

ARSENIC TOLERANCE IN RICE: A COMPARATIVE STUDY ON GERMINATION AND EARLY GROWTH STAGE

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Abstract

This study assessed the arsenic tolerance of seven rice cultivars (BRRI Dhan 92, 99, 100, 101, 102, 104, and 105) based on germination performance and early seedling growth. Seeds were exposed to 0, 5, 10, 15, and 20 ppm arsenic for 14 days. Arsenic markedly diminished germination percentage, index and speed of seed emergence, as well as the seedling growth parameters including root and shoot length, and their fresh and dry weight. Among the cultivars, BRRI Dhan 105 showed the highest tolerance across all treatments, with 81.67% germination percentage and 76.42% germination speed at 20 ppm arsenic, while BRRI Dhan 104 recorded the lowest performance with 10.00% GP and 8.48% GS. Growth metrics consistently declined with increasing arsenic concentration. BRRI Dhan 105 showed a relative resilience for the majority of the parameters, resulting into a reduction rate of 48.21 and 69.97% in the length and fresh weight of the shoot. Whereas, the declining rate was highest in BRRI Dhan 104 (70.28 and 74.61%) and comparatively higher in BRRI Dhan 99 (58.37 and 80.92%). Overall, BRRI Dhan 105 was identified as the comparatively more arsenic-tolerant cultivar during germination and seedling stages, while BRRI Dhan 99 and 104 were highly susceptible.

Introduction

Arsenic (As) is recognized as a non-threshold potentially toxic pollutant (Cui *et al.* 2020) which can be encountered in nearly every environmental compartment. According to the analysis of world's statistics by Shaji *et al.* (2021), about 107 nations have groundwater contamination from As, which is above the World Health Organization (WHO) maximum allowable limit of 10 ppb. This issue is particularly evident in certain rivers and deltas across East and South Asia, including Bangladesh as well as in South American nations (Aziz and Ahmed 2010, Kobya *et al.* 2020).

Being an analogue of the phosphate molecule, As competes for binding sites in the solid phase of soil and undergoes similar biogeochemical cycling in aerobic environments (Lambkin and Alloway 2003). The crops and vegetables cultivated in soil and irrigated with As-contaminated water are a great source of As consumption by humans and animals (Arslan *et al.* 2016). Being a water-intensive crop, rice is more susceptible to As accumulation than other crops from soil and water (Richards *et al.* 2020). Following drinking water, this staple crop may serve as a possible source of As exposure for those residing in As-affected regions (Panaullah *et al.* 2009). In Bangladesh, As contaminated water is mostly employed for irrigating rice fields, especially during the boro season, where it contributes an As load of 1.36-5.5 kg/ha/year (Nriagu *et al.* 2007). Phytotoxicity caused by this toxic metalloid is characterized by the disruption of essential physiological and metabolic processes, negatively affecting plant growth and development. Toxicity symptoms may manifest as diminished seed germination, stunted root and shoot growth (Khanam *et al.* 2025). Rice genotypes exhibit variability in their response to As stress (Halim *et al.* 2016), making it crucial to identify the cultivars with enhanced tolerance during germination and early seedling stages. In view of this, the present research aimed to examine the impact of different As toxicity levels on germination and the early seedling phase as well as to assess As tolerance across seven boro rice cultivars.

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Materials and Methods

Seeds from seven boro rice (*Oryza sativa* L.) cultivars (BRRI dhan-92, 99, 100, 101, 102, 104, and 105) were collected from the Bangladesh Rice Research Institute (BRRI). The experiment was conducted in the Plant Physiology and Biochemistry Laboratory, Department of Botany, Jahangirnagar University. A completely randomized design with three replications was employed. Sodium arsenate ($\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$) with five different concentrations (0, 5, 10, 15, and 20 ppm) were administered in order to assess the effects on germination and early seedling growth. Twenty surface sterilized seeds from each treatment were placed on moistened blotting paper in Petri dishes, incubated at room temperature, and observed for germination at 24-hour intervals over 14 days. The germination percentage (GP), germination index (GI), and speed of germination (SG) were determined following the methodologies of Kandil *et al.* (2012), Karim *et al.* (1992) and Mohammad *et al.* (1989), respectively. Shoot and root lengths were assessed on the 14th day. The same day, seedlings were desiccated at 50°C until a consistent weight was attained. The germination and seedling growth attributes of each treatment were compared with those of the control. Data were analyzed using IBM SPSS Statistics version 25. A one-way analysis of variance (ANOVA) was conducted, presenting mean \pm standard deviation (SD), and the least significant difference (LSD) test was utilized at a 5% significance level (Gomez and Gomez 1984).

