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RESEARCH ARTICLE

Exploring arsenic (As) tolerant and exclusion donors for use in rice (*Oryza sativa* L.) breeding

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Abstract

Growing rice under arsenic (As) stress inevitably invites a huge risk of As exposure to humans and livestock in Asian countries. Identification of As-tolerant rice genotype(s) with accumulation of As in straw and grains below the threshold limit can be a way forward to mitigate such a life-threatening problem. The present study systematically evaluated 131 diverse rice genotypes for As tolerance based on germination and seedling growth parameters and selected a few elite As tolerant genotypes at appropriate lethal (LD_{50}). The rice genotypes responded differentially with marked differences in tolerance under As stress. Exposure to As adversely affected germination and seedling growth. Significantly higher estimates of relative seedling vigor index and both stress tolerance indices and relative tolerance indices are coherently associated with tolerant rice genotypes with no symptoms of damage on leaves. A major proportion of As uptake was shown to be retained in roots in tolerant genotypes with a progressive decrease in the order of leaf sheath> leaf blade> husk> kernel under As stress, although the extent of partitioning was genotype-specific, signifying As exclusion in shoot and grains. The first Principal component alone explained 78.16% of the total phenotypic variation. Seedling tolerance indices, vigor indices and germination percentage were shown to be important criteria for As tolerance based on PCA and correlation analysis. PCA biplot revealed highly As tolerant genotypes, e.g., Ashutosh, BRRI Dhan-72, CST Sel. 4, Mahanadi, MI 156, OR(CZ) 78-1, PB-1, Pusa Sugandha 3 and Pusa Sugandha 3-1 with higher positive score value on 1st Principal Component. The As-tolerant genotypes identified in this pursuit would certainly help in planning As tolerance breeding in rice.

Keywords: Arsenic (As) stress, early growth parameters, vigor index, rice.

Introduction

Rice is the major crop in more than 70 countries, and it serves as the staple food of nearly half of the world's population (Hu et al. 2025). The rice straw either being used as fodder or incorporated with soil as manures, and on average, it requires 2,500 liters of water to produce rough rice (Hijam et al. 2025). Nowadays, a large number of shallow and deep tube wells are being used to irrigate millions of hectares of land, and in this context, arsenic (As) toxicity raised serious concern in areas where rice is being grown continuously using As-contaminated groundwater for irrigation (Kumar et al. 2022). As is a non-essential toxic metalloid and it is ubiquitous around the globe (Zaidi et al. 2024). However, the average As concentration is about 5 to 10 mg kg^{-1} and it becomes much higher (even 10-fold) in mining areas, waste sites and specific geological areas of As-rich minerals (Bolan et al. 2022). This problem is more challenging in Southeast Asian countries, including parts of India, Pakistan and Bangladesh (Shaji et al. 2021).

Arsenic binds to soft tissues and prevents the organs from functioning. It can cause serious health problems, including

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cancers, as well as adverse effects on cardiovascular, neurological, hematological, renal, and respiratory systems (Gupta and Chatterjee 2017). Such toxic heavy metal not only causes life-threatening and irreversible damage to humans and other organisms but also significantly reduces crop yield (Haider et al. 2023). Muehe et al. (2019) reported a 40% yield loss of rice in areas with 24.5 ppm As stress. In another study, rice yield declined from 7.5 to 2.5 t ha^{-1} in soil As concentrations ranging from 12 to 60 mg kg^{-1} in conventional paddy fields, which was due to the fact that rice plants have a unique ability to take up arsenic from the soil and water used for irrigation (Bakhat et al. 2017). There are more than 200 numbers of As compounds exit on the Earth (Geng et al. 2023), and the uptake of different As species in rice is in the order of AS^{III}>AS^{V}>DMA^{V}>MMA^{V} (de Oliveira et al. 2018). Inorganic forms (Arsenite: As^{III} and Arsenate: As^{V}) are more harmful than organic ones, and As^{III} species are more toxic to all organisms than As^{V} (Hughes et al. 2011).

Inorganic As enters the root system either as As^{III} or As^{V} species of which the former is more mobile in flooded paddy fields (Emily 2014) and hence, highly available for uptake by rice. The lethal dose (LD_{50}) of As^{III} is reported to be much less (15–42 mg kg^{-1}) compared to As^{V} (20–800 mg kg^{-1}) (Kaise and Fukui 1992). Nearly all plant species, including rice, inherently possess As^{V} reduction ability through arsenate reductases (ARs, e.g., OsHAC1;1, OsHAC1; 2, and OsHAC4) to form As^{III}, and thereby, As^{III} is considered as the dominant species within the plant tissues including rice grains (Abedin and Meharg 2002a; Huang et al. 2012). Indica rice accumulates As up to 2.0 mg kg^{-1} in grain (Meharg 2004) and up to 92 mg kg^{-1} in straw (Biswas et al. 2016), but japonica cultivars are reported to be less accumulator of As (Suriyagoda et al. 2018). Brown rice kernel harbors high As in its outer layers (Meharg et al. 2008), which become minimized upon policing. As per WHO, the permissible limit of As in brown rice grain is 1-mgkg^{-1} (Abedin et al. 2002b) and 0.2 mg kg^{-1} in polished rice (Olson, 2021). Thus, approaches that prevent and control As bioaccumulation in rice plants, especially reducing As accumulation in rice grains, seem to be a logical step for designing a breeding programme for food safety against As (Vasilachi et al. 2023).

