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EFFECT OF ARSENIC-INDUCED TOXICITY ON SEED GERMINATION OF *Vigna radiata* (L.) R. WILCZEK AND *Vigna mungo* (L.) HEPPER: A COMPARATIVE STUDY

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Abstract

Arsenic (As) is a highly toxic metalloid present in soils, sediments and water. Arsenic contamination in soil and/or groundwater is a global alarm because of its quick mobilization in the environment during recent decades. Exposure to arsenate causes considerable stress in plants, including inhibition of growth, physiological disorders and finally death. In West Bengal (India), several areas with agricultural practices are arsenic contaminated. The increased arsenic levels in soil severely affect the normal growth and development of plants and eventually result in a reduction in the yield of many crops. Arsenic is not only being bioaccumulated via groundwater-plant-soil system, it is severely affecting the rural economy by reducing the crop yield. Development of safe crops for cultivation in arsenic contaminated soil is an important strategy to counter the detrimental effect of arsenic accumulation in crop plants. Thus, understanding of different morphological traits is extremely important from very early stage of growth and development. Several studies on the effect of arsenic on some crops have shown that arsenic stress significantly hampers the growth, development and yield of several plants. However, comparative analyses of the effects of arsenic-stress on different crop plants have not been studied thoroughly. This study has been done with two species of *Vigna* viz. *Vigna radiata* (L.) R. Wilczek and *Vigna mungo* (L.) Hepper to study their response to arsenic stress. Both of these crops showed significant decrease in seed germination and radicle growth with increasing arsenic concentration. However, regarding seed germination, the two species responded differently upto 150 µM of arsenic concentration, while at 200 µM, they responded similarly. Additionally, *V. mungo* was found to be more sensitive than *V. radiata* regarding radicle growth at lower arsenic concentration. The study will help for future agricultural practices of these economically important crops.

Keywords: ANOVA, arsenate, arsenic response index, phytotoxicity, radicle growth

INTRODUCTION

Arsenic (As) is a highly toxic metalloid present in soils, sediments and water (Ahsan et al., 2010). Primarily as a consequence of drawing up large quantities of groundwater by shallow tube-wells for agriculture as well as some other factors like industrialization and contemporary agricultural practices, many aquifers have now been contaminated with arsenic (Talukdar, 2011). Pollution in the groundwater has been reported in approximately 21 countries in different parts of the world; the largest population at risk is mainly in Southeast Asian countries (Mohan and Pittman, 2007). Almost 51 million people or more in West Bengal and Bangladesh are exposed to elevated level of As in their drinking water (Pearce, 2003). The maximum acceptable level of As in agricultural soils is 20 mg/kg (Kabata-Pendias and Pendias, 1992). In recent years, the impact of irrigation with highly arsenic contaminated groundwater on soil and crop has drawn more attention due to entry of As to the food chain via groundwater-plant-soil system (Rahman et al., 2008). In soils, As can exist in both organic and inorganic forms and be found in at least four different chemical forms *viz.* arsenate (As^{V}), arsenite (As^{III}), monomethyl arsenic acid (MMAA) and dimethyl arsenic acid (DMAA) (Ahsan et al., 2010). Among these forms, As^{V} is the predominant phytoavailable form of arsenic in aerobic soils, and is an analogue of phosphate (Ahsan et al., 2010). It can frequently enter or be taken up by roots through the phosphate transporter and be transported to the aerial parts of plants, including the seeds (Meharg and Macnair, 1992; Abedin et al., 2002; Meharg and Hartley-Whitaker, 2002; Raab et al., 2005; Pickering et al., 2006). Using X-ray absorption spectroscopy imaging, it has been demonstrated that As^{V} was transported from the root to shoots via the xylem (Smith et al., 2007). Also, it has been demonstrated that after transportation into the cells, As^{V} can be quickly reduced to As^{III} or other forms (Pickering et al., 2000).