Results and Discussion

The results of this study revealed a consistent decrease in germination rates with increasing As concentrations across all rice cultivars (Table 1). Among the cultivars, BRRI Dhan 104 exhibited the most significant decline in germination percentage (GP), decreasing to merely 10.00% at 20 ppm As, relative to the control group. The GP decreased by almost half in BRRI Dhan 99, 100, 101, and 102 at the maximum As treatment compared to 0 ppm (Table 1). BRRI Dhan 92 showed a more uniform germination rate at 20 ppm As concentration. However, the highest tolerance to As stress was observed in BRRI Dhan 105, attaining GP of 100, 98.33, 96.67, 93.33, and 81.67% at 0, 5, 10, 15, and 20 ppm As treatments, respectively. Arsenic disrupts the integrity of cell membranes, preventing seeds from absorbing water and essential nutrients necessary for expected germination (Mehta *et al.* 2012). The results underscore the relative resilience of BRRI Dhan 105 to As-induced stress whereas BRRI Dhan 104 demonstrated the lowest GP of 10.00% and the most variability.

Comparable observations were noted in the germination index (GI) as well. Under control conditions, all cultivars exhibited a GI of 100% (Table 1). Nonetheless, as the As levels escalated, a notable reduction in GI was observed throughout the majority of cultivars. BRRI Dhan 104 demonstrated the most significant decline, decreasing from 100 to only 10.34% at 20 ppm As, whereas BRRI Dhan 105 displayed considerable resilience, with a GI fall from 100 to 81.67% at the same treatment (Table 1). These findings align with previous research in rice (Hossain and Uddin 2007) and wheat (Mahdieh *et al.* 2013).

The speed of seed germination was dramatically affected by As levels. The CV% varied from 10.19% in BRRI Dhan 105 to 51.01% in BRRI Dhan 104, indicating differences in the cultivars' responses to arsenic (Table 1). BRRI Dhan 104 demonstrated the greatest sensitivity, with a high reduction rate (91.52%) in germination speed at 20 ppm As, whilst BRRI Dhan 105 displayed the least reduction (23.58%) over the control, signifying a more stable response to the stressor. When compared to the control, the germination speed of BRRI Dhan 99, 100, 101, and 102 was decreased by nearly 50% at 20 ppm.

Table 1. Effects of different concentrations of arsenic on seed germination percentage (GP), germination index (GI) and germination speed (GS) of seven boro rice cultivars.