While extensive research has been conducted on As uptake, translocation, and toxicity in rice, significant gaps remain in identifying and utilizing genetic resources that exhibit both As tolerance and exclusion mechanisms (Huang et al. 2025). Current studies often focus on either tolerance or accumulation separately, leaving a need for integrated approaches that combine these traits for effective breeding programs (Cao et al. 2025). Additionally, the genetic diversity of As-responsive traits in rice germplasm remains underexplored, limiting the development of low-As-accumulating varieties (Khan et al. 2025). Furthermore, the molecular mechanisms underlying As exclusion and tolerance are not fully understood, hindering the application of advanced breeding techniques such as marker-assisted selection or genetic engineering (Basharat et al. 2025). To address these gaps, the present study aimed to identify the most suitable As-tolerant rice genotypes with the least accumulation of As in grains under lethal concentration (LD_{50}) of As stress.

Materials and methods

Plant materials and experimental design

A set of 131 rice genotypes were tested in complete randomized design (CRD) with three replicates for their tolerance to different levels of arsenous acid-sodium salt (Sodium arsenite, $NaAsO_2$, AS^{III}) under controlled environmental conditions (25 ± 1^{0}C temperature, 68% relative humidity, and 12h/12h dark/light-2000 lux). Seeds of the test genotypes were oven-dried for 72 hours at 50°C to break residual dormancy, if any, and soaked in distilled water for 24 hours in the dark (Jockson 2010). One hundred pre-soaked seeds/replicate (in each treatment) were placed on petri dishes (100 x 15 mm) lined with Whatman No. 1 filter paper and moistened with 8ml aqueous $NaAsO_2$ solutions at varying concentrations (0, 5, 10, 15 and 20 ppm) as such concentrations frequently occur in the topsoil of the rice-growing regions (Hossain et al. 2007). Following As treatment, each genotype was assessed for As-toxicity tolerance limit based on LD_{50} concentration for germination percentage, and accordingly, they were categorized as tolerant (T), highly tolerant (HT), moderately tolerant (MT), moderately susceptible (MS) and susceptible (S) to As toxicity (Hossain et al. 2007).

Exploring elite As-tolerant rice genotypes based on seedling tolerance indices

Besides, the full set of germplasm was subjected to seedling-stage screening (till 18 days) in small plastic cups (150 x 60 mm) at 15 ppm As ($NaAsO_2$, AS^{III}) stress in Yoshida nutrient solution (Wu et al. 2017) to explore elite As-tolerant rice genotypes based on seedling tolerance indices (basing on shoot and root length), relative seedling vigor index (RSVI), and percentage leaf area damage (LAD score, 0: no damage, 1–3: up to 30%, 4–6: 40–60%, 7–9:70–90% damage or above). The experiment was carried out in a glasshouse to eliminate the interaction of other environmental factors. The pH was adjusted to 5.4 every alternate day and nutrient solution with 15 ppm As was renewed every three days. The treatment without As in the nutrient solution served as a control. Seedling vigor indices (SVI_S and SVI_c) were calculated as Germination (%) x Mean seedling length (cm) under stress and control, respectively. Relative seedling vigor index (RSVI) was calculated as SVI_S/SVI_c. Moreover, the Seedling Tolerance Index (STI) was also calculated as mean root or shoot length under As-stress/ mean root or shoot length in control) as described by Abedin and Meharg (2002a). Further, two tolerant and two susceptible test genotypes were subjected to As- stress ($NaAsO_2$, AS^{III} at 15 ppm) in plastic pots (Size 30 x 30 x 25 cm) alongside their control till maturity. Pots are filled with soil (As content 5.2 ppm) and the required amount of arsenic was added to simulate As-stress (15 ppm) under field conditions. Optimum fertilizer application and plant protection measures were carried out to ensure good plant growth. The As content in different parts of the rice plant (root, leaf sheath, leaf blade and seed) was estimated to elucidate the comparative As uptake status in the test genotypes. The plant samples were oven-dried at 50^0C for 72 hours and the fine ground samples (0.5 g each) in three replicates were digested with a di-acid mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) as per the standard procedure (Jahan et al. 2013) with minor modification. Plant samples were digested with high-purity di-acid mixture in a microwave oven. A few drops of 10% KI and 5% Ascorbic acid (pre-reducing reagents) were added to the sample in an acidic medium (HCl) and kept for 30 minutes in the dark, followed by final reduction with sodium borohydride ($NaBH_4$) to convert AS^V if any to As^{III}. Finally, the samples were analyzed for As accumulation using inductively coupled plasma-optical emission spectrometry (ICP-OES) at 193.7 nm wavelength (Sun et al. 2021).

Statistical analysis

Correlation analysis was employed to explore relationships between or agronomic traits, such as yield, root morphology, and biomass (Murugaiyan et al. 2021). This was critical for understanding how arsenic tolerance interacts with key plant characteristics, providing insights into potential trade-offs or synergies that could inform breeding strategies (Niazi et al. 2022). Principal component analysis (PCA) was chosen to reduce the dimensionality of the dataset and identify patterns of variation among rice genotypes in response to As stress (Rai et al. 2015). By visualizing the relationships between genotypes and their As tolerance and accumulation profiles, PCA allowed to prioritize donors with desirable traits for further breeding (Saeed et al. 2024). Both methods were integral to achieving the objective of identifying As-tolerant and low-accumulating rice donors.