Unfortunately, in several countries, the level of As in contaminated agricultural soils is much higher than the acceptable level (Mohan and Pittman, 2007). The bioaccumulation of As in different crop plants including beans, cereals, fruits and vegetables has huge negative impact on public health issues in both rural and urban population (Nickson et al., 1998; Katz and Salem, 2005), and this is of great environmental concern because arsenic is known to be a carcinogen and a powerful co-mutagen (Patra et al., 2004; Fayiga and Ma, 2006). The extent of As contamination is severe in Bangladesh followed by West Bengal, India (Rahaman et al., 2013). It is reported that 10 million people are to be affected from nine districts of West Bengal such as Malda, Murshidabad, Nadia, North and South 24 Parganas, Burdwan, Howrah, Hooghly and South Kolkata (Nickson et al., 2000; Chakraborti et al., 2002). Pulses, fruits, and oilseeds which are grown in arsenic-contaminated soil, can accumulate arsenic in them (Larsen et al., 1992). Effect of arsenic has been shown in several legume crops like *Cicer arietinum* L. (Gupta et al., 2008), *Lathyrus sativus* L., *Trigonella foenum-graecum* L. (Talukdar, 2011) and *Phaseolus vulgaris* L. (Talukdar, 2013).

Vigna radiata (L.) R. Wilczek (mungbean) is an economically important food legume, known for protein-rich nutritional values (Sengupta et al., 2013). The seeds and sprouts of this plant are also commonly used as a fresh salad vegetable or common food in India, Bangladesh, South East Asia and western countries (Fery, 1990). As a food, mungbeans contain balanced nutrients, including protein and dietary fiber and significant amounts of bioactive phytochemicals (Tang et al., 2014). In West Bengal, about 4.4 thousand tonnes of mungbean production was recorded from 11.7 thousand hectares of area in 2004 - 05 (Kundu et al., 2009). *Vigna mungo* (L.) Hepper is another important pulse crop of the world (Agnihotri et al., 2015). It is a cheap source of protein for direct human consumption and has great value as food, fodder as well as green manure (Hussain et al., 2006). In India, it is mainly cultivated in Madhya Pradesh, Uttar Pradesh, Punjab, Maharashtra, West Bengal, Andhra Pradesh and Karnataka (Indira and Kurup, 2003). Considering the severity of the As contamination in West Bengal, it is, thus, worth investigating the effect of As in these two species of *Vigna*.

Development of safe legume crops for cultivation in arsenic contaminated soil is an important strategy to counter the detrimental effect of arsenic accumulation in protein and mineral rich legumes (Talukdar, 2011). Minimizing the uptake and translocation of arsenic to edible parts would form the basis for improving crops (Tripathi et al., 2007) for which understanding of different morpho-physiological traits is extremely important from very early stage of growth and development

(Bayuelo-Jiménez et al., 2002). Seed germination is the most critical first stage in seedling establishment, determining successful crop production (Almansouri et al., 2001). Many abiotic stress facors like salinity and drought are known to inhibit seed germination in different magnitudes leading to loss of crop establishments in legume crops (Bayuelo-Jiménez et al., 2002; Li, 2008). To improve the reliability and selection efficiency for arsenic tolerance, knowledge of arsenic-induced response of different crop species at the seed germination stage is particularly important for successful stand establishment and growth (Talukdar, 2011). Although effect of arsenic has been previously studied in *Vigna radiata* (Gupta and Bhatnagar, 2015) and *Vigna mungo* (Srivastava and Sharma, 2014), comparative account of effect of arsenic between these two species is lacking. Considering the detrimental effect of arsenic and economic importance of these two crops, the present study was performed to compare the effect of different concentrations of arsenic on some seed germination traits of *Vigna radiata* (L.) R. Wilczek and *Vigna mungo* (L.) Hepper.