Cultivars	Parameter	0 ppm	5 ppm	10 ppm	15 ppm	20 ppm	CV%	LSD
BRR1 92	GP	95.00 ± 5.00 a	93.33 ± 7.64 a	83.33 ± 7.63 ab	78.33 ± 11.55 ab	73.33 ± 10.41 b	13.48%	7.96
	GI	100 ± 5.26 a	98.25 ± 8.03 a	87.72 ± 8.03 ab	82.46 ± 12.15 ab	77.19 ± 10.95 b	13.47%	8.38
	GS	5.50 ± 0.52 a	5.27 ± 0.77 ab	4.50 ± 0.34 bc	3.73 ± 0.47 cd	3.32 ± 0.37 d	21.91%	0.47
			(95.82%)	(81.82%)	(67.82%)	(60.36%)		
BRR1 99	GP	98.33 ± 2.88 a	96.67 ± 2.88 a	96.67 ± 2.88 a	91.67 ± 2.88 a	53.33 ± 11.54 b	21.08%	5.25
	GI	100 ± 2.93 a	98.30 ± 2.93 a	98.30 ± 2.93 a	93.22 ± 2.93 a	54.23 ± 11.74 b	21.08%	5.34
	GS	5.73 ± 0.23 a	5.52 ± 0.34 a	5.38 ± 0.47 a	4.55 ± 0.00 b	2.33 ± 0.55 c	28.91%	0.33
			(96.34%)	(93.89%)	(79.41%)	(40.66%)		
BRR1 100	GP	91.67 ± 2.88 a	88.33 ± 5.77 ab	86.67 ± 2.88 ab	83.33 ± 2.88 b	45.00 ± 5.00 c	22.97%	3.71
	GI	100 ± 3.15 a	96.36 ± 6.29 ab	94.54 ± 3.15 ab	90.91 ± 3.15 b	49.09 ± 5.45 c	22.97%	4.05
	GS	4.65 ± 0.17 a	4.57 ± 0.34 a	4.42 ± 0.30 a	3.37 ± 0.12 b	1.42 ± 0.27 c	34.90%	0.23
			(98.28%)	(95.05%)	(72.47%)	(31.07%)		
BRR1 101	GP	98.33 ± 2.89 a	95.00 ± 5.00 a	88.33 ± 2.89 a	88.33 ± 7.63 a	45.00 ± 17.32 b	25.84%	8.14
	GI	100 ± 2.94 a	96.61 ± 5.08 a	89.83 ± 2.94 a	89.83 ± 7.77 a	45.76 ± 17.61 b	25.84%	8.27
	GS	6.10 ± 0.18 a	5.88 ± 0.21 ab	5.05 ± 0.33 bc	4.83 ± 0.63 c	2.28 ± 0.89 d	30.56%	0.48
			(96.39%)	(82.79%)	(79.18%)	(37.38%)		
BRR1 102	GP	98.33 ± 2.89 a	95.00 ± 5.00 a	90.00 ± 5.00 a	68.33 ± 7.64 b	43.33 ± 16.07 c	28.62%	7.88
	GI	100 ± 2.93 a	96.61 ± 5.08 a	91.53 ± 5.08 a	69.49 ± 7.77 b	44.07 ± 16.35 c	28.62%	8.01
	GS	4.63 ± 0.34 a	4.57 ± 0.20 a	4.08 ± 0.32 a	3.27 ± 0.35 b	1.63 ± 0.77 c	33.33%	0.40
			(98.70%)	(88.12%)	(70.63%)	(35.21%)		
BRR1 104	GP	96.67 ± 2.89 a	86.67 ± 7.64 a	85.00 ± 5.00 a	61.67 ± 16.07 b	10.00 ± 10.00 c	48.92%	8.63
	GI	100 ± 2.99 a	89.65 ± 7.90 a	87.93 ± 5.17 a	63.79 ± 16.62 b	10.34 ± 10.34 c	48.92%	8.90
	GS	4.48 ± 0.48 a	4.27 ± 0.34 a	3.95 ± 0.46 a	2.83 ± 0.79 b	0.38 ± 0.38 c	51.01%	0.47
			(95.31%)	(88.17%)	(63.17%)	(8.48%)		
BRR1 105	GP	100 ± 0.00 a	98.33 ± 2.89 a	96.67 ± 2.89 a	93.33 ± 5.77 a	81.67 ± 5.77 b	8.09%	3.71
	GI	100 ± 0.00 a	98.33 ± 2.89 a	96.67 ± 2.89 a	93.33 ± 5.77 a	81.67 ± 5.77 b	8.09%	3.71
	GS	5.98 ± 0.12 a	5.87 ± 0.10 ab	5.82 ± 0.18 ab	5.50 ± 0.23 b	4.57 ± 0.37 c	10.19%	0.20
			(98.16%)	(97.32%)	(91.97%)	(76.42%)		

In a column followed by same letters do not differ significantly at 5% level of significance. Values within parentheses indicate percent change over control.

Shoot length measurements also revealed the adverse impact of elevated arsenic concentrations on seedling growth (Table 2). BRR1 Dhan 92, 99, and 100 exhibited reductions exceeding 50%, although BRR1 Dhan 104 demonstrated the most significant decrease in shoot length, declining from 4.98 cm at control to 1.48 cm at 20 ppm As, exhibiting an almost 70.28% reduction. Under the same conditions, however, BRR1 Dhan 105 had the least reduction (48.21%), dropping the shoot length from 5.58 to 2.89 cm. Ma *et al.* (2001) suggested that As can interfere with auxin biosynthesis, which is crucial for cell division, elongation, and shoot development. These findings corroborate previous research on rice by Halim *et al.* (2014).

