingestion can promote the prevalence of  
74 diabetes (Li et al., 2007, Navas-Acien et al., 2008) while higher concentrations of arsenic can  
75 cause death by obstructing vital metabolic processes.

76 Arsenic can also negatively impact on germination, plant growth and plant development  
77 and thus poses a great threat to food production (Waseem et al., 2014; Abbas et al., 2018). In  
78 plants, most of the arsenic is retained in root cells and although translocation to shoots and grains  
79 is relatively low, it varies substantially both between and within species (Finnegan and Chen  
80 2012). Arsenate acts as analogue of phosphate due to chemical similarity of phosphate and  
81 arsenate, thus it enters the cell using phosphate transporters (Tripathi et al., 2012).

82 Inside the cells, phosphate is an important element of different cellular processes and  
83 being its analogue, arsenate can cause the disruption of phosphate-dependent processes and  
84 metabolism (Finnegan and Chen 2012; Niazi et al., 2017). This similarity also means that a  
85 higher P/As ratio in the environment reduces arsenic accumulation in plants (Gomes et al.,  
86 2014). Application of iron to the soil has likewise been reported to play a key role in the  
87 reduction of arsenic accumulation in rice grain by increasing the iron percentage and by forming  
88 more iron plaque in the paddy field (Liu et al., 2015; Yu et al., 2016a, 2017). Addition of organic  
89 fertilizers can affect the bioavailability and mobilization of arsenic in a positive as well as a  
90 negative manner depending on soil conditions. In anaerobic conditions, organic matter content of  
91 soil affect the pH that cause the modification of iron redox cycle, mobilization of phosphate and

92 also the microbial community in the rhizosphere of paddy field, affecting the mobilization of  
93 metal (Yu et al., 2016b).

94 Rice is a major staple food crop and contributes 1.3-1.6% to GDP in Pakistan. Beside its  
95 use as a staple food, rice is a major ingredient in a number of products especially baby formulas.  
96 Concentrations of arsenic in rice grain beyond the safe limit of  $200 \mu\text{g kg}^{-1}$  of FAO in polished  
97 rice pose a great risk as well as a ban on rice export (Codex Alimentarius Commission report,  
98 2014, 2016). Thus, there is an urgent need to evaluate the arsenic toxicity in rice and strategies to  
99 develop less arsenic accumulating rice varieties. However, currently there is no information  
100 available regarding the uptake and accumulation of arsenic in rice grain and related dietary  
101 toxicity in Pakistan. The objectives of this study were, therefore, to compare potential dietary  
102 toxicity of arsenic and the effect of various soil amendments on arsenic accumulation in rice  
103 grain in two rice genotypes that contrast in arsenic sensitivity.

104

## 105 **2. Material and Methods**

### 106 **2.1. Soil collection and contamination**

107 Soil was obtained from a non-contaminated area near river bank. It was air dried, spread  
108 on plastic sheets and then artificially contaminated by spraying it either with distilled water or  
109 with four levels of arsenic i.e. 10, 25, 50 and  $100 \text{ mg kg}^{-1}$ . Soils were equilibrated for 6-weeks,  
110 undergoing several cycles of saturation with distilled water and then air-drying. Sodium arsenate  
111 ( $\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$ ) was used as a source of arsenic. After 6 weeks soil was filled in plastic pots  
112 of about 7 kg capacity for pot experiments.

113 Soil was collected from a well-known arsenic contaminated area, i.e. Manga-Mandi, was  
114 used to grow the plants with soil amendments as iron (Fe), phosphate (PO<sub>4</sub>) and farmyard  
115 manure (FYM) at the rate of 80 kg ha<sup>-1</sup>, 50 mg kg<sup>-1</sup> and 10 t ha<sup>-1</sup> respectively.

116

## 117 **2.2. Physico-chemical properties of soil**

118 Soil used in experiments was analyzed to determine its physicochemical properties. The  
119 Bouyous hydrometer method was used to determine the soil texture (Bouyoucos, 1962) whereas  
120 organic matter was analysed by the Walkley method (Walkley and Black, 1934). For chemical  
121 analysis of soil samples, suspensions were prepared in 1:2.5 ratio of soil to water. The suspension  
122 was shaken at 200 rpm for 30 minutes.

123 The filtrate was then used for analysis of electrical conductivity (EC) and pH. To  
124 measure the total arsenic, phosphorous, and iron, soil was sieved by sieve size 425 µm and acid  
125 digested using nitric acid. Briefly, about 1 g soil was weighed and concentrated HNO<sub>3</sub> and  
126 H<sub>2</sub>SO<sub>4</sub> (5:1) was added to it for digestion. Soil was digested at 100- 175 °C for 6 hours by  
127 gradual increase of temperature and the digests were diluted with de-ionized water and then  
128 concentration of arsenic, iron and phosphorous were analyzed using ICP-OES. For the  
129 measurement of bioavailable arsenic, phosphorous and iron, DTPA extraction was carried out.  
130 Briefly, about 5 g of soil was weighed and 10 ml of 5 mM Diethylene Triamine Pent acetic Acid  
131 (DTPA) with pH 7.3 was added in a flask. The flask was shaken at 200 rpm for 2 hrs and after  
132 centrifugation at 3000 rpm, supernatant was collected, filtered and analyzed using inductively  
133 coupled plasma - optical emission spectrometry (ICP-OES, iCAP 7000 series, Thermo  
134 Scientific).

135



### 136 **2.3. Germination and early seedling studies**

137 Seed germination and early seedling growth experiment were conducted to screen the  
 138 rice varieties for their ability to germinate and grow under arsenic stress. Twelve popular rice  
 139 genotypes named as BR-1, BR-18, BR-23, BAS-PAK, SUP-BAS, BAS-385, GSR-1, GSR-2, IR-  
 140 6, PK-386, PS-2, KS-282 were used in this study. Prior to germination, seeds were surface-  
 141 sterilized with 1% sodium hypochlorite (NaOCl<sub>4</sub>) for 5 min and then washed with distilled water.  
 142 Seeds were sown with four levels of arsenic in petri plates (50, 250, 500 and 1000 µg L<sup>-1</sup>) and  
 143 special germinators having soil (10, 25, 50 and 100 mg kg<sup>-1</sup>) and young seedlings were grown for  
 144 three weeks in a greenhouse with controlled growth conditions in the season of May-June having  
 145 natural light, day/night humidity of 70-90% and day/night temperature of 25-30 °C. Germination  
 146 count was taken five days after sowing whereas seedling growth parameters such as plant height,  
 147 root length, fresh and dry weights were recorded after three weeks. Germination index was  
 148 calculated from the formula as given in equation (1).

$$149 \quad \text{GI}\% = \frac{G_T * L_T}{G_C * L_C} \times 100 \quad (1)$$

150 where  $G_T$  and  $G_C$  are numbers of germinated seeds, while  $L_T$  and  $L_C$  are the average of root  
 151 length in arsenic treatment and control, respectively (Fatima et al., 2018). Based on this  
 152 experiment, two promising genotypes i.e. BR-1 and Basmati-385 were selected and grown in  
 153 large pots (7 kg capacity) for detailed studies including metal uptake by rice grains.

### 154 **2.4. Pot experiment of rice and growth observation**

155 Healthy seeds of rice genotype BR-1 and Basmati-385 were surface sterilized and sown  
 156 in germination trays for 3-4 weeks. After that, uniform and healthy seedlings were transplanted

157 in pots prepared for rice transplants. Five seedlings/pot were transplanted and thinning was done  
158 after 2 weeks keeping 2 plants per pot for growth till grain stage. Plants were grown in the  
159 greenhouse for approximately 5 months with a 12/12 h light/dark cycle.

160 Water levels were regularly adjusted by arsenic free irrigation water whenever needed  
161 and fertilizer was applied as per rice plant requirement with the dosage of nitrogen-phosphate-  
162 potassium at the rate of 140-80-65 kg h<sup>-1</sup>. Growth parameters such as plant biomass, fresh and  
163 dry weights, number of panicles, panicles weight, and grain yield were measured at the time of  
164 harvest. Different plant tissues were separated as root, shoot and grain and oven dried at 70 °C  
165 for 72 hour.

166

#### 167 **2.5. Determination of photosynthesis**

168 Photosynthesis parameters such as leaf CO<sub>2</sub> assimilation rate, stomatal conductance (gs)  
169 and transpiration rate (E) were determined using a porometer (LI-1600 System, Li-COR  
170 Company). Data was recorded before the flowering stage and flag leaf was used to record the  
171 photosynthesis parameters. All data was recorded during day time in full sunlight exposure  
172 (10.00-12.00).

173

#### 174 **2.6. Arsenic concentrations, translocation factor and soil arsenic thresholds for** 175 **potential dietary toxicity**

176 Oven dried plant parts (root, shoot and grain) of rice were finely ground in a stainless  
177 steel mill while grain was dehusked prior to grinding. The powdered dry materials (0.4 g) were  
178 digested by single acid digestion using concentrated HNO<sub>3</sub>. The digests were diluted with de-

179 ionized water, stored in 15ml falcon tubes and then concentration of arsenic, iron, phosphorous  
180 and zinc were analyzed using ICP-OES.

181 Translocation factor refers to translocation of arsenic from root to shoot and was  
182 determined by the formula given in equation (2):

$$183 \quad \mathbf{TF = C_{shoot}/C_{root}} \quad \mathbf{(2)}$$

184 where  $C_{shoot}$  and  $C_{root}$  are arsenic concentrations in dry weight of shoot and root of plant,  
185 respectively.  $TF > 1$  represent that effective translocation of arsenic was made to the shoot from  
186 root (Baker and Brooks, 1989). Bioaccumulation factor was also determined to evaluate the  
187 arsenic accumulation efficiency of each rice genotype according to formula in equation (3).

$$188 \quad \mathbf{BF = C_{plant}/C_{soil}} \quad \mathbf{(3)}$$

189 Where  $C_{plant}$  and  $C_{soil}$  are arsenic concentrations in dry weight of plant and soil, respectively.

190 To determine the soil threshold for arsenic, safe limits of arsenic in rice as developed by  
191 Codex Alimentarius Commission and FAO were used and soil thresholds for potential dietary  
192 toxicity were calculated from regression equation as described by Long et al., (2003) using  
193 arsenic concentration in soil and grain.