MATERIALS AND METHODS

Analysis of arsenic induced toxicity

Fresh, dry, healthy and uniform-sized seeds of *Vigna radiata* (L.) R. Wilczek cultivar "B-1" and *Vigna mungo* (L.) Hepper cultivar "Kalindi" were used in the present study. Seeds were surface sterilized with sodium hypochlorite (NaOCl) (0.6 %, w/v) and continuously washed under running tap water followed by distilled water. Seeds were then imbibed in distilled water for two hours and placed on two filter papers into 9 cm diameter Petri plates with a tight-fitting lid. The experiment was carried out at 25±0.5°C to test the germination in four different concentrations of arsenic (50μM, 100μM, 150μM and 200μM), prepared as solution of sodium arsenate ($Na_2HAsO_4 \cdot 7H_2O$), in three replicates. Control sets were also prepared which was comprised of only distilled water. The seed germination was evaluated after six days and the radicle lengths were also measured. Measurement of radicle lengths was performed from photographs with the help of the image processing software ImageJ (Abràmoff et al., 2004). Several parameters regarding seed germination were calculated according to Talukdar (2011) as follows:

$$\text{Germination percentage} = \frac{\text{Total no. of seeds germinated} \times 100}{\text{Total no. of seeds taken for germination}}$$

$$\text{Relative germination rate} = \frac{\text{Germination percentage in arsenic concentration}}{\text{Germination percentage in control}}$$

$$\text{Relative arsenic-injury rate} = \frac{(\text{Germination percentage in control} - \text{Germination percentage in arsenic treatment})}{\text{Germination percentage in control}}$$

The % Phytotoxicity for radicle length was calculated according to the formula of Chou et al. (1978).

$$\%\ \text{Phytotoxicity} = \frac{(\text{Radicle length in control} - \text{Radicle length of test})}{\text{Radicle length of control}} \text{ X } 100$$

Tolerance to arsenic was determined by calculating ARI *i.e.* Arsenic Response Index (following Talukdar, 2011) for radicle length as follows:

$$\text{ARI} = \frac{\text{value from treatment x } 100}{\text{value from control}}$$

Statistical analysis

Independent sample *t*-test was used for comparing differences between two groups. For comparing differences between multiple groups, one-way ANOVA was used followed by the comparison of mean values using post-hoc Tukey's HSD (honest significant difference) test. Differences were considered significant at $P < 0.05$. All these statistical analyses were performed with R package (R Core Team, 2013).

RESULTS

Effect of arsenic-induced toxicity on seed germination rate

Germination percentage at control as well as at different arsenic concentrations is shown in figure 1a and 1b, for *V. radiata* and *V. mungo*, respectively. At germination stage, the two species behaved differently. In *Vigna radiata*, 50µM, 100µM, 150µM and 200µM of arsenic concentrations showed 15.47%, 16.66%, 57.14% and 75% reduction in seed germination, respectively, compared to control (table 1). However, *Vigna mungo* showed 46.67% and 73.33% reduction at 50µM and 100µM of arsenic concentration, respectively. However, 80% decrease in germination percentage was observed at both 150µM and 200µM of arsenic concentration in this species. It is noteworthy that more than 50% decrease in seed germination in *V. radiata* was observed at 150µM of arsenic concentration while in *V. mungo*, 50% decrease in seed germination was reached at 100µM of arsenic concentration. To compare the germination percentage of the two species, we have compared the means by independent sample *t*-test. We have found that, in control, no significant difference was found between the two species ($P>0.05$). However, significant difference was found at 50 µM ($P<0.01$), 100µM ($P<0.01$) and 150µM ($P<0.05$). Again, at 200µM, no significant difference was found ($P>0.05$). This also showed that the two species responded differently upto 150 µM of arsenic concentrations, while at higher concentration, they responded similarly.