Results and discussion

Effect of As on germination

As is known to inhibit the overall germination ability of rice plants by acting as a metabolic inhibitor (Murugaiyan et al. 2019), hence extent of germination may be considered one of the best indicators for the establishment of a plant under As stress (Abedin and Meharg 2002a; Abedin et al. 2002b). The mean germination ability over the control significantly declined with increasing As concentration ($p < 0.01$) (Supplementary Table S1) in the order of 0 ppm As (99.5%) <5 ppm As (77.3%) < 10 ppm As (57.7%) < 15 ppm As (37.1%) < 20 ppm As (26.0%), which is consistent with the results of previous studies (Murugaiyan et al. 2021). This study reported a reduction of germination to about one-fourth (26%) at 20 ppm As (Supplementary Table S1), thus confirming its toxic effect during germination metabolism. However, still higher concentration was also reported for an appreciable reduction in germination percentage, root length and shoot length of rice varieties (Ahmed 2014). However, Halim et al. (2014) screened seven cultivars of rice against varying As-stress (1–12 ppm) and they showed a significant gradual decrease in germination percentage with the increase of arsenic levels and BRRI-29 showed a maximum percentage of germination.

In the present investigation, the response of genotypes to varying As stress treatments is shown to be genotype-dependent as evidenced by significant G (genotype) x T (Treatment) interaction (Supple. Table 2). Germination was unaffected till 5 ppm in BRRI Dhan 72, CST Sel. 4, Ganjamgedi, Harishankar, IR 97443-11-2-1-1-1-3B, IR 82475-110-2-2-1-2, Kanchan, Labangalata, OR(CZ) 78–1, PB 1, Poornabhog and PusaSug. 3-1 (Supplementary Table S2), although As is reported to have no effect on germination till 8 ppm in a rice variety cv. 'Purbachi'(Abedin and Meharg 2002a). In contrast, germinability was drastically reduced to 38 to 40% at even 5 ppm As in Karpurakranti -1, Karpurakranti -2, IR 96248-16-3-3-2-B, Lalachounyl and OR(CZ)-63 indicating acute sensitivity to As stress.However, BRRI Dhan 72, CST sel. 4, OR (CZ) 78-1, PB 1 and PusaSug. 3-1alongwith Ashutosh, Mahanadi, MI 156 and Pusa Sugandha 3 able to surpass 50% germinability at even 15 ppm (LD 50 >15 ppm) with maximum (60–65%) in BRRI Dhan 72, CST Sel. 4, OR(CZ) 78-1and Pusa Sug.3-1. However, germination % dropped sufficiently below 50% in such highly tolerant varieties at 20 ppm As stress. Thus, the response for germination in the present experiment shows that the 15 ppm As concentration is close to LD_{50} in the tolerant genotypes (Supplementary Table S2) and, hence, sufficient to discriminate rice genotypes for arsenic phytotoxicity tolerance at the early growth stage. Moreover, Murugaiyan et al. (2021) found that the treatment with 10 ppm had 50% lethal effects on the germination of seeds in most of the 58 rice genotypes. For instance, BR11 showed 48% germination in the 10 ppm As treatment but failed to germinate in the 15 ppm As treatment.

Effect of As on seedling growth

Seedling growth assessed in terms of shoot length and root length varied widely in control (0 ppm As), suggesting instant inherent genetic variation for initial growth and vigor among the genotypes (Supplementary Table S2). The current research imposed As stress at erstwhile mentioned LD_{50} (15 ppm) and the initial growth declined under As stress over the control irrespective of the test genotypes due to oxidative damage by the As-induced reactive oxygen species (ROS) (Liang 2018), although differential genotype-specific response exists. While a low As concentration of 0.75 to 1.25 mg l^{-1} was reported for screening of rice genotypes of Bangladesh (Syed et al. 2019). The rice variety BRRI Dhan 47 showed more tolerance to Arsenic contaminated water in terms of root length, shoot length and the root-shoot ratio at 1 to 1.25 mg/l concentration of arsenic (Sodium arsenate:NaH_2AsO_4) (Syed et al. 2019). Further, the differential response in the present context may be attributed to different defense mechanisms operating within the rice genotypes (Geng et al. 2023). Moreover, Kalita and Tanti (2020) showed varying degrees of susceptibility in terms of different morphological and physiological parameters among seedlings of 23 different traditional rice cultivars subjected to 0.5 mg l^{-1} and 0.8 mg l^{-1} arsenic stress under hydroponic conditions. They identified 'Monasali' as the best overall tolerance at the high arsenic concentration, whereas 'BiyoiSali,' 'Baismuthi,' and 'Bora' were most susceptible.

Earlier, Marin et al. (1992) found a significant reduction in rice shoot length when arsenite or monomethyl arsenic acid was applied at a dose of 0.8 mg/l. 'As' seems to have more harsh effects on roots than shoot growth (Abedin et al. 2002b), as plant roots were the first tissue of contact with arsenic. However, Biswaset al. (2016) reported a significant decrease in root and shoot length, germination percentage, dry biomass, protein content, chlorophyll, ascorbic acid content, and peroxidase activity with increasing exposure to arsenic in two rice varieties, Nayanmani and Satabdi.