194

## 195 **2.7. Quality control**

196 Arsenic analyses were validated using a standard reference material (SRM) for rice.  
197 Certified rice flour ERM-BC211 from European commission supplied by Sigma Aldrich was  
198 used as SRM for total arsenic. ICP-OES analysis showed the average arsenic concentration  
199  $257.51 \pm 4.02 \mu\text{g kg}^{-1}$  DW very close to the ERM certified value ( $260 \pm 13 \mu\text{g kg}^{-1}$  DW) showing  
200 99.04% recovery.

201

## 202 **2.8. Statistical analysis**

203 All data was analyzed by statistical software SPSS (IBM version 24.0). Reported values  
204 are means of three replicates. In each rice genotype, means were compared by one way analysis  
205 of variance and two way analysis of variance (ANOVA) followed by Tukey's test at significance  
206 level of  $P < 0.05$ , while graphical work was carried out by Sigma Plot software (v.10).  
207 Correlation matrices were generated using corrplot library in R software (version 3.4.0).  
208 Correlations were stated statistically significant if P value was  $< 1\%$ . Pearson correlation was  
209 considered positive for the value of correlation coefficient  $>0.5$  while it was negative if the value  
210 for coefficient was  $<0.5$ .

## 211 **3. Results**

### 212 **3.1. Physico-chemical properties of soil**

213 The texture of soil used in study was clay loam with EC 920  $\mu\text{S}/\text{cm}$ , while pH was 7.02.  
214 Organic matter of the soil was recorded to be 0.81%. Detailed physicochemical properties of soil  
215 before and after amendments are given in supplementary table 1. Total and bioavailable  
216 concentrations of arsenic, phosphorous and iron in both control and Manga-Mandi soil (MMS)  
217 are given in Fig.1, while concentrations of arsenic, phosphorous and iron in Manga-Mandi soil  
218 after amendments are given in supplementary Fig. 1.  
219

### 220 **3.2. Effect of arsenic on seed germination, hypocotyl and radical lengths**

221 Arsenic treatment caused variation in seed germination among different genotypes with  
222 stimulatory effect in most cases. At  $50 \mu\text{g L}^{-1}$  and  $250 \mu\text{g L}^{-1}$  arsenic concentration observed in  
223 water in contaminated region- unpublished results and  $500 \mu\text{g L}^{-1}$  arsenic treatment, both basmati  
224

225 and coarse grain rice exhibited stimulation in germination except Bas-385 that showed a negative  
226 effect at  $50 \mu\text{g L}^{-1}$  and then showed an improvement in germination at  $250 \mu\text{g L}^{-1}$  and  $500 \mu\text{g L}^{-1}$   
227 arsenic. Treatment of seeds with  $1000 \mu\text{g L}^{-1}$  arsenic led to a decrease in germination percentage  
228 in all the basmati genotypes. A similar trend was observed for hypocotyl and radical lengths  
229 (Table1). Based on germination index (Table1) and early seedling studies, two contrasting  
230 basmati genotypes BR-1 and Basmati-385 (Bas-385) were selected for pot experiments to study  
231 the toxicity of arsenic in details.

232

### 233 **3.3.Effect of arsenic on growth and yield of rice in pot experiment**

234 It was noted that arsenic treatment caused early flowering in BR-1 where it was started  
235 first in  $25 \text{mg kg}^{-1}$  treatment followed by  $50 \text{mg kg}^{-1}$  treatment and then in remaining treatments.  
236 While in Bas-385 all levels of treatments showed simultaneous early flowering as compared to  
237 control. Low concentration of arsenic in soil showed a positive effect on growth in genotype BR-  
238 1 with an increase in plant height and shoot fresh weight. At the highest arsenic concentration, a  
239 decrease of 19% and 21% in plant height and 36% and 60% in shoot fresh weight was observed  
240 in both BR-1 and Bas-385 genotypes respectively (Table. 2).

241 Number of tillers was also affected by soil arsenic concentration with more pronounced  
242 effects in Bas-385. Effect on yield parameter was significant among the treatments and  
243 genotypes with more severe impact on BR-1 showing 40-50% decrease in grain yield ( $50$  and  $100$   
244  $\text{mg kg}^{-1}$  soil arsenic). Application of soil amendments in Manga-Mandi soil (MMS) caused  
245 significantly different responses in various parameters (Table. 2).

246 In BR-1, plant height was stimulated by iron and farmyard manure, while in the case of  
247 Bas-385 it was phosphate and farmyard manure. Plant biomass and yield showed variation due to

248 application of different soil amendments in both genotypes with a significant stimulatory effect  
249 of iron and phosphate amendment in Bas-385 while reduction in yield was observed in BR-1  
250 after these amendments.

251

### 252 **3.4. Effect of arsenic on photosynthesis**

253 In spiked soil experiments, photosynthesis parameters such as transpiration rate (E) and  
254 stomatal conductance (gs) exhibited significant variation ( $P < 0.05$ ) in both genotypes at different  
255 levels of arsenic in soil, while leaf  $\text{CO}_2$  assimilation rate was significantly ( $P < 0.05$ ) different  
256 among both genotypes but remained unaffected by soil arsenic concentration (Fig. 2A, B, C).  
257 Transpiration rate (E) showed a significant decrease in Bas-385 at initial arsenic treatments of 10  
258 and  $25 \text{ mg kg}^{-1}$  and while in BR-1 it remained unaffected and then showed a significant decline.

259 However, in Bas-385 it showed a significant improvement at highest treatment ( $P < 0.05$ ).  
260 Stomatal conductance followed a similar trend as the transpiration rate in Bas-385, while in case  
261 of BR-1 it showed an increase at  $10 \text{ mg kg}^{-1}$  treatment and then remained unaffected. There were  
262 no significant differences in transpiration rate (E), stomatal conductance (gs) and leaf  $\text{CO}_2$   
263 assimilation rate between genotypes grown in Manga-Mandi soil with various amendments (Fig.  
264 2D, E, F).

265

### 266 **3.5. Arsenic concentration in grain, shoot and root**

267 Arsenic concentration was significantly ( $P < 0.05$ ) different among different tissues of the  
268 two genotypes growing at various levels of arsenic. An increase in the uptake in concentration of  
269 arsenic in grain was observed in both genotypes with increasing soil arsenic treatment up to  $25$   
270  $\text{mg kg}^{-1}$ , while at higher soil treatment, arsenic concentrations increased in BR-1 but the opposite

271 was observed in Bas-385 (Fig. 3A). Both genotypes exhibited consistent increases in arsenic  
272 uptake in shoot and root (Fig. 3B and C) with increases in soil arsenic except BR-1 which  
273 exhibited a decrease in shoot arsenic at arsenic level of  $100 \text{ mg kg}^{-1}$  (Fig. 3B).  
274 Application of amendments in Manga-Mandi soil showed significant ( $P < 0.05$ ) difference among  
275 genotypes. Both genotypes showed lower arsenic concentration in grain with iron amendment  
276 followed by farmyard manure with more profound effects in Bas-385. Genotype Bas-385  
277 showed 24% reduction in grain arsenic, while the reduction was 14% in case of BR-1 compared  
278 to growth in Manga-Mandi soil without any amendment (Fig.3D). Soil amendments also affected  
279 root and shoot arsenic concentration with significant reduction in shoot arsenic in BR-1 while an  
280 increase was observed in Bas-385. On the other hand, root arsenic concentration was increased  
281 with iron and remained unaffected with phosphate in both genotypes, while farmyard manure  
282 caused an increase in arsenic concentration of root in Bas-385 (Fig.3E and F).

283

### 284 **3.6. Effect of arsenic on grain phosphorous, zinc and iron**

285 Arsenic treatment had a significant effect on iron and phosphorous concentration in rice  
286 grain, while it was non-significant for zinc. Also, a significant effect of genotype was observed  
287 for phosphorous concentration in grain (Suppl. Fig.2). The combined effect of soil  
288 treatment  $\times$  genotype was non-significant for grain zinc while it was significant for iron and  
289 phosphorous as analyzed by ANOVA at  $P \leq 0.05$  (Suppl.Table.2). From Pearson correlation  
290 analysis, BR-1 showed a strong and significant positive correlation between grain arsenic and  
291 phosphorous ( $r = 0.81$ ) and moderate but non-significant correlation between grain zinc and iron  
292 ( $r = 0.69$ ) respectively (Fig.4A).

293 On the other hand, a strong positive correlation of grain arsenic with zinc, iron and  
294 phosphorous ( $r = 0.76, 0.82$  and  $0.81$  respectively) and between grain zinc and iron ( $r = 0.95$ ) was  
295 observed for genotype Bas-385 (Fig.4B), however except for the correlation between grain  
296 arsenic and zinc, all these correlations were significant ( $P \leq 0.01$ ) in Bas-385.

297

### 298 **3.7. Soil thresholds for arsenic toxicity**

299 Total arsenic thresholds of soil that cause potential dietary toxicity were  $12 \text{ mg kg}^{-1}$  and  
300  $10 \text{ mg kg}^{-1}$  for Bas-385 and BR-1 respectively, while the bioavailable thresholds were  $0.96 \text{ mg}$   
301  $\text{kg}^{-1}$  and  $0.79 \text{ mg kg}^{-1}$  respectively. Bioavailable arsenic was significantly correlated with total  
302 arsenic concentrations in soil ( $P \leq 0.01$ ). A strong positive and significant correlation was  
303 observed for soil total arsenic with root and grain arsenic concentration in genotype BR-1 ( $r =$   
304  $0.81, 0.93$ ). Furthermore, a non-significant but moderate positive correlation ( $r = 0.54, 0.56$  and  
305  $0.52$ ) was observed for shoot arsenic with grain arsenic, zinc and phosphorous content  
306 respectively (Fig. 4A).

307 Arsenic concentration of soil was strongly and significantly correlated with root and  
308 shoot arsenic content of genotype Bas-385. Furthermore, there was a weak to moderate  
309 correlation of grain arsenic concentration with arsenic content of root, shoot and soil in Bas-385  
310 (Fig. 4B). Arsenic concentration in root of Bas-385 was found both positively and significantly  
311 correlated with soil arsenic concentration ( $r = 0.89, P < 0.01$ ).