Table 1: Effect of different concentrations of arsenic on seed germination of the investigated plant species

Species	Arsenic concentration (µM)	Germination percentage (Mean ± SE)	Relative germination rate	Relative arsenic-injury rate
Vigna radiata	Control	93.33 ± 1.92	--	--
	50 µM	78.89 ± 1.11	0.85	0.15
	100 µM	77.78 ± 10.94	0.83	0.17
	150 µM	40 ± 7.7	0.43	0.57
	200 µM	23.33 ± 6.94	0.25	0.75
Vigna mungo	Control	75 ± 8.66	--	--
	50 µM	40 ± 2.89	0.53	0.47
	100 µM	20 ± 2.89	0.27	0.73
	150 µM	15 ± 2.89	0.2	0.8
	200 µM	15 ± 2.89	0.2	0.8

To study the response of each species under different arsenic concentrations regarding germination percentage, we have performed one-way ANOVA. ANOVA showed that significant variation was there regarding germination percentage at different arsenic concentrations in both the species ($F=18.81$; $df=4$; $P=1.2 \times 10^{-4}$ for *V. radiata* and $F=30.35$; $df=4$; $P=1.44 \times 10^{-5}$ for *V. mungo*). To further investigate the variation, we have performed post-hoc Tukey's HSD test. In *V. radiata*, germination percentage was not significantly different between control and 50 µM as well as 100 µM ($P>0.05$). Significant reduction, compared to control, was observed at 150µM ($P=1.7 \times 10^{-3}$) and 200µM ($P=2.03 \times 10^{-4}$) (figure 1a). Significant difference ($P=1.8 \times 10^{-2}$) has also been found between 100 µM and 150µM regarding germination percentage. However, in *V. mungo*, significant reduction from control was observed at all the concentrations ($P=2.4 \times 10^{-3}$, $P=6.12 \times 10^{-5}$, $P=2.83 \times 10^{-5}$ and $P=2.83 \times 10^{-5}$ at 50µM, 100 µM, 150 µM and 200µM, respectively) (figure 1b). This again showed that *V. mungo* is more sensitive to arsenic stress than *V. radiata*. However, no significant differences have been found between the two consecutive arsenic concentrations in this species.