Although As stress is initially perceived in terms of decline in germination percentage, shoot length, root length and scorching on leaves, estimates of relative seedling vigor index (RSVI) and tolerance indices (STI and RTI) seem to be physiologically important seedling parameters for critical assessment of As tolerance. Significantly higher estimates of RSVI and both STI and RTI coherently associated with the tolerant rice genotypes namely, genotypes e.g., Ashutosh (1), BRRI Dhan-72(9), CST Sel. 4(17), Mahanadi (71), MI 156(74), OR(CZ) 78-1(91), PB-1(98), Pusa Sugandha-3(99) and PusaSugandha 3-1(102) (Figure 1, Suppl. Table 1). Such highly As tolerant genotypes also showed almost no symptoms of damage on leaves (LAD score 1 on a 0-9 scale). Similar toxic symptoms, such as stunted growth, decreased biomass and impairment of the photosynthetic process, have been reported widely in rice (Murugaiyan et al. 2019). As affects the transportation of water and mineral elements in vascular tissues (Biswas 2022) and arrests biomass accumulation (Anjum et al. 2011) by disrupting photosynthetic apparatus, leading to a drop in productivity (Khan et al. 2022). At even 4 mg l^{-1} sodium arsenite concentration of cv. Nayanmani, the total chlorophyll content decreased by 42.36%, but the effect of As toxicity is not apparent in the tolerant cultivar 'Satabdi' (Biswas and Patra 2016). Additionally, As checks CO_2 entry by reduced stomatal conductance (Majumdar et al. 2020), which is also associated with a reduction in the ability of gaseous exchange through transpiration (Anjum et al. 2016). Intensive As-induced oxidative stress may also lead to severe membrane leakage, increased malondialdehyde production and inactivation of functional enzymes (Hu et al. 2020), DNA damage and genomic instability (Majumderet al. 2019), which alters its coding properties and ultimately affects cellular functionality (Polyn et al. 2015).

Association among germination and seedling traits under As stress

In the present study, germination percentage, shoot length, root length and leaf area damage (LAD) are primarily measured traits, while seedling vigor indices and tolerance indices are derived traits. Germination percentage (C1) is the initial genotypic response to As stress and it was shown to be strongly associated with relative seedling vigor index (C5) followed by seedling vigor index (C4), and both shoot and root stress tolerance index (C6 and C7) (Table 2). LAD score (C8) correlated negatively with all seedling traits and specifically strongly with germination percentage (C1), relative seedling vigor index (C5) and stress tolerance indices (STI_S-C6 and STI_R-C7). Such an inverse relationship may be attributed to the fact that As tolerance based on LAD (C8) was implicated by a low score value on 0-9 scale (0-resistant, 9-sensitive) in contrast to the rest of the traits. Relative seedling vigor index (RSVI-C5) revealed a maximum significant positive association with germination percentage

Table 1. Accumulation of arsenic (ppm) in different plant parts at 15ppm As- stress

Genotype	Root		Leaf sheath		Leaf blade		Husk		Kernel	
	Control	Stress	Control	Stress	Control	Stress	Control	Stress	Control	Stress
Tolerant genotypes										
CST Sel. 4	10.56	133.02	3.05	9.20	2.64	6.89	0.16	0.20	0.08	0.10
PS 3 Sel. 1	11.60	153.12	3.20	12.02	2.80	8.34	0.18	0.23	0.10	0.12
As-sensitive genotypes LowAS Content high										
OR(CZ) 61	14.45	90.20	4.04	28.32	3.02	24.20	0.16	0.78	0.11	0.43
Gelei	12.21	83.52	5.10	32.60	3.84	26.72	0.20	0.69	0.13	0.40
$CD_{0.05}$	0.50	23.40	0.24	6.05	0.05	4.30	0.01	0.13	0.005	0.03

Table 2. Correlation among seedling traits under 15ppm As stress

Variables	Germination %	Shoot length	Root length	Seedling vigor index	Relative seedling Vigor index	Stress tolerance indices	
	(C1)	(C2)	(C3)	(C4)	(C5)	STI_S(C6)	STI_R(C7)
C2	0.26						
C3	0.41	0.94					
C4	0.81	0.74	0.83				
C5	0.97	0.4	0.55	0.89			
C6	0.86	0.54	0.65	0.86	0.93		
C7	0.83	0.59	0.72	0.88	0.92	0.98	
C8	-0.9	-0.24	-0.4	-0.72	-0.91	-0.92	-0.9

*, **-Significant at $P_{0.05}$ and $P_{0.01}$, STI_S and STI_R- Stress tolerance index based on shoot and root growth respectively, C8-Leaf area damage (LAD) score, Colour range:

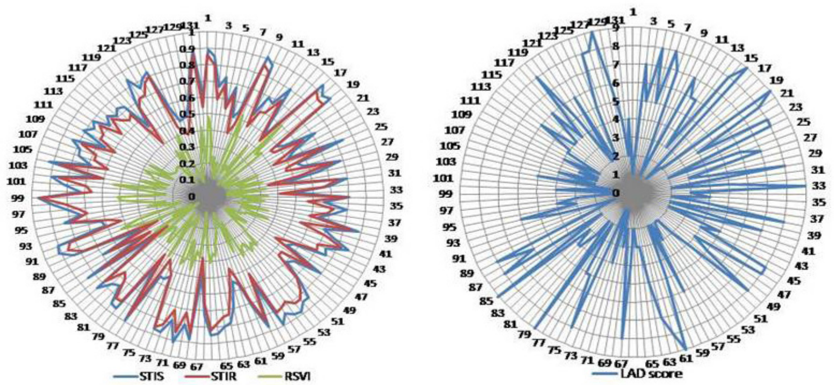

Fig. 1. Visualization of comparative data points for STIs, STIR, RSVI and LAD score of rice germplasm (Sl. 1-131)

(C1) followed by seedling vigor index (C4) and Seedling tolerance indices(C6 and C7). All the derived traits, e.g., C4, C5, C6 and C7 had strong inter se relationships. Among these, relative seedling vigor index (C5) being derived from a combination of raw data sets of seedling growth (both shoot and root length) and germination percentage, it may be considered as the most important criterion for screening As tolerant genotypes (Majumdar et al. 2020).