312

## 313 **4. Discussion**

314 Exposure to arsenic led to disruption of several physiological mechanisms and affected  
315 plant growth, yield and uptake. However, these effects vary among the plants depending on the



316 type of plants, genetics, translocation properties and level of exposure (Suriyagoda et al., 2018).  
317 Arsenic in rice is of utmost concern due to heavy consumption of rice by human population and  
318 its use in different baby foods. Selection of rice genotypes that can avoid arsenic uptake or  
319 accumulate less arsenic in grain can be a useful strategy to reduce its exposure in food chain  
320 (Zhu et al., 2006). Amendment of soil with nutrients or organic matter is another way to reduce  
321 the arsenic accumulation in rice grain.

322

#### 323 **4.1. Effect of arsenic on germination**

324 Arsenic has been shown to cause a reduction in seed germination for example in  
325 *Trigonella foenum-graecum L. and Lathyrus sativus L* (Talukdar 2011). Shri et al. (2009)  
326 reported the sensitivity of rice seed germination upon exposure to arsenic can be attributed to the  
327 toxicity due to interaction of arsenic with enzyme of starch metabolism, thus affecting the  
328 germination. However, low concentrations of arsenic, Cd and Cu can stimulate germination due  
329 to the generation of reactive oxygen and nitrogen species caused by the metal(loid) (Kjaer et al.,  
330 1998; Li et al., 2007; Lefevre et al., 2009). In the present study, stimulation in germination was  
331 observed in most of the genotypes at arsenic treatment from 50  $\mu\text{g L}^{-1}$  to 500  $\mu\text{g L}^{-1}$  (see  
332 germination index in Table.1). In contrast, at higher concentration of arsenic, a significant  
333 decrease was observed in all genotypes suggesting  $\sim 250 \mu\text{g L}^{-1}$  arsenic treatment as an  
334 “optimum” level with no negative effect on germination of seeds.

335

#### 336 **4.2. Effect of arsenic on plant growth**

337 Toxicity of arsenic was observed at increasing arsenic concentration in both genotypes.  
338 Furthermore, a significant effect of soil and treatment interaction ( $P < 0.05$ ) was observed for all  
339 growth parameters when analyzed by two way analysis of variance (Suppl.Table.2). Geng et al.

340 (2005) observed a drop in rice plant height and biomass by increasing the arsenic concentration  
341 and similar results were observed by Rahman et al. (2007). The toxicity of arsenic is likely due  
342 to the anaerobic environment in paddy fields where reducing redox conditions favour the  
343 bioavailability of arsenite which is more toxic than arsenate (Zia et al., 2017). This rice specific  
344 aspect affects both arsenic translocation and seed setting and consequently overall yield  
345 (Finnegan and Chen, 2012; Wang et al., 2018; Islam, S. et al., 2017).

346

### 347 **4.3. Effect of arsenic on photosynthesis**

348 Photosynthesis is an important parameter for plant growth that provides the energy for all  
349 essential functions. Arsenic being a phytotoxic element can impact on photosynthesis by  
350 affecting the chlorophyll contents and structure of chloroplast (Rahman et al., 2007). As an  
351 analogue of phosphate it interferes with photophosphorylation (Meharg, 1994). In bean plants,  
352 photosynthesis was not affected by low concentrations of soil arsenic up to  $\sim 25 \text{ mg kg}^{-1}$  but  
353 inhibitory effects were observed at higher concentrations of 50 and  $100 \text{ mg kg}^{-1}$  (Miteva and  
354 Merakchiyska, 2002). In a sand culture experiment of bean plants, Stoeva et al. (2005) reported a  
355 negative effect of arsenic at  $5 \text{ mg L}^{-1}$  treatment. In this study, arsenic treatment did not alter  $\text{CO}_2$   
356 assimilation rate (Fig. 2C), but a negative effect was observed on transpiration (E) and stomatal  
357 conductance (gs) as showed in Fig. 2A and 2B.

358 Stoeva and Bineva (2003) reported that in stress condition, limitation of mesophyll and  
359 stomatal cells due to metal induced changes in pigment apparatus and biochemical pathway of  
360 Calvin cycle, can cause a reduction in photosynthesis activity. In contrast to our findings with  
361 spiked soil, no significant change in transpiration rate, stomatal conductance or  $\text{CO}_2$  assimilation  
362 was observed when plants were grown in Manga-Mandi soil with various soil amendments. This

363 can be attributed to the fact that all these amendments were in Manga-Mandi soil having the  
364 same arsenic concentration. It could also be due to the activation of antioxidant defense system  
365 and high concentration of glutathione that has been reported to ameliorate the effects of stress,  
366 thus helping to sustain the activity of important photosynthetic enzymes under stress conditions  
367 (Alexieva et al., 2001; Pietrini et al., 2003).

368

#### 369 **4.4. Arsenic concentrations in grain, shoot and root**

370 Uptake and accumulation of arsenic in different tissues of rice is of utmost concern when  
371 considering food chain toxicity. There were significant differences in arsenic concentration in  
372 grains, shoots and roots. In both genotypes the highest concentration of arsenic was observed in  
373 roots followed by shoots and grains. Grain arsenic levels were genotype and soil amendment-  
374 dependent. Although the both genotypes have high accumulation factor at various levels of  
375 treatment but high grain and shoot concentrations of arsenic and translocation factor of BR-1  
376 suggest that this genotype is sensitive to arsenic toxicity. This may be due to the difference in  
377 uptake, defense mechanism and metabolic pathways among BR-1 and Bas-385. A number of  
378 processes are involved in arsenic translocation from root to grain that differ considerably among  
379 genotypes (Islam, S. et al., 2017). Arsenic tolerant rice lines balanced the stress by antioxidants,  
380 phytochelation and scavenging of reactive oxygen species (ROS) through glutathione (Tripathi,  
381 P. et al., 2012). Change in expression level of genes that involves in phytochelation, transport  
382 pathways and detoxification of arsenic can play a plausible role in differential uptake between  
383 genotypes. Zvobgo et al. (2018) reported the upregulation of phosphate and silicon transporter  
384 genes under arsenic stress in barley. Differential response in activities of antioxidants was also  
385 observed in various genotype of rice (Rai et al., 2011).

#### 386 4.4.1. Effect of arsenic on grain phosphorous, zinc and iron

387 Contamination of arsenic in rice grain can cause the restricted uptake of other  
388 micronutrients, thus disturbing the nutrient value of grain. It was reported that low soil arsenic  
389 concentration support the uptake of iron, zinc and phosphorous, while high levels of arsenic in  
390 soil can hampered the uptake of essential micronutrients in rice (Dwivedi et al., 2010). In our  
391 experiment, a strong positive correlation was observed for grain arsenic with phosphorous and  
392 iron with zinc in BR-1 (Fig.4A) while Bas-385 showed a strong positive correlation of grain  
393 arsenic with zinc, iron and phosphorous (Fig.4B). However, it was noted that the correlation was  
394 significant only between grain arsenic and phosphorous for genotype BR-1, while in Bas-385 it  
395 was significant with both iron and phosphorous, showing non-significant correlation with zinc at  
396  $P < 0.01$ . Punshon et al. (2018) reported a positive trend for iron, zinc and arsenic abundance in  
397 rice grain, exposed to high concentration of arsenic at grain filling stage. These findings might  
398 suggest the difference in nutrient uptake efficiency and interaction among various nutrients  
399 across different genotypes. Beesley et al. (2018) also found that rice genotypes played substantial  
400 role for variation in grain phosphorous and iron uptake with a significant correlation between  
401 genotype and micronutrients.

#### 402 4.5. Effect of soil amendments

404 Iron can promote formation of root iron plaque that sequesters most of the soluble arsenic  
405 and thus reduces arsenic uptake and ultimately its accumulation in grain. The use of 2% iron  
406 oxide as a soil amendment was reported to be effective to lower rice grain arsenic (Farrow et al.,  
407 2015). Supplementation of soil with iron at grain filling stage led to a decrease in arsenic  
408 accumulation (Yu et al., 2017). Other amendments such as pine sawdust and biochar550

409 (prepared from pine sawdust at 550<sup>0</sup>C) have been reported to increase the arsenic mobility and  
410 plant availability, possibly because of an increase in pH. Furthermore, studies also revealed that  
411 amendment of soil with biochar can change the soil metagenomics that influence the availability  
412 of arsenic in rice fields (Qiao et al., 2017; Qiao et al., 2018).

413 With variable results, it is crucial that amendments should be selected carefully,  
414 especially in paddy field applications where soil properties fluctuate considerably (Beiyuan et al.,  
415 2017a). Findings in this study illustrate significant effect of soil amendments during flowering  
416 stage, with iron sulfate (FeSO<sub>4</sub>) being more effective than farmyard manure and phosphate the  
417 least effective. Application of Fe(II) enhances opportunity for Fe(II)-sulfide formation  
418 sequestering As on its surface or As(III)-sulfide formation which are stable under reduced paddy  
419 soil conditions (Niazi and Burton 2016). The efficacy of amendments was influenced by the rice  
420 genotype with more profound effects observed in Bas-385 in comparison to BR-1. In genotype  
421 Bas-385, addition of phosphate caused a significant increase in shoot arsenic concentration while  
422 in grain this increase was non-significant. This increase in shoot arsenic can be supported by the  
423 findings that competitive mobilization of arsenic in paddy soils in presence of phosphate can  
424 results in high root to shoot translocation that also depend on other factors such as rice genotype,  
425 soil redox status, dose of phosphate and type of soil (Lee et al., 2016). Hossain et al. (2009) also  
426 observed that addition of phosphate in soil used to grow rice increased the concentration of  
427 arsenic in straw and grain.

428

#### 429 **4.6. Soil thresholds for arsenic toxicity**

430 With growing concerns of arsenic toxicity, it is important to determine the soil threshold  
431 arsenic value and its bioaccumulation in crops in order to avoid contamination of edible parts.

432 According to the definition by Islam et al. (2007) the soil threshold is the highest permissible  
433 limit of heavy metal/metalloid in the soil without potential dietary toxicity in humans. The  
434 maximum limit for inorganic arsenic in rice is  $200 \mu\text{g kg}^{-1}$  and  $350 \mu\text{g kg}^{-1}$  for polished and  
435 husked rice respectively (Codex alimentarius commission report-2016).