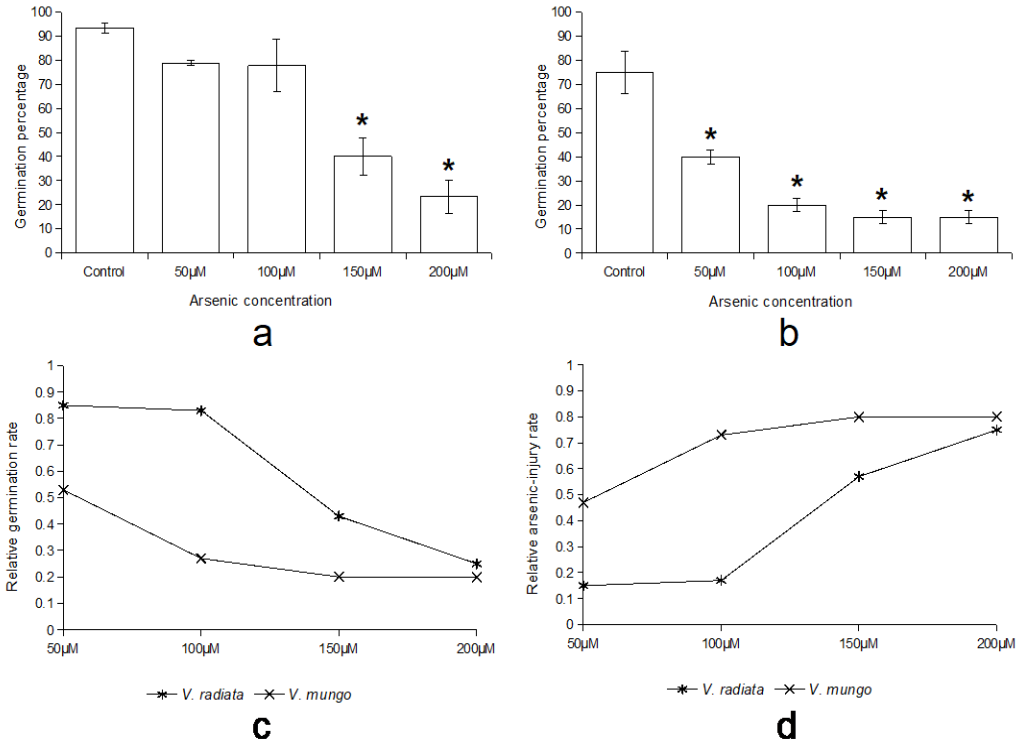

Figure 1: Effect of increasing arsenic concentration on seed germination of the two investigated plant species. a) germination percentage of *Vigna radiata*; b) germination percentage of *Vigna mungo*; c) relative germination rate of the two species; d) relative arsenic injury rate of the two species. The error bars represent ± SE. * indicate significant difference from control (Tukey's HSD test, $P<0.05$).

Relative germination rate was found to be reduced with increasing concentration of arsenic in both the species (table 1). However, they differed in their pattern of reduction. For *V. radiata*, relative germination rate was found to be similar at 50µM and 100µM of arsenic concentration. After that, at 150µM, it drastically decreased (about 1.9-fold than that of at 100µM) (figure 1c). In *V. mungo*, relative germination rate decreased considerably at 100µM (about 1.9-fold than that of at 50µM). However, after that, not much decrease was observed (figure 1c). Moreover, in *V. mungo*, relative germination rate was much lower than that of *V. radiata* (about 1.6-fold) at 50µM. At 100 µM, *V. mungo* showed even much lower relative germination rate than *V. radiata* (about 3-fold). At 150 µM, this difference came down to about 2-fold and at 200 µM, the relative germination rate of these two species was found to be similar.

Relative arsenic-injury rate was calculated based on germination percentage in arsenic treatment. Compared to control, this parameter showed increase with increasing arsenic concentration in both the species (table 1). The highest arsenic injury rate was observed in 150 µM and 200µM of arsenic concentration in *V. mungo*. The lowest value was observed in *V. radiata* at 50µM of arsenic concentration. Like relative germination rate, relative arsenic-injury rate was also found to be similar at 50µM and 100µM of arsenic concentration in *V. radiata*. After that, at 150µM, it increased considerably (about 3.35-fold than that of at 100µM) (figure 1d). At 200µM, relative arsenic-injury rate increased further (about 1.31-fold than that of at 150µM). In *V. mungo*, however, drastic increase in relative arsenic-injury rate was observed at 100µM (about 1.5-fold than that of at 50µM). After that, not much increase in relative arsenic-injury rate was observed. Moreover, at 50µM, *V. mungo* showed considerably more relative arsenic-injury rate than *V. radiata* (about 3-fold). At 100µM, this increased further to about 4.3-fold. But at 150µM, this difference came down to about 1.4-fold and at 200µM, they became almost similar.

Effect of arsenic-induced toxicity on radicle growth

Radicle length at control as well as at different arsenic concentrations is shown in figure 2a and 2b, for *V. radiata* and *V. mungo*, respectively. Radicles of *V. radiata* were found to be significantly (independent sample *t*-test, P<0.01) longer than *V. mungo* at control (table 2). Notably, no significant difference was found between these two species at 50µM of arsenic concentration (independent sample *t*-test, P>0.05). At 50µM, compared to control, the radicle length decreased about 3.7-fold and about 3-fold for *V. radiata* and *V. mungo*, respectively. However, at 100µM, significant difference was found between the radicle length of *V. radiata* and *V. mungo* (independent sample *t*-test, P<0.01). At 50µM, the mean radicle length of *V. radiata* was similar to that of at 100µM, while the mean radicle length of *V. mungo* decreased about 1.7-fold. At 150µM and 200µM, the mean radicle length was significantly different between *V. radiata* and *V. mungo* (independent sample *t*-test, P<0.01). All these results indicate that above 50µM of arsenic concentration has a more pronounced effect on the radicle length of *V. mungo* compared to *V. radiata*.