Screening of rice genotypes for As-tolerance using principal component analysis (PCA)

In the present study, the Seedling vigor index (SVI-C4) revealed the highest sample variance, kurtosis and skewness. Hence, such a parameter has greater implications in screening genotypes for arsenic tolerance (Supplementary Table S3). Besides, an attempt was undertaken to select As-tolerant genotypes using PCA based on seedling traits recorded at the erstwhile mentioned LD_{50} dose (15 ppm As). In the current study, 1st Principal component alone explained 78.16% of the total phenotypic variation (Figure 2), followed by PCA 2 (17.89%). Further, PCA and correlation analysis (Fig. 2, Table 3) indicated that seedling tolerance indices (STI_S-C6 and STI_R-C7), SVI(C4), RSVI(C5) and germination percentage(C1) seem to be important criteria for As- tolerance. This is evidenced by the fact that these were far away from the origin with higher positive loading on the 1st principal component and these (except SVI-C4) clustered together in the lower right quadrant, suggesting that they are significantly connected, even more so than other seedling parameters related to root and shoot growth. It is surprising to note that all highly As tolerant genotypes e.g., Ashutosh (1), BRRI Dhan-72 (9), Mahanadi (71), MI 156 (74), OR(CZ) 78-1(91), PB-1(98), Pusa Sugandha 3(99) and Pusa Sugandha 3-1(102) with higher positive score value on 1st PCA are positioned in the lower right quadrant of PCA biplot except the genotype CST Sel. 4(17). Conversely, the leaf area damage (LAD) score is shown to be far away from the origin with large negative loading on the 1st principal component and therefore, the genotypes that appear in the upper and lower-left quadrant of the PCA biplot may be considered more sensitive to As stress (Fig. 2).

Notable among those sensitive genotypes are BasnabParijat

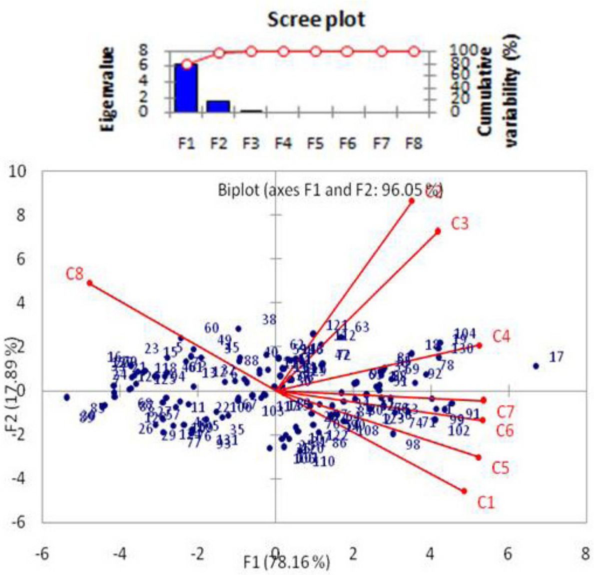

Fig. 2. Sree Plot and biplot graph using Principal component analysis for seedling traits of a set of 131 rice germplasm accessions under 15ppm As-stress. Genotypes Sl. No. (1-131) as described in Supplementary Table S1 and Seedling traits (C1-C8) as described in Table 2

(5), Basuabhog (7), CR SugandhaDhan 907 (15), CRM-839 sel.-1 (16), Dhoiabankoi (20), Dimapur local (21), Dudhamani (23), Dulhabhog (24), Gelei (30), Heerakhandi (33), IR I5M-1546 (38), IR 95044:8-B-5-22-19-GBS (45), IR 95133 -1-B-16-14-10-GBS-P6-1-5(46), IR 96248-16-3-3-2-B (49), Karpurakranti-1 (60), Karpurakranti-2 (61), Lalachounyl(68), Mitimiti (75), Nuachinikamini (79), OR(CZ)-61(85), OR(CZ)-63(87), OR(CZ)-65(89), Sheetalkani (118), Thakurabhoga (125), Thakurasuna (126) and TulasiKanthi (127) with LAD score 8–9 (in 0–9 scale). Previously, principal component analysis has been used effectively in rice to categorize genotypes into different drought, salinity, and disease tolerance groups (Kakar et al. 2019).

As uptake and accumulation in rice plants

As contamination in rice cultivation poses a global challenge, as As bioaccumulation in rice grains is primarily influenced by As bioavailability in the anaerobic rhizosphere where toxic As^{III} dominates as a complex polygenic trait (Hughes et al. 2011). Therefore, the present experiment was set up to verify the transport and accumulation of As to grain in tolerant and sensitive genotypes under arsenite (As^{III}) stress. Several genes are involved in As uptake, translocation, sequestration and loading to grains. Their coordinated interactions play a key role in the regulation of metal homeostasis in rice. As^{III} is absorbed by the root through nodulin 26-like intrinsic protein (OsNIP) by the silicon transport pathway and plasma membrane intrinsic protein aquaporins at the rhizosphere (Mitra et al. 2017). The Silicon transporters Lsi1 and Lsi 2 are the other mediators of arsenite uptake (Sahoo and Kim 2013). Accumulation of As decreased from root to foliage and even husk to the kernel in both tolerant and sensitive genotypes (Table 1), although differential partitioning of As during the entire life cycle is shown to be genotype-specific under As stress.