436 Soil threshold for potential dietary toxicity as calculated from the regression equation  
437 between soil and grain arsenic concentrations (Long et al., 2003) was  $\sim 10 \text{ mg kg}^{-1}$  and  $12 \text{ mg kg}^{-1}$   
438 <sup>1</sup> (considering maximum limit of inorganic arsenic in rice) for BR-1 and Bas-385 respectively.  
439 Threshold values for potential toxicity are related to the translocation and accumulation factor of  
440 the genotype (Table 3). Overall, translocation factors were higher for genotype BR-1, making it  
441 more sensitive. The results are supported by the findings of Long et al. (2003) where available  
442 zinc threshold was low for pakchoi due to its high accumulation and translocation compared to  
443 Chinese cabbage and celery. Soil amendments also changed the TF and BF (Table. 3) which  
444 could be due to the changes in pH and organic matter, leading to change in arsenic uptake among  
445 both genotypes.

446

## 447 5. Conclusion

448 Genotype dependent effects of arsenic on the growth and yield of rice plants were observed and  
449 both genotypes have notable differences in accumulation and translocation of arsenic with  
450 variable growth and yield responses. Soil thresholds for potential dietary toxicity suggest that  
451 genotype Bas-385 can be used safely for rice production in areas with soil arsenic contamination  
452 up to  $12 \text{ mg kg}^{-1}$  and that iron sulfate amendment can be used effectively to reduce the  
453 translocation of arsenic to rice grain, allowing cultivation in soils with arsenic content as high as  
454  $15 \text{ mg kg}^{-1}$ . Though this is a considerable improvement, costs of amendments are still a big

455 challenge in many farming communities (Punshon et al., 2018), However, considering the  
456 genotype dependent response towards iron sulfate amendments, an appropriate and cautious use  
457 of iron sulfate is required to reduce the arsenic translocation. For BR-1 the values are less  
458 encouraging, reflecting its sensitivity for arsenic due to high translocation factor and grain  
459 arsenic concentration. The difference in uptake can be attributed to variation in antioxidants,  
460 uptake mechanism, and regulation of detoxification and transport pathways that need to be  
461 investigated.

462

### 463 **Acknowledgments**

464 The study was financially supported by a grant (No. 1887) from Higher Education Commission  
465 of Pakistan. Samra Irem was supported by Commonwealth commission, UK by split-site PhD  
466 fellowship (PKCN-2016-235). Provision of rice seeds by Dr. Muhammad Arif, NIBGE, Pakistan  
467 and Rice research institute, Kala Shah Kaku, Pakistan is highly acknowledged.

468

469

470

471

472

473

474

475

476

477

478 **References**

- 479 1. Abbas, G., Murtaza, B., Bibi, I., Shahid, M., Niazi, N.K., Khan, M.I., Amjad, M.,  
480 Hussain, M., 2018. Arsenic uptake, toxicity, detoxification, and speciation in plants:  
481 physiological, biochemical, and molecular aspects. *International journal of environmental*  
482 *research and public health* 15, 59.
- 483 2. Alexieva, V., Sergiev, I., Mapelli, S., Karanov, E., 2001. The effect of drought and  
484 ultraviolet radiation on growth and stress markers in pea and wheat. *Plant, Cell &*  
485 *Environment* 24, 1337-1344.
- 486 3. Baker, A., Brooks, R., 1989. Terrestrial higher plants which hyperaccumulate metallic  
487 elements. A review of their distribution, ecology and phytochemistry. *Biorecovery*. 1, 81-  
488 126.
- 489 4. Beesley, L., Hough, R., Deacon, C.M., Norton, G.J., 2018. The Impacts of Applying  
490 Metal (loid) Enriched Wood Ash to Soils on the Growth and Elemental Accumulation of  
491 Rice. *Exposure and Health*, 1-14.
- 492 5. Beiyuan, J., Awad, Y.M., Beckers, F., Tsang, D.C., Ok, Y.S., Rinklebe, J., 2017a.  
493 Mobility and phytoavailability of As and Pb in a contaminated soil using pine sawdust  
494 biochar under systematic change of redox conditions. *Chemosphere* 178, 110-118.
- 495 6. Beiyuan, J., Li, J.-S., Tsang, D.C., Wang, L., Poon, C.S., Li, X.-D., Fendorf, S., 2017b.  
496 Fate of arsenic before and after chemical-enhanced washing of an arsenic-containing soil  
497 in Hong Kong. *Science of the total environment* 599, 679-688.
- 498 7. Briat, J.-F., 2010. Arsenic tolerance in plants: "Pas de deux" between phytochelatins  
499 synthesis and ABC transporters. *Proceedings of the National Academy of*  
500 *Sciences* 107, 20853-20854.



- 501 8. Codex alimentarius commission, Joint FAO/WHO food standards programme. 39th  
502 Session Rome, Italy, 27 June - 1 July 2016.
- 503 9. Codex alimentarius commission, Joint FAO/WHO food standards programme. 37th  
504 Session. Geneva, Switzerland, 14-18 July 2014.
- 505 10. Dwivedi, S., Tripathi, R., Tripathi, P., Kumar, A., Dave, R., Mishra, S., Singh, R.,  
506 Sharma, D., Rai, U., Chakrabarty, D., 2010. Arsenate exposure affects amino acids,  
507 mineral nutrient status and antioxidants in rice (*Oryza sativa* L.) genotypes.  
508 *Environmental science & technology* 44, 9542-9549.
- 509 11. Farrow, E.M., Wang, J., Burken, J.G., Shi, H., Yan, W., Yang, J., Hua, B., Deng, B.,  
510 2015. Reducing arsenic accumulation in rice grain through iron oxide amendment.  
511 *Ecotoxicology and environmental safety* 118, 55-61.
- 512 12. Fatima, K., Imran, A., Amin, I., Khan, Q.M., Afzal, M., 2018. Successful  
513 phytoremediation of crude-oil contaminated soil at an oil exploration and production  
514 company by plants-bacterial synergism. *International journal of phytoremediation* 20,  
515 675-681.
- 516 13. Finnegan, P., Chen, W., 2012. Arsenic toxicity: the effects on plant metabolism. *Frontiers*  
517 *in physiology* 3, 182.
- 518 14. Geng, C.-N., Zhu, Y.-G., Liu, W.-J., Smith, S.E., 2005. Arsenate uptake and translocation  
519 in seedlings of two genotypes of rice is affected by external phosphate concentrations.  
520 *Aquatic botany* 83, 321-331.
- 521 15. Gomes, M., Carvalho, M., Carvalho, G., Marques, T., Garcia, Q., Guilherme, L., Soares,  
522 A., 2013. Phosphorus improves arsenic phytoremediation by *Anadenanthera peregrina* by

- 523 alleviating induced oxidative stress. *International journal of phytoremediation* 15, 633-  
524 646.
- 525 16. Haque, I.U., Nabi, D., Baig, M., Hayat, W., Trefry, M., 2008. Groundwater arsenic  
526 contamination--A multi-directional emerging threat to water scarce areas of Pakistan.  
527 IAHS publication 324, 24.
- 528 17. Hossain, M., Jahiruddin, M., Loeppert, R., Panaullah, G., Islam, M., Duxbury, J., 2009.  
529 The effects of iron plaque and phosphorus on yield and arsenic accumulation in rice.  
530 *Plant and Soil* 317, 167-176.
- 531 18. Islam, E., Yang, X.-e., He, Z.-l., Mahmood, Q., 2007. Assessing potential dietary toxicity  
532 of heavy metals in selected vegetables and food crops. *Journal of Zhejiang University*  
533 *Science B* 8, 1-13.
- 534 19. Islam, S., Rahman, M.M., Islam, M., Naidu, R., 2017. Effect of irrigation and genotypes  
535 towards reduction in arsenic load in rice. *Science of the Total Environment* 609, 311-318.
- 536 20. Kjaer, C., Pedersen, M., Elmegaard, N., 1998. Effects of soil copper on black bindweed  
537 (*Fallopia convolvulus*) in the laboratory and in the field. *Archives of environmental*  
538 *contamination and toxicology* 35, 14-19.
- 539 21. Kumarathilaka, P., Seneweera, S., Meharg, A., Bundschuh, J., 2018a. Arsenic speciation  
540 dynamics in paddy rice soil-water environment: sources, physico-chemical, and  
541 biological factors-a review. *Water research* 140, 403-414.
- 542 22. Kumarathilaka, P., Seneweera, S., Meharg, A., Bundschuh, J., 2018b. Arsenic  
543 accumulation in rice (*Oryza sativa* L.) is influenced by environment and genetic factors.  
544 *Science of The Total Environment* 642, 485-496.

- 545 23. Lee, C.-H., Wu, C.-H., Syu, C.-H., Jiang, P.-Y., Huang, C.-C., Lee, D.-Y., 2016. Effects  
546 of phosphorous application on arsenic toxicity to and uptake by rice seedlings in As-  
547 contaminated paddy soils. *Geoderma* 270, 60-67.
- 548 24. Lefèvre, I., Marchal, G., Corréal, E., Zanuzzi, A., Lutts, S., 2009. Variation in response to  
549 heavy metals during vegetative growth in *Dorycnium pentaphyllum* Scop. *Plant Growth*  
550 *Regulation* 59, 1-11.
- 551 25. Li, C.-x., Feng, S.-l., Shao, Y., Jiang, L.-n., Lu, X.-y., Hou, X.-l., 2007. Effects of arsenic  
552 on seed germination and physiological activities of wheat seedlings. *Journal of*  
553 *Environmental Sciences* 19, 725-732.
- 554 26. Li, J.-S., Bei Yuan, J., Tsang, D.C., Wang, L., Poon, C.S., Li, X.-D., Fendorf, S., 2017.  
555 Arsenic-containing soil from geogenic source in Hong Kong: leaching characteristics and  
556 stabilization/solidification. *Chemosphere* 182, 31-39.
- 557 27. Liu, C., Yu, H.-Y., Liu, C., Li, F., Xu, X., Wang, Q., 2015. Arsenic availability in rice  
558 from a mining area: is amorphous iron oxide-bound arsenic a source or sink?  
559 *Environmental pollution* 199, 95-101.
- 560 28. Long, X., Yang, X., Ni, W., Ye, Z., He, Z., Calvert, D., Stoffella, J., 2003. Assessing zinc  
561 thresholds for phytotoxicity and potential dietary toxicity in selected vegetable crops.  
562 *Communications in Soil Science and Plant Analysis* 34, 1421-1434.
- 563 29. Meharg, A., 1994. Integrated tolerance mechanisms: constitutive and adaptive plant  
564 responses to elevated metal concentrations in the environment. *Plant, Cell &*  
565 *Environment* 17, 989-993.