Table 2: Effect of different concentrations of arsenic on radicle growth of the investigated plant species

Species	Arsenic concentration (µM)	Radicle length in mm (Mean ± SE)	% Phytotoxicity	ARI
Vigna radiata	Control	25.45 ± 0.85	--	--
	50 µM	6.81 ± 0.3	73.24	26.76
	100 µM	6.56 ± 0.25	74.22	25.78
	150 µM	5.86 ± 0.22	76.97	23.03
	200 µM	5.35 ± 0.2	78.98	21.02
Vigna mungo	Control	19.82 ± 1.48	--	--
	50 µM	6.43 ± 0.77	67.56	32.44
	100 µM	3.83 ± 0.22	80.68	19.32
	150 µM	3.56 ± 0.16	82.04	17.96
	200 µM	3.49 ± 0.38	82.39	17.61

To study the response of each species under different arsenic concentrations regarding radicle length, we have performed one-way ANOVA. ANOVA showed that significant variation was there regarding radicle length at different arsenic concentrations in both the species ($F=253.08$; $df=4$; $P=3.46 \times 10^{-91}$ for *V. radiata* and $F=30.35$; $df=4$; $P=2.73 \times 10^{-15}$ for *V. mungo*). To further investigate the variation, we have performed Tukey's HSD test. In both the species, significant reduction was observed at all the concentrations compared to control ($P=4.23 \times 10^{-13}$ at all the concentrations for *V. radiata* and $P=4.42 \times 10^{-9}$, $P=9.37 \times 10^{-8}$, $P=8.29 \times 10^{-8}$ and $P=3.59 \times 10^{-10}$ at 50µM, 100 µM, 150 µM and 200µM, respectively, for *V. mungo*). However, no significant differences have been found between the two consecutive arsenic concentrations in both the species.

The % Phytotoxicity was found to be increased with increasing concentration of arsenic in both the species (table 2). However, they differed in their pattern of increase. For *V. radiata*, % Phytotoxicity ranged from 73.24% (at 50µM) to 78.98% (at 200µM). It increased in a linear way in *V. radiata* (figure 2c). However, in *V. mungo*, at 50µM, the % Phytotoxicity was the lowest (67.56%). After that, it increased considerably to 80.68% at 100 µM (about 1.2-fold increase). After that, not much increase in % Phytotoxicity has been observed. Moreover, % Phytotoxicity at 50µM was slightly higher in *V. radiata* than *V. mungo*. However, in 100µM, 150µM and 200µM of arsenic concentration, *V. mungo* showed higher phytotoxicity than *V. radiata*.