According to Murugaiyan et al. (2021), shoot As content ranged from 16.08 mg kg^{-1} (Binam) to 27.85 mg kg^{-1} (Xing-Ying-Zhan) and root As content ranged from 119.86 mg kg^{-1} (Huang-HuaZhan) to 146.54 mg kg^{-1} (BR11) at 15 ppm As treatment. In fact, a large proportion of As uptake was retained in the root region (133.02–153.12 mg l^{-1}) compared to foliar and reproductive parts in tolerant genotypes (CST Sel. 4 and PS 3 Sel. 1) than sensitive genotypes (83.52-90.2 mg l^{-1}) (Table 1) indicating inherent efficient physiological As exclusion mechanism to shoot (Suriyagoda et al. 2018) to safeguard above ground parts against As stress (Lu et al. 2010). Thus, the exclusion of As to shoot is likely to be related to As tolerance. In contrast, despite As inclusion in the shoot, IR64 is reported to be As tolerant owing to the lowest As content in the unpolished grain (<0.20 mgkg-1) among all test genotypes, indicating the possibility of further partitioning of As to grain (Dasgupta et al. 2004).

In general, As accumulation in shoot is mainly through xylem loading, while 90% of As^{III} is uploaded to the grain via phloem transport (Carey et al. 2010). In the present study, bioaccumulation of As was shown to be appreciably high in root than foliar and reproductive parts in As tolerant genotypes (CST Sel. 4 and PS 3 Sel. 1). Whereas the reverse is the trend in sensitive genotypes (OR(CZ) 61 and Gelei). As accumulation was shown to be more than double in leaf sheath, triple in leaf blade and husk, and about four-fold in a kernel of sensitive genotypes as compared to tolerant ones. Partitioning of As further revealed a progressive decrease of As content in the order : leaf sheath >leaf blade >husk >kernel under As stress. This corroborates the findings of Liu et al. (2004) in rice cv. "Ratna" and, as such, explains the status of As towards toxicity symptoms in sensitive genotypes. Arsenic concentration in the root and shoot of tolerant cultivar 'JX-17' is reported to be about 50% of the As-sensitive variety 'ZYQ8' (Zhang and Duan 2008). With regard to As accumulation in grains, there may be 4-5 fold variations among diverse germplasms under As stress (Norton et al. 2019). Activation of the serine acetyltransferase gene is reported to indirectly decrease the translocation of As from shoot to grains (Sun et al. 2021) in tolerant genotypes.

Further, the rice ecosystem is by and large anaerobic, favoring more availability of As^{III} (highly toxic) than As^{V}(less toxic) in the rhizosphere (Arao et al. 2009), but in the current study, As uptake to root and transport to above-ground parts was shown to be appreciably restricted in tolerant genotypes possibly due to intrinsic regulatory mechanisms under complex genetic control. Rai et al. (2011) identified a few genes e.g., Phytochelatin synthase, GST and γ-ECS upregulated with considerable variation in all tolerant genotypes except the susceptible cultivar IET-4786 where those are down-regulated in higher As^{III} stress. Another comparative transcriptional profiling study suggests up-and down-regulation of a number of unique genes involved in various pathways and biological processes in response to As stress in six rice genotypes (Raiet al. 2015). Usually, $AS^{III,}$ after entry to root cells, gets chelated by glutathione sulfhydryl (GSH) and phytochelatins (PCs), and sequestrated to vacuoles via OsABCC1 gene (Genget al. 2023), resulting in tolerance to As stress (Batista et al. 2014). Besides, screening of 108 RILs of a cross Bala x Azucena revealed the presence of a major gene AsTol (for As-tolerance) flanked between RZ 516 and RG213 on Chromosome 6 (Dasgupta et al. 2004). Besides, two QTLs for As content in roots were mapped on chromosome 8, and six QTLs for As content in shoots were mapped on chromosomes 2, 5, 6, and 9 (Murugaiyan et al. 2019).

Genotypic differences in grain As accumulation by rice genotypes have been reported by several field studies (Fernández-Baca et al. 2021). Also, it has been reported that *indica* rice cultivars tend to accumulate higher amounts of inorganic As in grain and shoot than japonica cultivars (Suriyagoda et al. 2018). Total As concentration in the unpolished grain from the 53 genotypes (brown rice) ranged from 0.12 to 0.48 mg kg^{-1} with an average value of 0.31 mg kg^{-1} (Murugaiyan et al. 2021). The maximum level of inorganic As allowed in brown rice is 0.20 mg kg^{-1} as per United Nations food safety standards (Islam et al. 2017). The tolerant genotypes, CST Sel. 4 and PS 3 Sel. 1, retained the permissible limit of As (0.10–0.12 mg kg^{-1}) in the kernel as compared to OR (CZ) 61 and Gelei (0.40–43 mg kg^{-1}), which tested acute sensitive to As stress using germination and seedling growth traits. A similar finding was also found in two sensitive varieties of Bangladesh (BR11 and BR28) with >0.40 mg kg^{-1} grain As content (Ahmed 2014).

Supplementary materials

Supplementary Tables S1 to S3 are provided, which can be accessed at www.isgpb.org

Authors' contribution

Conceptualization of research (SKT); Designing of the experiments (SKT and JK); Contribution of experimental materials (JK and SKT); Execution of field/lab experiments and data collection (DS); Analysis of data and interpretation (SKT and JPS); Preparation of the manuscript (SKT and JPS).