Arsenic also impaired root development, constraining plants' ability to absorb vital nutrients. Unlike previous parameters, the most significant reductions in root length occurred in BRR1 Dhan 92 and 102, which fell from 5.72 and 5.67 cm at 0 ppm As to 0.30 and 0.27 cm at 20 ppm As, indicating a decline of 94.8 and 95.24% of the root length, respectively (Table 2). BRR1 Dhan 99, 100, and 104 exhibited comparable decreases in root length with increasing As exposure. However, BRR1 Dhan 101 exhibited greater tolerance, with reductions from 6.28 to 0.51 cm under 20 ppm As with a reduction rate of 91.88% (Table 2). Despite showing relative strength in earlier parameters, BRR1 Dhan 105 had a slight decrease in root length compared to BRR1 Dhan 101

(from 7.86 cm at 0 ppm As to 0.50 cm at 20 ppm As, showing a 93.64% fall). Shamim and Pandey (2017) in black gram, also obtained similar outcomes.

Table 2. Effects of different concentrations of arsenic on shoot and root length of seven boro rice cultivars.

Cultivar	Shoot length (cm)					CV%	LSD
	0 ppm	5 ppm	10 ppm	15 ppm	20 ppm		
BRR1 92	5.39±0.64 a	3.91±0.17 b	3.43±0.22 b	3.31±0.33 b	2.11±0.51 c	31.75	0.37
BRR1 99	4.42±0.31 a	3.33±0.41 b	2.91±0.09 bc	2.64±0.23 c	1.84±0.18 d	29.97	0.24
BRR1 100	4.00±0.42 a	3.51±0.07 b	3.01±0.26 c	2.48±0.28 d	1.70±0.15 e	29.65	0.24
BRR1 101	4.40±0.52 a	3.65±0.11 b	3.29±0.22 b	2.79±0.07 c	2.52±0.17 c	21.69	0.25
BRR1 102	4.37±0.09 a	3.38±0.36 b	3.20±0.43 bc	2.67±0.26 cd	2.50±0.33 e	22.69	0.29
BRR1 104	4.98±0.19 a	4.06±0.18 b	2.97±0.21 c	2.87±0.31 c	1.48±0.58 d	38.42	0.29
BRR1 105	5.58±0.12 a	4.47±0.60 b	3.59±0.14 c	3.21±0.24 cd	2.89±0.16 d	26.29	0.28

Table 2. right side contd.

0 ppm	Root length (cm)					CV%	LSD
	5 ppm	10 ppm	15 ppm	20 ppm			
5.72±0.46 a	3.20±0.33 b	1.92±0.57 c	1.03±0.29 d	0.30±0.13 e	82.15	0.35	
6.63±0.67 a	2.60±0.44 b	2.03±0.49 bc	1.17±0.81 cd	0.47±0.12 d	88.32	0.51	
4.83±0.50 a	2.97±0.74 b	1.57±0.45 c	1.00±0.35 cd	0.47±0.06 d	77.36	0.43	
6.28±0.47 a	3.08±0.13 b	1.06±0.19 c	0.74±0.06 cd	0.51±0.02 d	96.67	0.21	
5.67±0.15 a	4.00±0.62 b	2.77±0.25 c	0.57±0.12 d	0.27±0.06 d	80.49	0.29	
5.70±0.20 a	2.33±0.29 b	0.92±0.02 c	0.67±0.04 c	0.50±0.03 c	99.63	0.14	
7.86±0.40 a	5.92±0.13 b	2.12±0.18 c	0.61±0.10 d	0.50±0.03 d	90.40	0.19	

In a column followed by same letters do not differ significantly at 5% level of significance. Values within parentheses indicate percent change over control.