- 566 30. Miteva, E., Merakchiyska, M., 2002. Response of chloroplasts and photosynthetic  
567 mechanism of bean plants to excess arsenic in soil. *Bulgarian Journal of Agricultural*  
568 *Science*.
- 569 31. Navas-Acien, A., Silbergeld, E.K., Pastor-Barriuso, R., Guallar, E., 2008. Arsenic  
570 exposure and prevalence of type 2 diabetes in US adults. *Jama* 300, 814-822.
- 571 32. Niazi, N.K., Singh, B., Shah, P., 2011. Arsenic speciation and phytoavailability in  
572 contaminated soils using a sequential extraction procedure and XANES spectroscopy.  
573 *Environmental science & technology* 45, 7135-7142.
- 574 33. Niazi, N.K., Burton, E.D., 2016. Arsenic sorption to nanoparticulate mackinawite (FeS):  
575 an examination of phosphate competition. *Environmental pollution* 218, 111-117.
- 576 34. Niazi, N.K., Bibi, I., Fatimah, A., Shahid, M., Javed, M.T., Wang, H., Ok, Y.S., Bashir,  
577 S., Murtaza, B., Saqib, Z.A., 2017. Phosphate-assisted phytoremediation of arsenic by  
578 *Brassica napus* and *Brassica juncea*: Morphological and physiological response.  
579 *International journal of phytoremediation* 19, 670-678.
- 580 35. Pietrini, F., Iannelli, M.A., Pasqualini, S., Massacci, A., 2003. Interaction of cadmium  
581 with glutathione and photosynthesis in developing leaves and chloroplasts of *Phragmites*  
582 *australis* (Cav.) Trin. ex Steudel. *Plant physiology* 133, 829-837.
- 583 36. Punshon, T., Carey, A.-M., Ricachenevsky, F.K., Meharg, A.A., 2018. Elemental  
584 distribution in developing rice grains and the effect of flag-leaf arsenate exposure.  
585 *Environmental and Experimental Botany* 149, 51-58.
- 586 37. Qiao, J.-t., Liu, T.-x., Wang, X.-q., Li, F.-b., Lv, Y.-h., Cui, J.-h., Zeng, X.-d., Yuan, Y.-  
587 z., Liu, C.-p., 2018. Simultaneous alleviation of cadmium and arsenic accumulation in

- 588 rice by applying zero-valent iron and biochar to contaminated paddy soils. *Chemosphere*  
589 195, 260-271.
- 590 38. Qiao, Y., Wu, J., Xu, Y., Fang, Z., Zheng, L., Cheng, W., Tsang, E.P., Fang, J., Zhao, D.,  
591 2017. Remediation of cadmium in soil by biochar-supported iron phosphate  
592 nanoparticles. *Ecological Engineering* 106, 515-522.
- 593 39. Rafiq, M.T., Aziz, R., Yang, X., Xiao, W., Stoffella, P.J., Saghir, A., Azam, M., Li, T.,  
594 2014. Phytoavailability of cadmium (Cd) to Pak choi (*Brassica chinensis* L.) grown in  
595 Chinese soils: A model to evaluate the impact of soil Cd pollution on potential dietary  
596 toxicity. *PloS one* 9, e111461.
- 597 40. Rahman, M.A., Hasegawa, H., Rahman, M.M., Islam, M.N., Miah, M.A.M., Tasmen, A.,  
598 2007. Effect of arsenic on photosynthesis, growth and yield of five widely cultivated rice  
599 (*Oryza sativa* L.) varieties in Bangladesh. *Chemosphere* 67, 1072-1079.
- 600 41. Rai, A., Tripathi, P., Dwivedi, S., Dubey, S., Shri, M., Kumar, S., Tripathi, P.K., Dave,  
601 R., Kumar, A., Singh, R., 2011. Arsenic tolerances in rice (*Oryza sativa*) have a  
602 predominant role in transcriptional regulation of a set of genes including sulphur  
603 assimilation pathway and antioxidant system. *Chemosphere* 82, 986-995.
- 604 42. Shahid, M., Niazi, N.K., Dumat, C., Naidu, R., Khalid, S., Rahman, M.M., Bibi, I., 2018.  
605 A meta-analysis of the distribution, sources and health risks of arsenic-contaminated  
606 groundwater in Pakistan. *Environmental Pollution*.
- 607 43. Shri, M., Kumar, S., Chakrabarty, D., Trivedi, P.K., Mallick, S., Misra, P., Shukla, D.,  
608 Mishra, S., Srivastava, S., Tripathi, R.D., 2009. Effect of arsenic on growth, oxidative  
609 stress, and antioxidant system in rice seedlings. *Ecotoxicology and environmental safety*  
610 72, 1102-1110.

- 611 44. Smith, E.R.G., Naidu, R., Alston, A., 1998. Arsenic in the soil environment. Academic  
612 Press.
- 613 45. Stoeva, N., Berova, M., Zlatev, Z., 2005. Effect of arsenic on some physiological  
614 parameters in bean plants. *Biologia Plantarum* 49, 293-296.
- 615 46. Stoeva, N., Bineva, T., 2003. Oxidative changes and photosynthesis in oat plants grown  
616 in As-contaminated soil. *Bulg J Plant Physiol* 29, 87-95.
- 617 47. Suriyagoda, L.D.B., Dittert, K., Lambers, H., 2018. Mechanism of arsenic uptake,  
618 translocation and plant resistance to accumulate arsenic in rice grains. *Agriculture,  
619 Ecosystems & Environment* 253, 23-37.
- 620 48. Talukdar, D., 2011. Effect of arsenic-induced toxicity on morphological traits of  
621 *Trigonella foenum-graecum* L. and *Lathyrus sativus* L. during germination and early  
622 seedling growth. *Current Research Journal of Biological Sciences* 3, 116-123.
- 623 49. Tripathi, R.D., Tripathi, P., Dwivedi, S., Dubey, S., Chakrabarty, D., 2012. Arsenomics:  
624 omics of arsenic metabolism in plants. *Frontiers in physiology* 3, 275.
- 625 50. Tripathi, P., Mishra, A., Dwivedi, S., Chakrabarty, D., Trivedi, P.K., Singh, R.P.,  
626 Tripathi, R.D., 2012. Differential response of oxidative stress and thiol metabolism in  
627 contrasting rice genotypes for arsenic tolerance. *Ecotoxicology and Environmental Safety*  
628 79, 189-198.
- 629 51. Walkley, A., Black, I.A., 1934. An examination of the Degtjareff method for determining  
630 soil organic matter, and a proposed modification of the chromic acid titration method.  
631 *Soil science* 37, 29-38.

- 632 52. Wang, J., Zeng, X., Zhang, H., Li, Y., Zhao, S., Su, S., Bai, L., Wang, Y., Zhang, T.,  
633 2018. Effect of exogenous phosphate on the lability and phytoavailability of arsenic in  
634 soils. *Chemosphere* 196, 540-547.
- 635 53. Waseem, A., Arshad, J., Iqbal, F., Sajjad, A., Mehmood, Z., Murtaza, G., 2014. Pollution  
636 status of Pakistan: a retrospective review on heavy metal contamination of water, soil,  
637 and vegetables. *BioMed research international* 2014.
- 638 54. Yu, H.-Y., Ding, X., Li, F., Wang, X., Zhang, S., Yi, J., Liu, C., Xu, X., Wang, Q.,  
639 2016a. The availabilities of arsenic and cadmium in rice paddy fields from a mining area:  
640 the role of soil extractable and plant silicon. *Environmental Pollution* 215, 258-265.
- 641 55. Yu, H.-Y., Li, F.-B., Liu, C.-S., Huang, W., Liu, T.-X., Yu, W.-M., 2016b. Iron redox  
642 cycling coupled to transformation and immobilization of heavy metals: implications for  
643 paddy rice safety in the red soil of South China. *Advances in Agronomy*. Elsevier, pp.  
644 279-317.
- 645 56. Yu, H.-Y., Wang, X., Li, F., Li, B., Liu, C., Wang, Q., Lei, J., 2017a. Arsenic mobility  
646 and bioavailability in paddy soil under iron compound amendments at different growth  
647 stages of rice. *Environmental pollution* 224, 136-147.
- 648 57. Yu, Z., Qiu, W., Wang, F., Lei, M., Wang, D., Song, Z., 2017b. Effects of manganese  
649 oxide-modified biochar composites on arsenic speciation and accumulation in an indica  
650 rice (*Oryza sativa* L.) cultivar. *Chemosphere* 168, 341-349.
- 651 58. Zhu, Y.-G., Geng, C.-n., Tong, Y.-P., Smith, S.E., Smith, F.A., 2006. Phosphate (Pi) and  
652 arsenate uptake by two wheat (*Triticum aestivum*) cultivars and their doubled haploid  
653 lines. *Annals of botany* 98, 631-636.

- 654 59. Zia, Z., Bakhat, H.F., Saqib, Z.A., Shah, G.M., Fahad, S., Ashraf, M.R., Hammad, H.M.,  
655 Naseem, W., Shahid, M., 2017. Effect of water management and silicon on germination,  
656 growth, phosphorus and arsenic uptake in rice. *Ecotoxicology and environmental safety*  
657 144, 11-18.
- 658 60. Zvobgo, G., Sagonda, T., Lwalaba, J.L.W., Mapodzeke, J.M., Muhammad, N., Chen, G.,  
659 Shamsi, I.H., Zhang, G., 2018. Transcriptomic comparison of two barley genotypes  
660 differing in arsenic tolerance exposed to arsenate and phosphate treatments. *Plant*  
661 *Physiology and Biochemistry* 130, 589-603.
- 662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676



### Figure Captions

**Fig.1:** Bioavailable (A) and total (B) Arsenic (As), Iron (Fe) and phosphorous (P) concentrations in control (CK) and Manga-Mandi soil (MMS). Error bars show  $\pm$ S.E of means of three replicates (n=3). Different bars for a same element (i.e. filled with different color) labeled with different alphabet are significantly different from each other (Tukey;  $P<0.05$ ).