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Supplementary Table S1. Screening rice germplasmfor arsenic tolerance based on seedling parameters

S. No.	Genotypes	LD_{50} based on gernimation %		Stress tole-rance index		Relative vigor index (RSVI)	LAD Score
		Conc.	Remark	STI_S	STI_R		
1	Ashutosh	>15ppm	T	0.89	0.86	0.48	1
2	Badshabhog	≤15ppm	HT	0.85	0.8	0.41	2
3	Basmati 564	≤10ppm	MS	0.67	0.59	0.19	7
4	Basmatibhog	>10ppm	MT	0.73	0.69	0.24	5
5	BasnaParijat	≤5ppm	S	0.56	0.54	0.14	8
6	Basnasapuri	>10ppm	MT	0.68	0.64	0.21	5
7	Basuabhog	≤5ppm	S	0.50	0.4	0.11	8
8	Bishnupriya	≤10ppm	MS	0.54	0.46	0.16	7
9	BRRI Dhan-72	>15ppm	T	0.91	0.86	0.53	1
10	CGZR -1	≤15ppm	HT	0.87	0.83	0.37	2
11	CGZR 2	≤10ppm	MS	0.55	0.48	0.16	7
12	Chandrahasini	≤10ppm	MS	0.69	0.59	0.21	6
13	Chinikamini	≤10ppm	MS	0.67	0.6	0.19	6
14	CR Dhan 311	≤15ppm	HT	0.80	0.72	0.38	3
15	CR SugandhaDhan 907	≤5ppm	S	0.56	0.54	0.14	8
16	CRM 839 sel.-1	≤5ppm	S	0.48	0.45	0.09	9
17	CST Sel. 4	>15ppm	T	0.94	0.89	0.60	1
18	Dhalamadhoi	≤15ppm	HT	0.89	0.86	0.37	2
19	Dhinkisiali	≤15ppm	HT	0.91	0.86	0.40	2
20	Dhoiabankoi	≤5ppm	S	0.49	0.45	0.11	9
21	Dimapur local	≤5ppm	S	0.53	0.46	0.12	8
22	DRR Dhan 48	>10ppm	MT	0.72	0.64	0.20	4
23	Dudhamani	≤5ppm	S	0.56	0.51	0.11	8
24	Dulhabhog	≤5ppm	S	0.51	0.42	0.11	8
25	FR 43B	≤15ppm	HT	0.84	0.72	0.31	2
26	Gangabali	≤10ppm	MS	0.54	0.48	0.17	6
27	Ganjam local -2	≤10ppm	MS	0.57	0.47	0.18	7
28	Ganjamgedi	≤15ppm	HT	0.78	0.74	0.32	3
29	Geetanjali	>10ppm	MT	0.64	0.53	0.18	4
30	Gelei	≤5ppm	S	0.43	0.35	0.11	8
31	Harisankar	≤15ppm	HT	0.79	0.75	0.33	2
32	Heerakani	>10ppm	MT	0.69	0.66	0.20	5
33	Heerakhandi	≤5ppm	S	0.49	0.41	0.11	9
34	Hundar	≤15ppm	HT	0.80	0.79	0.34	3
35	IET 16383	>10ppm	MT	0.66	0.57	0.20	4
36	IET 24780	≤15ppm	HT	0.79	0.72	0.32	2
37	IR 15 M 1537	>10ppm	MT	0.72	0.69	0.25	4
38	IR I5 M 1546	≤5ppm	S	0.64	0.59	0.16	8

39	IR 15 M 1633	≤15ppm	HT	0.88	0.84	0.35	2
40	IR 15 M 1689	≤10ppm	MS	0.69	0.55	0.20	7
41	IR 64	>10ppm	MT	0.76	0.71	0.22	4
42	IR 84847-RIL 195-1-1-1-1	≤15ppm	HT	0.86	0.82	0.37	2
43	IR 91143-AC-239-1	>10ppm	MT	0.74	0.69	0.25	5
44	IR 91143-AC-290-1	>10ppm	MT	0.76	0.70	0.22	4
45	IR 95044:8-B-5-22-19-GBS	≤5ppm	S	0.57	0.53	0.15	8
46	IR 95133 -1-B-16-14-10-GBS-P6-1-5	≤5ppm	S	0.54	0.46	0.13	8
47	IR 95133:1-B-16-14-10-GBS-P5-1-3	>10ppm	MT	0.79	0.73	0.27	4
48	IR 95133:1-B-16-14-10-GBS-P1-2-2	>10ppm	MT	0.63	0.54	0.22	5
49	IR 96248-16-3-3-2-B	≤5ppm	S	0.60	0.54	0.13	8
50	IR 97443-11-2-1-1-1-1B	>10ppm	MT	0.73	0.71	0.26	4
51	IR 97443-11-2-1-1-1-3B	≤15ppm	HT	0.84	0.78	0.41	3
52	IR 99704-24-2-1	≤15ppm	HT	0.84	0.82	0.37	2
53	IR82475-110-2-2-1-2	≤15ppm	HT	0.88	0.82	0.42	2
54	Jagabandhu	≤15ppm	HT	0.87	0.78	0.35	2
55	Kadalipenda	≤15ppm	HT	0.84	0.80	0.37	3
56	Kalamulia	≤15ppm	HT	0.89	0.81	0.42	2
57	Kalikati-1	≤10ppm	MS	0.60	0.53	0.18	6
58	Kanchan	≤15ppm	HT	0.87	0.83	0.37	2
59	Karhani	>10ppm	MT	0.72	0.69	0.22	5
60	Karpurakranti -1	≤5ppm	S	0.57	0.52	0.11	9
61	Karpurakranti -2	≤5ppm	S	0.54	0.46	0.14	8
62	Kasturi	≤10ppm	MS	0.69	0.59	0.23	7
63	Ketakijoha	>10ppm	MT	0.78	0.73	0.27	5
64	Khadiratnachudi	≤15ppm	HT	0.80	0.74	0.37	3
65	Khajurikandi	≤15ppm	HT	0.84	0.78	0.35	3
66	Labangalata	≤15ppm	HT	0.85	0.82	0.41	2
67	Lajakulibadan	>10ppm	MT	0.73	0.66	0.24	4
68	Lalachounyl	≤5ppm	S	0.48	0.38	0.10	8
69	M -48	≤15ppm	HT	0.88	0.84	0.38	2
70	Mahalaxmi	≤15ppm	HT	0.79	0.72	0.34	3
71	Mahanadi	>15ppm	T	0.91	0.85	0.46	1
72	Malliphulajhuli	>10ppm	MT	0.78	0.72	0.28	4
73	MI 127	≤15ppm	HT	0.87	0.82	0.40	2
74	MI 156	>15ppm	T	0.86	0.85	0.44	1
75	Mitimiti	≤5ppm	S	0.53	0.52	0.13	8
76	Mrunalini	>10ppm	MT	0.56	0.48	0.19	5
77	Neelabati	>10ppm	MT	0.56	0.44	0.18	5