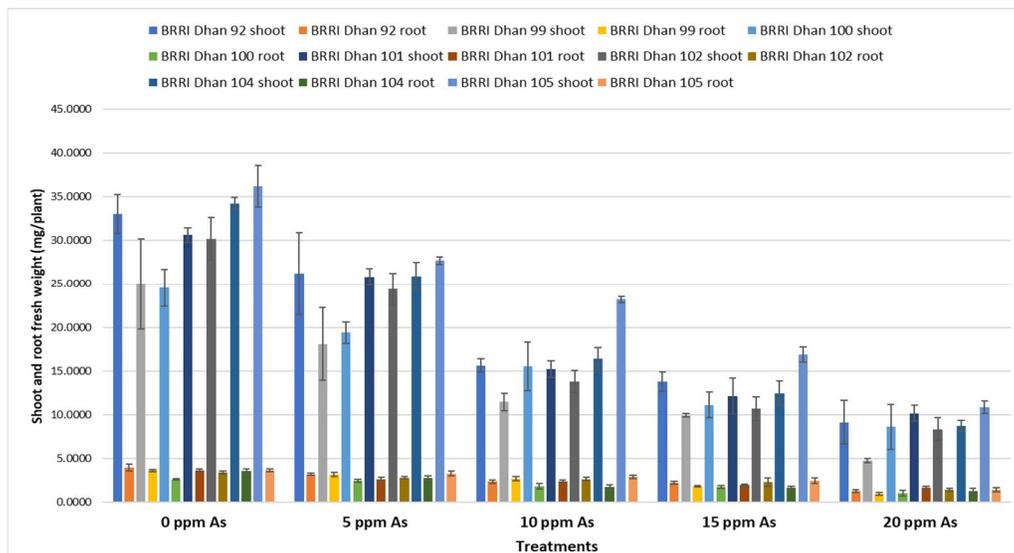


Fig. 1. Changes in the shoot and root fresh weight of seven boro rice cultivars owing to different concentration of arsenic.

Regarding shoot fresh weight, BRRi Dhan 105 had the highest relative values across all As concentrations (36.20, 27.71, 23.23, 16.92, and 10.87 mg at 0, 5, 10, 15, and 20 ppm As, respectively, as displayed in Fig. 1), showing relatively minimum reduction in BRRi Dhan 105 (69.97% at 20 ppm). Whereas with the same treatments, BRRi Dhan 99 exhibited the most pronounced decrease, having 25.00, 18.10, 11.47, 9.90, and 4.77 mg of weight, respectively. This result showed the highest weight fall in BRRi Dhan 99 (80.92% at the maximum As treatment). Other cultivars, including BRRi Dhan 92, 100, 101, 102, and 104, exhibited moderate reductions relative to the control (Fig. 1). The findings suggested that BRRi Dhan 105 has a comparatively superior capacity to sustain biomass under arsenic stress.

The root fresh weight also exhibited comparable patterns, with BRRi Dhan 99 and 100 demonstrating the most significant reductions, declining from 3.60 and 2.60 mg in the control group to 0.93 and 1.03 mg at 20 ppm As (Fig. 1). In alignment with root length results, BRRi Dhan 101 had more tolerance in root fresh weight than BRRi Dhan 105, showing reductions of 54.50 and 61.04%, respectively (Fig. 1).

A substantial drop in dry weight of the shoot and root, with BRRi Dhan 99 demonstrating the most considerable reduction (90.99 and 88.56% decline in shoot and root biomass at 20 ppm As, respectively) (Fig. 2). BRRi Dhan 105 exhibited a relatively higher dry mass of both shoot and root (83.61 and 61.67% drop rate in shoot and root dry weight at 20 ppm As, respectively). The higher root dry weight in BRRi Dhan 105, despite its lower root length and fresh weight, might suggest greater efficiency in transforming water and nutrients into biomass, potentially attributable to denser or more effective root tissue. Other cultivars exhibited moderate reductions in dry weight. These results are in agreement with the findings of the previous studies on maize and barley (Zvobgo *et al.* 2019, Várallyay *et al.* 2021).