**Fig.2:** Transpiration rate (E), Stomatal conductance (gs) and leaf CO<sub>2</sub> assimilation rate of two rice genotypes grown in soil having different arsenic concentrations (0 mg kg<sup>-1</sup>, 10 mg kg<sup>-1</sup>, 25 mg kg<sup>-1</sup>, 50 mg kg<sup>-1</sup>, and 100 mg kg<sup>-1</sup>) and arsenic contaminated soil from Mangamandi (MMS) along with iron (Fe), phosphate (PO<sub>4</sub>) & farmyard manure (FYM) as an amendment. Error bars show  $\pm$ S.E of means of three replicates (n=3). Similar bars (i.e. filled with similar color) labeled with different alphabet are significantly different from each other (Tukey;  $P<0.05$ ).

**Fig.3:** Arsenic concentration in grain (A&D), shoot (B&E) and root (C&F) of two rice genotypes grown in soil having different arsenic concentrations (0 mg kg<sup>-1</sup>, 10 mg kg<sup>-1</sup>, 25 mg kg<sup>-1</sup>, 50 mg kg<sup>-1</sup>, and 100 mg kg<sup>-1</sup>) and arsenic contaminated soil from Manga-Mandi (MMS) along with iron (Fe), phosphate (PO<sub>4</sub>) & farmyard manure (FYM) as an amendment. Error bars show  $\pm$ S.E of means of three replicates (n=3). Similar bars (i.e. filled with similar color) labeled with different alphabet are significantly different from each other (Tukey;  $P<0.05$ ).

**Fig.4:** Pearson's correlation matrix between concentration of soil total As (ST.As), soil bioavailable As (SB.As), shoot (S), root (R) & grain (G) As, Zn, Fe and P of two rice genotypes (A&B). Genotypes are represented as G1 for BR-1 & G2 for Bas-385. Correlation was statistically significant with P value <1%. All non-significant correlations were crossed.

**Table 1:** Effect of arsenic on seed germination, radical & hypocotyl length and germination index in two genotypes of rice in different concentrations on Arsenic. Values are means  $\pm$ SE (n = 3). Values with different alphabet are significantly different from each other (Tukey;  $P < 0.05$ ).

	As Treatment (mg L <sup>-1</sup> )	BR-1	BR-18	BR-23	BAS-PAK	SUP-BAS	BAS-385	GSR-1	GSR-2	IR-6	PK-386	PS-2	KS-282
Germination %	0	91.7 $\pm$ 4.2ab	95.8 $\pm$ 4.2ab	87.5 $\pm$ 0.0b	91.7 $\pm$ 4.2a	91.7 $\pm$ 4.2ab	83.3 $\pm$ 4.2a	87.5 $\pm$ 0.0a	83.3 $\pm$ 4.2a	91.7 $\pm$ 4.2a	100.0 $\pm$ 0.0a	100.0 $\pm$ 0.0a	95.8 $\pm$ 4.2ab
	0.05	100.0 $\pm$ 0.0a	100.0 $\pm$ 0.0a	100.0 $\pm$ 0.0a	100.0 $\pm$ 0.0a	83.3 $\pm$ 4.2ab	79.2 $\pm$ 4.2a	87.5 $\pm$ 0.0a	95.8 $\pm$ 4.2a	95.8 $\pm$ 4.2a	100.0 $\pm$ 0.0a	100.0 $\pm$ 0.0a	91.7 $\pm$ 4.2ab
	0.25	100.0 $\pm$ 0.0a	95.8 $\pm$ 4.2ab	100.0 $\pm$ 0.0a	95.8 $\pm$ 4.2a	100.0 $\pm$ 0.0a	91.7 $\pm$ 4.2a	91.7 $\pm$ 4.2a	91.7 $\pm$ 4.2a	95.8 $\pm$ 4.2a	100.0 $\pm$ 0.0a	100.0 $\pm$ 0.0a	83.3 $\pm$ 4.2b
	0.5	100.0 $\pm$ 0.0a	87.5 $\pm$ 0.0b	100.0 $\pm$ 0.0a	100.0 $\pm$ 0.0a	75.0 $\pm$ 7.2b	95.8 $\pm$ 4.2a	91.7 $\pm$ 4.2a	91.7 $\pm$ 4.2a	95.8 $\pm$ 4.2a	87.5 $\pm$ 0.0b	95.8 $\pm$ 4.2a	100.0 $\pm$ 0.0a
	1	87.5 $\pm$ 0.0b	87.5 $\pm$ 0.0b	91.7 $\pm$ 4.2ab	95.8 $\pm$ 4.2a	83.3 $\pm$ 4.2ab	83.3 $\pm$ 4.2a	87.5 $\pm$ 0.0a	95.8 $\pm$ 4.2a	100.0 $\pm$ 0.0a	91.7 $\pm$ 4.2ab	95.8 $\pm$ 4.2a	100.0 $\pm$ 0.0a
Hypocotyl length (cm)	0	0.84 $\pm$ 0.07b	1.22 $\pm$ 0.16a	1.42 $\pm$ 0.16c	2.37 $\pm$ 0.12ab	1.23 $\pm$ 0.20a	1.68 $\pm$ 0.08ab	4.30 $\pm$ 0.07a	2.45 $\pm$ 0.11ab	2.61 $\pm$ 0.17a	2.16 $\pm$ 0.08b	3.01 $\pm$ 0.06a	2.92 $\pm$ 0.13a
	0.05	1.26 $\pm$ 0.14a	1.26 $\pm$ 0.21a	2.44 $\pm$ 0.07a	2.35 $\pm$ 0.21ab	1.37 $\pm$ 0.14a	1.26 $\pm$ 0.11bc	4.69 $\pm$ 0.25a	2.44 $\pm$ 0.13ab	3.30 $\pm$ 0.07a	2.75 $\pm$ 0.16ab	3.52 $\pm$ 0.10a	3.20 $\pm$ 0.12a
	0.25	0.97 $\pm$ 0.10ab	1.77 $\pm$ 0.12a	2.28 $\pm$ 0.15ab	2.80 $\pm$ 0.29a	1.24 $\pm$ 0.07a	1.91 $\pm$ 0.11a	4.20 $\pm$ 0.12a	2.20 $\pm$ 0.11b	2.75 $\pm$ 0.19a	2.95 $\pm$ 0.06a	3.63 $\pm$ 0.31a	2.78 $\pm$ 0.34a
	0.5	1.35 $\pm$ 0.03a	2.04 $\pm$ 0.28a	2.48 $\pm$ 0.04a	2.67 $\pm$ 0.17ab	1.03 $\pm$ 0.02a	1.21 $\pm$ 0.12c	4.34 $\pm$ 0.17a	3.67 $\pm$ 0.22a	2.73 $\pm$ 0.10a	2.65 $\pm$ 0.12ab	3.58 $\pm$ 0.24a	3.25 $\pm$ 0.17a
	1	1.09 $\pm$ 0.00ab	1.57 $\pm$ 0.28a	1.62 $\pm$ 0.31bc	1.92 $\pm$ 0.08b	1.35 $\pm$ 0.17a	1.04 $\pm$ 0.07c	3.81 $\pm$ 0.38a	3.47 $\pm$ 0.57ab	3.10 $\pm$ 0.23a	2.49 $\pm$ 0.29ab	3.10 $\pm$ 0.25a	3.22 $\pm$ 0.11a
Radical length (cm)	0	1.44 $\pm$ 0.10b	1.73 $\pm$ 0.20b	2.07 $\pm$ 0.25b	2.50 $\pm$ 0.30b	2.05 $\pm$ 0.33a	3.07 $\pm$ 0.13a	3.85 $\pm$ 0.31a	1.80 $\pm$ 0.07b	2.56 $\pm$ 0.21b	2.12 $\pm$ 0.07b	2.98 $\pm$ 0.17b	2.53 $\pm$ 0.06a
	0.05	1.79 $\pm$ 0.10b	2.26 $\pm$ 0.08ab	3.87 $\pm$ 0.10a	2.82 $\pm$ 0.16b	1.60 $\pm$ 0.21a	2.26 $\pm$ 0.25ab	4.04 $\pm$ 0.49a	2.05 $\pm$ 0.06b	3.74 $\pm$ 0.14a	3.15 $\pm$ 0.08a	4.59 $\pm$ 0.13ab	2.92 $\pm$ 0.21a
	0.25	2.98 $\pm$ 0.41a	2.75 $\pm$ 0.41ab	3.87 $\pm$ 0.25a	4.13 $\pm$ 0.29a	2.49 $\pm$ 0.10a	3.42 $\pm$ 0.24a	3.77 $\pm$ 0.27a	2.12 $\pm$ 0.18b	2.78 $\pm$ 0.33ab	3.42 $\pm$ 0.19a	5.00 $\pm$ 0.13a	3.01 $\pm$ 0.48a
	0.5	2.89 $\pm$ 0.21a	3.53 $\pm$ 0.33a	4.45 $\pm$ 0.01a	4.28 $\pm$ 0.34a	1.62 $\pm$ 0.19a	2.66 $\pm$ 0.64ab	3.90 $\pm$ 0.43a	3.77 $\pm$ 0.22a	2.81 $\pm$ 0.09ab	3.20 $\pm$ 0.15a	4.41 $\pm$ 0.84ab	3.62 $\pm$ 0.04a
	1	2.94 $\pm$ 0.16a	2.85 $\pm$ 0.37ab	3.76 $\pm$ 0.49a	3.32 $\pm$ 0.17ab	2.36 $\pm$ 0.28a	1.42 $\pm$ 0.17b	2.88 $\pm$ 0.28a	3.10 $\pm$ 0.28a	3.41 $\pm$ 0.19ab	2.90 $\pm$ 0.26a	3.92 $\pm$ 0.11ab	3.62 $\pm$ 0.13a
Germination Index %	0.05	136.4 $\pm$ 5.7b	139.5 $\pm$ 11.6a	221.9 $\pm$ 35.4a	124.8 $\pm$ 4.3c	82.4 $\pm$ 30.7a	69.3 $\pm$ 2.7ab	108.3 $\pm$ 20.9a	131.2 $\pm$ 7.0b	155.1 $\pm$ 15.5a	148.5 $\pm$ 4.6ab	154.6 $\pm$ 4.8a	111.9 $\pm$ 13.5a
	0.25	224.1 $\pm$ 19.1a	161.8 $\pm$ 24.1a	220.7 $\pm$ 34.1a	175.0 $\pm$ 11.3ab	144.4 $\pm$ 34.8a	124.4 $\pm$ 16.9a	103.6 $\pm$ 10.1a	129.2 $\pm$ 10.6b	114.2 $\pm$ 13.1a	161.2 $\pm$ 8.0a	168.8 $\pm$ 6.4a	102.7 $\pm$ 12.1a
	0.5	222.9 $\pm$ 28.3a	190.1 $\pm$ 17.4a	253.7 $\pm$ 32.7a	188.8 $\pm$ 2.5a	68.8 $\pm$ 16.1a	103.3 $\pm$ 27.7ab	108.8 $\pm$ 18.1a	230.6 $\pm$ 15.1a	116.7 $\pm$ 10.6a	132.9 $\pm$ 10.7ab	138.8 $\pm$ 18.9a	150.7 $\pm$ 11.8a
	1	196.1 $\pm$ 8.5ab	158.0 $\pm$ 36.3a	190.9 $\pm$ 14.8a	142.2 $\pm$ 14.5bc	119.2 $\pm$ 41.9a	46.3 $\pm$ 4.7b	77.1 $\pm$ 13.9a	197.5 $\pm$ 14.9a	146.2 $\pm$ 1.3a	124.2 $\pm$ 4.9b	126.5 $\pm$ 6.0a	151.1 $\pm$ 15.4a