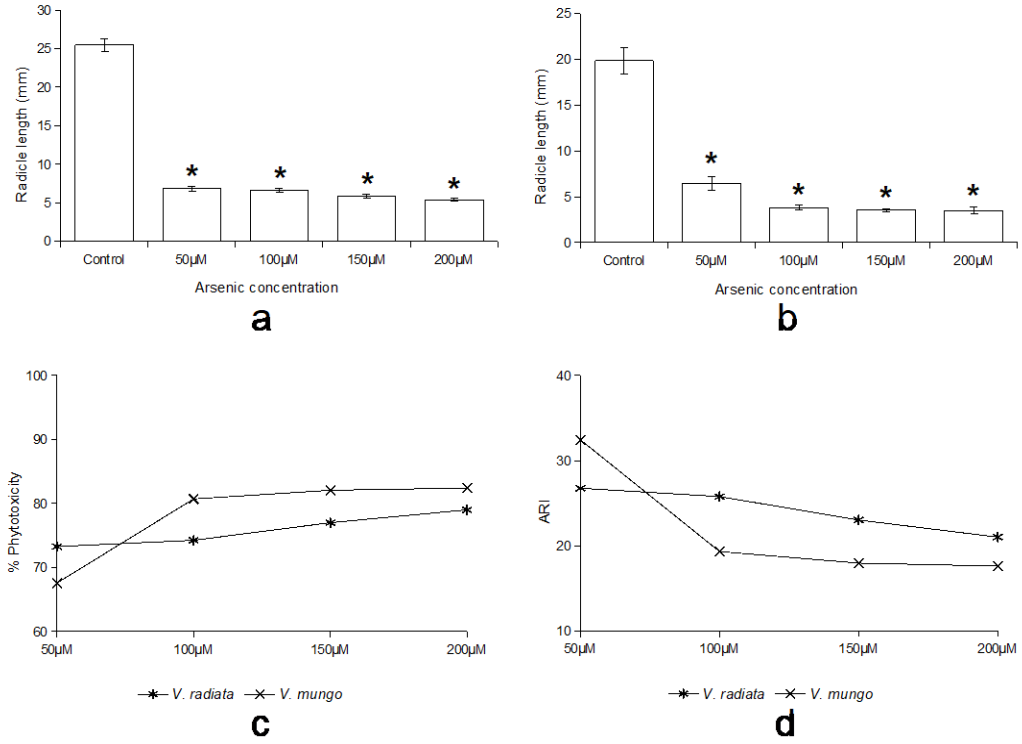

Figure 2: Effect of increasing arsenic concentration on radicle growth of the two investigated plant species. Radicle length of a) *Vigna radiata* and b) *Vigna mungo*; c) % Phytotoxicity of the two species; d) ARI of the two species. The error bars represent ± SE. * indicate significant difference from control (Tukey's HSD test, P<0.05).

ARI (Arsenic Response Index) was found to decrease in both the species with increased arsenic concentration. Notably, *V. mungo* showed the highest as well as the lowest ARI (table 2). However, in *V. radiata*, ARI decreased gradually while in *V. mungo*, a certain drop in ARI was found at 100µM (about 1.7-fold) than that of at 50µM (figure 2d). It was also noted that at 50µM, *V. mungo* showed an ARI value of 32.44 while *V. radiata* showed only 26.76. However, ARI value of *V. mungo* decreased considerably after that and at 100µM, 150µM and 200µM, it showed less value of ARI than *V. radiata* in respective concentrations of arsenic.

DISCUSSION

Heavy metal toxicity is found in agricultural soils in many parts of the world (Yadav, 2010). Assuming that heaviness and toxicity are inter-related, heavy metals also include metalloids, such as arsenic (Duffus, 2002) that are able to induce toxicity at low level of exposure (Tchounwou et al., 2012). Arsenic has no known biological function but inactivates diverse enzymatic processes (Gupta et al., 2009). Seed germination is one of the most sensitive processes to metal pollution because of lack of defense mechanisms at this stage and consequently it is worth studying the effects of heavy metals on seedling growth (Liu et al., 2005). In this study, we have showed reduced germination percentage and radicle length with increasing arsenate concentration in *V. radiata* and *V. mungo*. Our results are in accordance with Ahmad et al. (2009) who stated that higher concentrations of heavy metals suppress the seed germination parameters. However, the two investigated species showed differences in some parameters regarding seed germination as well as radicle length. For example, significant difference in seed germination percentage between the two species was found in 50 µM, 100µM and 150µM of arsenic concentration. Similarly, at 100µM and above concentrations of arsenic, significant difference was found between the radicle length of *V. radiata* and *V. mungo*. It has been opined that plants show a great variation in their response to arsenic toxicity (Meharg, 2003). In rice, it has been reported that germination and early seedling growth of rice decreased significantly with increasing concentrations