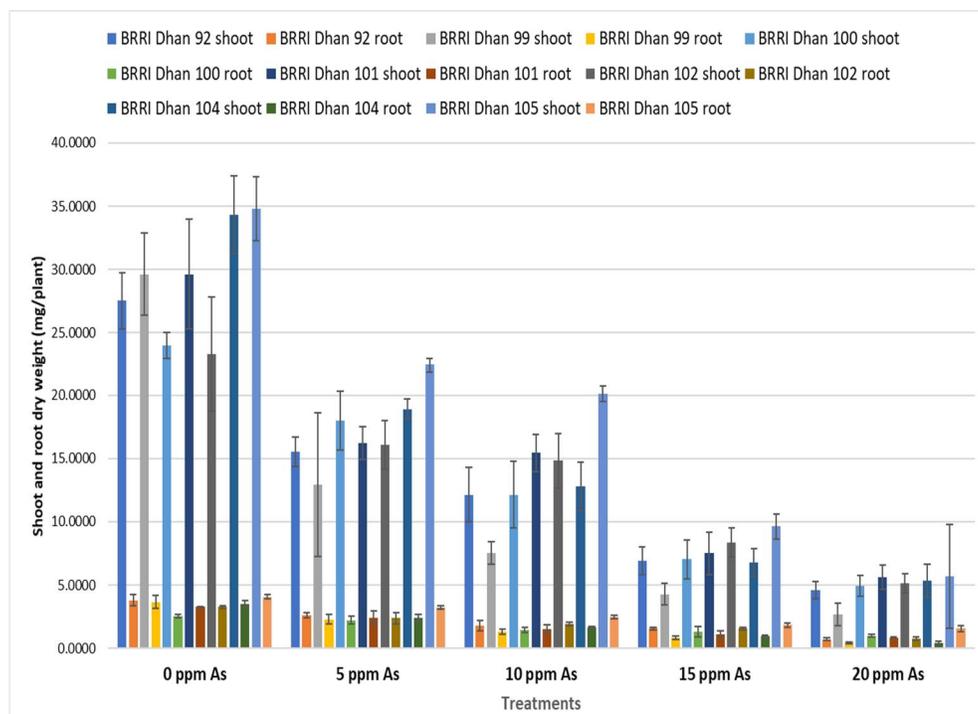


Fig. 2. Changes in the shoot and root dry weight of seven boro rice cultivars owing to different concentration of arsenic.

Based on the present findings, it can be concluded that elevated arsenic adversely affects the germination performance and early growth of rice seedlings. Among the seven boro rice cultivars, BRRI Dhan 105 showed the minimum reduction rate to As toxicity in terms of germination, shoot, and root development. Conversely, BRRI Dhan 99 and 104 were considered to have higher susceptibility across all concentrations. These results suggest that BRRI Dhan 105 could be a promising candidate for field trials, and subsequent research should concentrate on elucidating the molecular mechanisms of As tolerance and exploring breeding strategies to incorporate resistance in more susceptible cultivars.