**Table 2:** Effect of arsenic on plant growth/biomass in two genotypes of rice grown in arsenic contaminated soil for six months. Values are means  $\pm$ SE (n = 3). MMS is Manga-Mandi soil, with amendments of Iron, phosphate and farmyard manure respectively. Values with different alphabet are significantly different from each other (Tukey;  $P < 0.05$ ).

	Soil As Treatment (mg kg <sup>-1</sup> )	Plant height (cm)	Shoot Fresh Wt.(g)	No. of Tillers	1000 grain weight (g)	Grain yield(g)
BR-1	0	98.21 $\pm$ 0.85b	35.17 $\pm$ 0.74b	16.00 $\pm$ 0.29a	18.95 $\pm$ 0.39a	14.12 $\pm$ 0.42a
	10	102.45 $\pm$ 1.12ab	40.78 $\pm$ 0.45a	12.50 $\pm$ 0.20b	16.12 $\pm$ 0.11cd	11.48 $\pm$ 0.09b
	25	93.13 $\pm$ 2.24b	33.62 $\pm$ 0.14b	16.00 $\pm$ 0.29a	17.02 $\pm$ 0.08bc	9.51 $\pm$ 0.10c
	50	93.39 $\pm$ 1.50b	23.43 $\pm$ 0.07c	13.50 $\pm$ 0.76b	15.42 $\pm$ 0.28d	6.82 $\pm$ 0.11e
	100	79.33 $\pm$ 1.70c	22.23 $\pm$ 0.36c	14.00 $\pm$ 0.50ab	18.10 $\pm$ 0.42ab	8.09 $\pm$ 0.22d
	MMS	87.21 $\pm$ 2.58ab	20.03 $\pm$ 0.61a	12.00 $\pm$ 0.29a	16.33 $\pm$ 1.09a	8.65 $\pm$ 0.55a
	MMS+Fe	92.35 $\pm$ 1.91ab	20.88 $\pm$ 0.32a	11.17 $\pm$ 0.60ab	20.45 $\pm$ 0.59a	8.37 $\pm$ 0.13a
	MMS+P	85.99 $\pm$ 1.45b	21.23 $\pm$ 0.42a	11.67 $\pm$ 0.44a	16.03 $\pm$ 1.44a	4.63 $\pm$ 0.39b
	MMS+FYM	96.01 $\pm$ 2.33a	22.27 $\pm$ 0.61a	9.67 $\pm$ 0.17b	17.40 $\pm$ 1.75a	7.42 $\pm$ 0.52a
Bas-385	0	124.63 $\pm$ 0.56a	41.87 $\pm$ 0.52a	12.00 $\pm$ 1.32a	21.55 $\pm$ 0.34b	5.87 $\pm$ 0.14b
	10	120.23 $\pm$ 1.85a	37.45 $\pm$ 0.58b	11.17 $\pm$ 0.60ab	26.23 $\pm$ 0.57a	9.18 $\pm$ 0.18a
	25	113.20 $\pm$ 0.75b	31.01 $\pm$ 0.30c	9.00 $\pm$ 0.58ab	17.68 $\pm$ 0.37c	3.91 $\pm$ 0.08d
	50	104.99 $\pm$ 1.12c	18.47 $\pm$ 0.19d	8.44 $\pm$ 0.22b	21.05 $\pm$ 0.75b	4.40 $\pm$ 0.18cd
	100	97.37 $\pm$ 2.24d	16.73 $\pm$ 0.11d	8.33 $\pm$ 0.33b	19.40 $\pm$ 0.27bc	4.98 $\pm$ 0.13c
	MMS	106.60 $\pm$ 1.09a	22.58 $\pm$ 0.94a	10.17 $\pm$ 0.33a	15.53 $\pm$ 0.34a	3.42 $\pm$ 0.07c
	MMS+Fe	105.51 $\pm$ 1.89a	20.73 $\pm$ 0.41ab	9.67 $\pm$ 0.44a	16.69 $\pm$ 0.32a	6.49 $\pm$ 0.20a
	MMS+P	110.79 $\pm$ 0.97a	22.38 $\pm$ 0.82a	10.50 $\pm$ 0.00a	15.47 $\pm$ 1.49a	4.86 $\pm$ 0.35b
	MMS+FYM	108.91 $\pm$ 0.80a	17.95 $\pm$ 0.67b	9.67 $\pm$ 0.17a	16.52 $\pm$ 0.63a	3.13 $\pm$ 0.03c

**Table 3:** Translocation factors<sup>a</sup> (TF) and bioaccumulation factors<sup>b</sup> (BAF) of Rice grown in soil with various treatments of As for 180 days.

Treatments (mg kg <sup>-1</sup> )	TF		BAF	
	BR-1	Bas-385	BR-1	Bas-385
<b>0</b>	0.252	0.067	3.549	5.036
<b>10</b>	0.034	0.049	7.975	4.483
<b>25</b>	0.046	0.023	5.069	4.820
<b>50</b>	0.050	0.014	3.079	3.479
<b>100</b>	0.019	0.014	2.176	4.648
<b>MMS</b>	0.100	0.008	3.523	3.952
<b>MMS+Fe</b>	0.002	0.011	8.191	10.530
<b>MMS+P</b>	0.010	0.025	3.487	4.093
<b>MMS+FYM</b>	0.029	0.002	3.702	14.491

<sup>a</sup>

Translocation factor is calculated as As concentrations in shoots/As concentrations in roots.

<sup>b</sup> Bioaccumulation factor is calculated as As concentrations in plant/As concentrations in soil