of As (Abedin and Meharg, 2002). However, in some cases, it has been shown that low concentrations of arsenic stimulate plant growth (Miteva, 2002; Garg and Singla, 2011). This event occurs under axenic conditions in cultured *Arabidopsis thaliana* plants (Chen et al., 2010) signifying that the trait is not based on arsenic disrupting plant-biotic interactions (Finnegan and Chen, 2012). It results either from a direct interaction of As with plant metabolism, or from an interaction of As with plant nutrients. It has been suggested that the growth benefit arises from As stimulation of Pi uptake (Tu and Ma, 2003). However, in the present investigation, gradual decrease in germination percentage as well as radicle growth has been observed with increasing arsenic concentration. This observation might be due to the fact that the seeds were not germinated under axenic culture conditions.

Since there are both inter- and intraspecific variations in As-induced toxicity profiles, it is pertinent to evaluate As toxicity in a wide variety of plant species (Singh et al., 2007). Response of legumes to arsenic-induced toxicity was investigated in a limited number of crops, but no study was carried out during germination except *Trigonella foenum-graecum* L. and *Lathyrus sativus* L. (Talukdar, 2011). In *Glycine max* Merril., Milivojević et al. (2006) reported decrease in phosphorus content with increasing As concentration, while in *Pisum sativum* L., Päivöke (2003) found negative correlation between growth parameters and arsenate treatment. Negative impact of As-induced toxicity on plant growth parameters and yield components was also reported in lentil (Ahmed et al., 2006). The present study indeed showed significant difference in seed germination as well as radicle growth between *V. radiata* and *V. mungo*. From this study, it has been found that significant interspcific differences are there regarding As-induced toxicity in germination rate as well as radicle growth. Regarding seed germination, among the two species, *V. mungo* was found to be more prone to arsenic toxicity upto 150 µM of arsenate concentration. Moreover, above 50µM of arsenic concentration was found to have more pronounced effect on the radicle length of *V. mungo* compared to *V. radiata*. All these showed that arsenic is more toxic in *V. mungo* than *V. radiata*, at least at lower concentrations.

The difference regarding arsenic toxicity between the two species indicated the difference in underlying physiological and biochemical aspects of the two species. It has been shown that arsenate in plants is absorbed and translocated through the phosphate channels (Abedin et al., 2002, Dhankher et al., 2006). It has also been reported that arsenate (As^V) is able to generate reactive oxygen species (ROS), as revealed by several ROS-related biochemical analyses (Hartley-Whitaker et al., 2001; Ahsan et al., 2008; Mishra et al., 2008; Shri et al., 2009) as well as altered enzymatic activities (Hartley-Whitaker et al., 2001; Srivastava et al., 2005; Shri et al., 2009). The enhanced production of ROS has also been reported under a variety of stress conditions in plants especially when exposed to heavy metals (Gallego et al., 1996; Shri et al., 2009). ROS accumulation damages nucleic acids, proteins, membrane lipid as well as impairment of enzymatic activities (Gill and Tuteja, 2010). Though as is not a redox metal (Ahsan et al., 2010), exposure of plants to As results in the generation of ROS (Britt, 1999). Considering all these facts, it is worth investigating the underlying physiological and biochemical aspects of the difference of arsenic-induced toxicity in the two investigated species.

In conclusion, in the present study, both the pulse crops showed inhibition in germination with increasing arsenic concentration, although the pattern of inhibition was somewhat different between them. Moreover, radicle growth of both the plants remained stunted with increase in arsenic concentration. However, there were differences in the magnitude of arsenic-induced toxicity in the two species. Further study is needed to investigate their morphological, anatomical, cytological, and physiological as well as biochemical effects due to arsenic stress. The information from the present study may provide some clues in understanding arsenic-induced toxicity in *Vigna radiata* as well as *Vigna mungo*. This will be helpful for future breeding programmes for these two species in arsenic affected parts of the world.

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