References

- Arslan B, Djamgoz MBA and Akiun E 2016. Arsenic: a review on exposure pathways, accumulation, mobility and transmission into the human food chain. *Environ. Contam. Toxicol.* **243**: 27-51.
- Aziz A and Ahmed A 2010. Effects of arsenic on biodiversity of rice field weeds. *Dhaka Univ. J. Biol. Sci.* **19(1)** 95-98.
- Cui J, Li Y, Jin Q and Li F. 2020. Silica nanoparticles inhibit arsenic uptake into rice suspension cells: via improving pectin synthesis and the mechanical force of the cell wall. *Environ. Sci. Nano.* **7**:162-171.
- Gomez KA and Gomez AA 1984. *Statistical Procedures for Agricultural Research*. 2nd ed. John Wiley, New York. 680.
- Halim MA, Ghosh M, Nigar M, Hossain F and Akhter N 2016. Screening of arsenic tolerance in rice at germination and early seedling stage as influenced by sodium arsenate. *Jahangirnagar Univ. J. Biol. Sci.* **3**: 17-26.
- Halim MA, Nigar M, Ghosh M, Akhter N and Hossain F 2014. Interaction effects of arsenic and phosphorus on seedling growth, leaf pigments and leaf protein of rice cultivars under hydroponic culture. *J. Asiat. Soc. Bangladesh Sci.* **40**: 141-150.
- Hossain MA and Uddin MN 2007. Toxicity of arsenic on germination and seedling growth of rice. *J. Bangladesh Soc. Agric. Sci. Technol.* **4**: 153-156.
- Kandil AA, Sharief AE and Ahmed SRH 2012. Germination and seedling growth of some chickpea cultivars (*Cicer arietinum* L.) under salinity stress. *J. Basic Appl. Sci.* **8**: 561-571.
- Karim MA, Utsunomiya N and Shigenaga S 1992. Effect of sodium chloride on germination and growth of Hexaploid triticale at early seedling stage. *JPN. J. Crop Sci.* **61**: 279-284.
- Khanam T, Kim K, Karim MA, Afrin S, Lopa FR, Hoque MM, Higuchi H, Walitang DI, Roy SK, Sa T and Akhtar N 2025. Salinity Tolerance of Two Rice Cultivars Is Related to Enhanced Activities of Enzymatic Antioxidants and Higher Proline Content. *Appl. Biol. Chem.* **68**: 58.
- Kobya M, Soltani RDC, Omwene PI and Khataee A 2020. A review on decontamination of arsenic-contained water by electrocoagulation: Reactor configurations and operating cost along with removal mechanisms. *Environ. Technol. Innov.* **17**: 100519.
- Lambkin DC and Alloway BJ 2003. Arsenate-induced phosphate release from soils and its effect on plant phosphorus. *Water Air Soil Poll.* **144**: 41-56.
- Ma LQ, Komatsubara Y, Zhao ZQ, Meng XG, Cai YM, Zhou WP and Wang TG 2001. Changes in root morphology and physiology of wheat under arsenic stress. *Plant Physiol.* **158**: 695-703.
- Mahdieh S, Ghaderian SM and Karimi N 2013. Effects of arsenic on germination, photosynthesis and growth parameters of two winter wheat varieties in Iran. *J. Plant Nutr.* **36**: 651-64.
- Mehta SK, Sharma P, Pandey R and Pandey VC 2012. Arsenic induced membrane damage and physiological and biochemical changes in germinating maize seeds. *Pestic. Biochem. Physiol.* **103**: 242-248.
- Mohammad RM, Campbell WF and Rumbaugh MD 1989. Variation in salt tolerance of alfalfa. *Arid Land Res. Manag.* **3**: 11-20.
- Nriagu J, Bhattacharya P, Mukherjee A, Bundschuh J, Zevenhoven R and Loeppert R 2007. Arsenic in soil and groundwater: An overview. *Trace Metals Environ.* **9**: 3-60.

- Panaullah GM, Alam T, Hossain MB, Loeppert RH, Lauren JG, Meisner CA, Ahmed ZU and Duxbury JM 2009. Arsenic toxicity to rice (*Oryza sativa* L.) in Bangladesh. *Plant Soil*. **317**: 31-39.
- Richards LA, Kumar A, Shankar P, Gaurav A, Ghosh A and Polya DA 2020. Distribution and geochemical controls of arsenic and uranium in groundwater-derived drinking water in Bihar, India. *Int. J. Environ. Res. Public Health*. **17**: 2500.
- Shaji E, Santosh M, Sarath KV, Prakash P, Deepchand V and Divya BV 2021. Arsenic contamination of groundwater: A global synopsis with focus on the Indian Peninsula. *Geosci. Front.* **12**: 101079.
- Shamim MZ and Pandey A 2017. Effects of arsenic toxicity on morphological characters in blackgram (*Vigna mungo* L.) during early growth stage. *Cell. Mol. Biol.* **63**: 38-43.
- Várallyay S, Bódi É, Garousi F, Veres S and Kovács B 2021. Effect of arsenic on dry weight and relative chlorophyll content in greening maize and sunflower tissues. *J. Microbiol. Biotechnol. Food Sci.* **4**: 167-169.
- Zvobgo G, Jonas LWL, Tichaona S, James MM, Noor M, Imran HS and Guo-ping Z 2019. Alleviation of arsenic toxicity by phosphate is associated with its regulation of detoxification, defense, and transport gene expression in barley. *J. Integr. Agric.* **18**: 381-94.

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