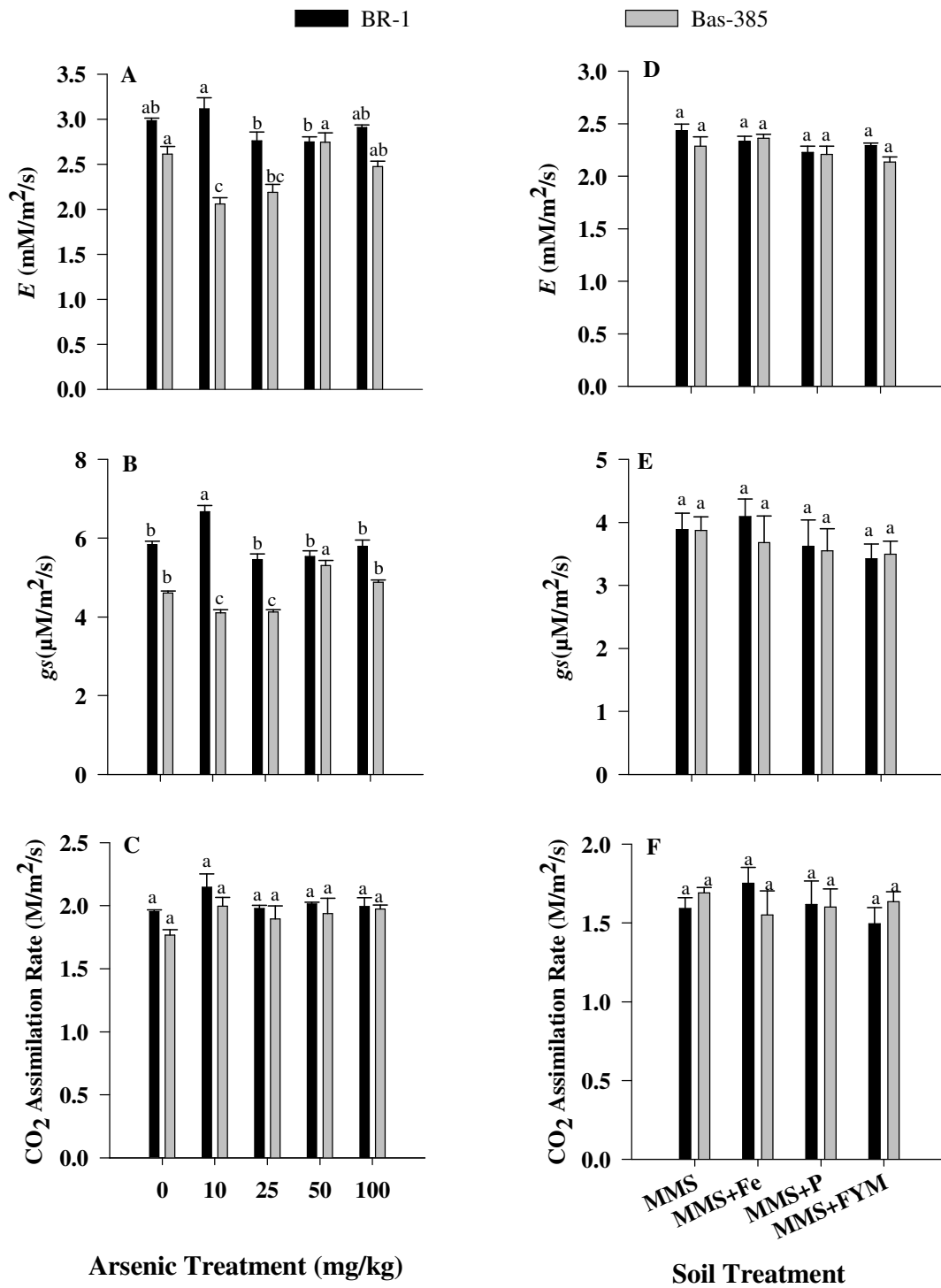


Fig.2

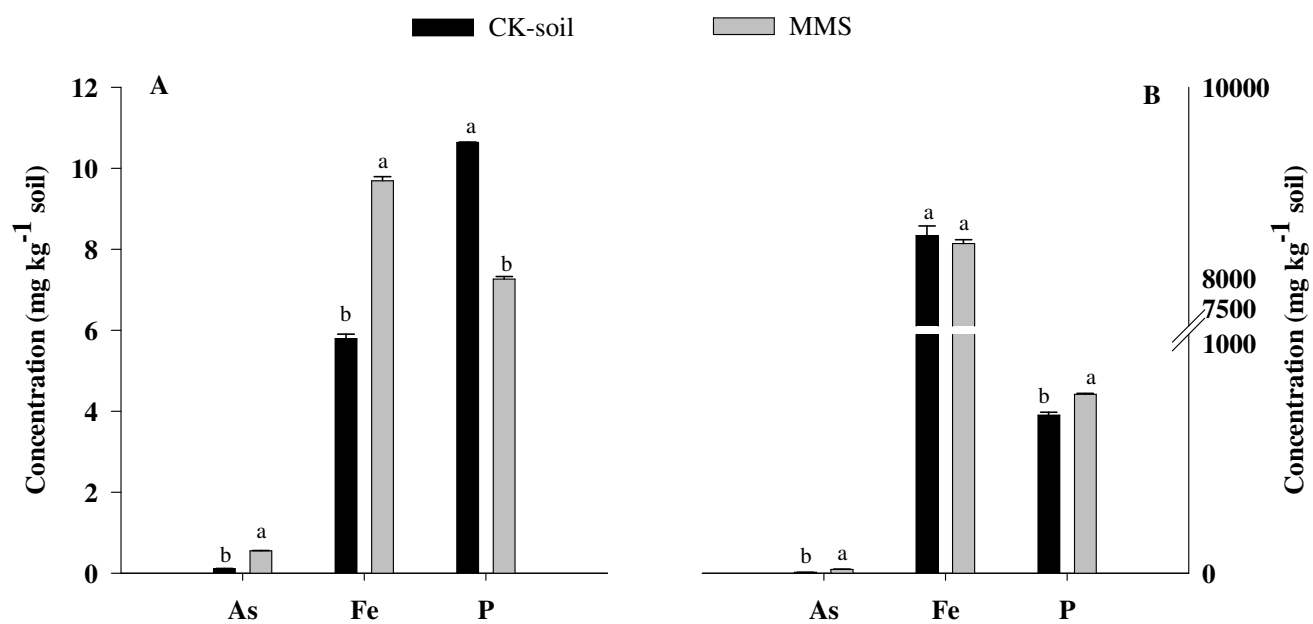


Fig.1

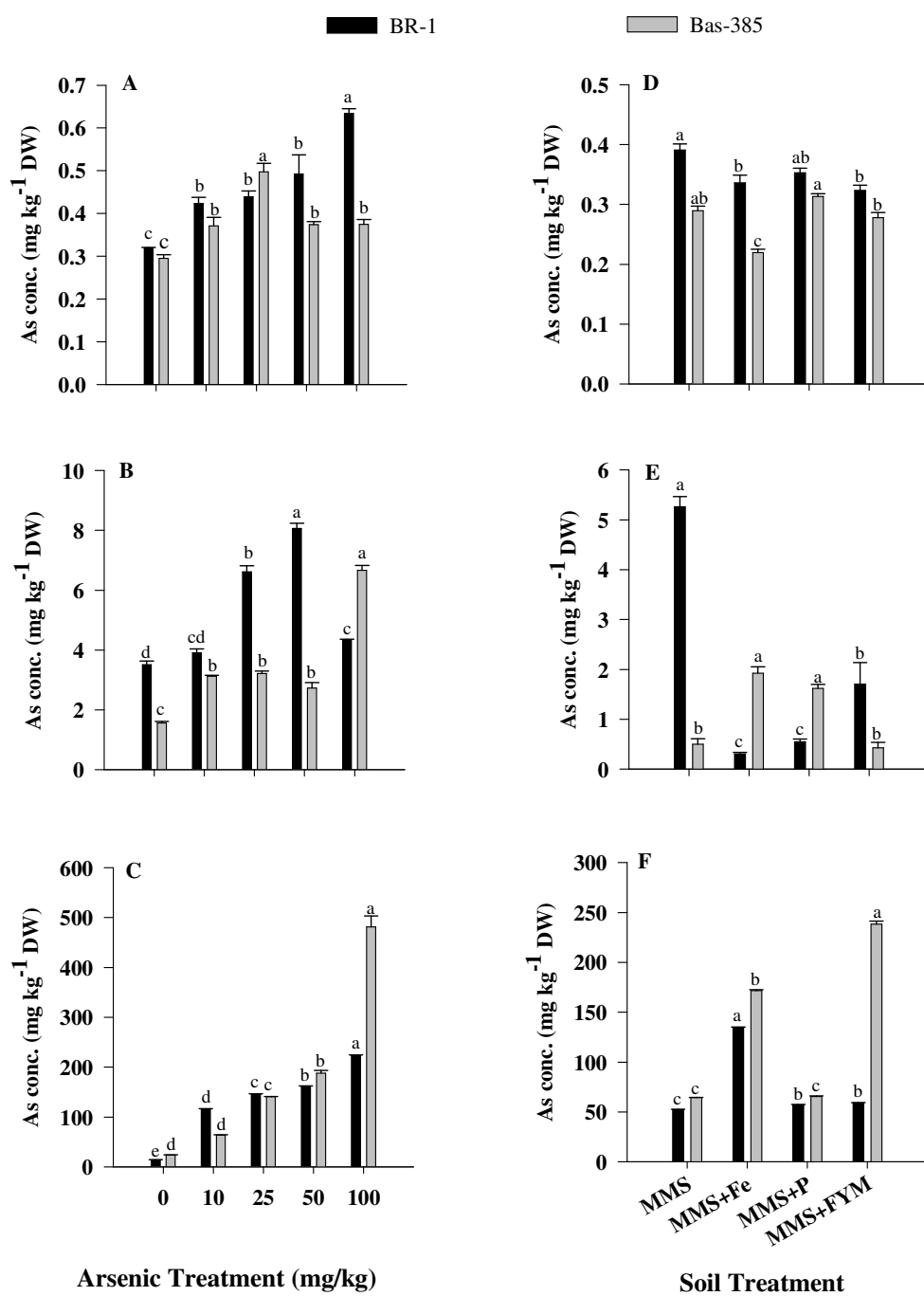


Fig.3

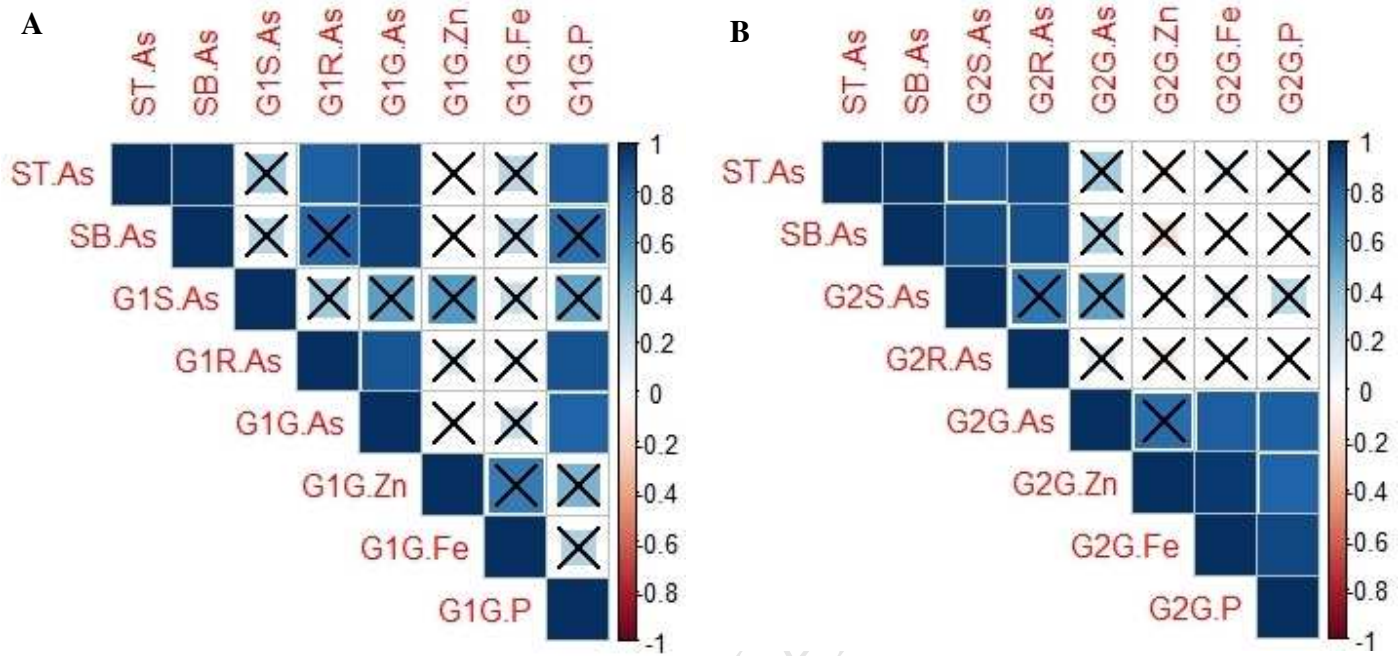


Fig.4



**Highlights**

- Arsenic (As) toxicity in basmati rice shows genotype dependent effects on growth
- Bas-385 showed substantial yield improvement at 10 mg kg<sup>-1</sup> soil arsenic
- Arsenic concentration in rice followed the order roots > shoot > grain in both genotypes
- Iron sulfate amendment caused a significant reduction in grain arsenic
- High concentration of arsenic in soil led to 40%-50% reduction in grain yield