78	Nikipankhia	≤15ppm	HT	0.89	0.85	0.43	2
79	Nuachinikamini	≤5ppm	S	0.51	0.43	0.12	9
80	OR 1898-2-35-1	≤15ppm	HT	0.86	0.81	0.36	2
81	OR-2327-23	≤15ppm	HT	0.85	0.81	0.36	3
82	OR(CZ) 48 sel.-1	>10ppm	MT	0.74	0.69	0.26	4
83	OR(CZ) 48-Sel. 2	>10ppm	MT	0.76	0.66	0.27	4
84	OR(CZ)- 58	≤15ppm	HT	0.84	0.78	0.37	3
85	OR(CZ)-61	≤5ppm	S	0.39	0.29	0.07	9
86	OR(CZ)-62	≤15ppm	HT	0.84	0.75	0.37	2
87	OR(CZ)-63	≤5ppm	S	0.45	0.39	0.11	8
88	OR(CZ)- 64	≤10ppm	MS	0.69	0.65	0.23	6
89	OR(CZ)-65	≤5ppm	S	0.44	0.32	0.11	8
90	OR(CZ)-66	≤15ppm	HT	0.84	0.78	0.36	2
91	OR(CZ) 78-1	>15ppm	T	0.91	0.86	0.53	1
92	OR(CZ) 80-1	≤15ppm	HT	0.9	0.83	0.43	2
93	OR(T)- 10	>10ppm	MT	0.61	0.51	0.21	4
94	OR(T) 10-1	≤5ppm	MS	0.62	0.58	0.16	6
95	OR(T) 10-2	≤15ppm	HT	0.83	0.79	0.35	3
96	OR(T) 30	>10ppm	MT	0.73	0.69	0.24	4
97	Palaka	≤15ppm	HT	0.80	0.74	0.33	3
98	PB-1	>15ppm	T	0.88	0.82	0.49	1
99	Pusa Sug. 3	>15ppm	T	0.96	0.95	0.51	1
100	Pimpudibasa -1	>10ppm	MT	0.72	0.66	0.24	4
101	Poornabhog	≤15ppm	HT	0.82	0.69	0.34	2
102	Pusa Sug. 3-1	>15ppm	T	0.89	0.85	0.54	1
103	Ramachandi	>10ppm	MT	0.65	0.60	0.24	5
104	Rasapanjari	≤15ppm	HT	0.92	0.86	0.39	2
105	R-RHP-MI 30	>10ppm	MT	0.69	0.59	0.23	4
106	R-RHZ -IB-80	≤15ppm	HT	0.77	0.68	0.32	2
107	R-RHZ –LI- 23	≤15ppm	HT	0.78	0.68	0.34	3
108	R-RHZ -MI -93	≤15ppm	HT	0.84	0.78	0.39	2
109	R-RHZ-SD 94	>10ppm	MT	0.65	0.59	0.22	4
110	R-RHZ-SM 14	≤15ppm	HT	0.81	0.7	0.38	2
111	Sakaribanki	>10ppm	MT	0.76	0.7	0.25	4
112	Sankarchini	>10ppm	MT	0.79	0.75	0.24	4
113	Sanwal Basmati	≤10ppm	MS	0.70	0.62	0.23	6
114	Saragadhuli	>10ppm	MT	0.75	0.72	0.23	4
115	Saragadhuli Sel. 1	>10ppm	MT	0.71	0.67	0.24	4
116	Sarubhajana	≤10ppm	MS	0.74	0.64	0.25	6
117	Savitri	>10ppm	MT	0.72	0.66	0.23	4
118	Sheetalkani	≤5ppm	S	0.54	0.41	0.10	8

119	Sunapani	>10ppm	MT	0.70	0.66	0.21	5
120	Swarna sel.-1	≤15ppm	HT	0.84	0.71	0.33	2
121	Swarna Sel.-2	≤10ppm	MS	0.76	0.71	0.24	6
122	Swarna Sub-1	≤15ppm	HT	0.80	0.77	0.34	2
123	Tanmayee	≤15ppm	HT	0.83	0.8	0.41	2
124	Taraori Basmati	>10ppm	MT	0.58	0.45	0.16	5
125	Thakurabhoga	≤5ppm	S	0.48	0.42	0.11	8
126	Thakurasuna	≤5ppm	S	0.49	0.39	0.09	8
127	Tulasikanthi	≤5ppm	S	0.50	0.43	0.12	9
128	Tulasiganthi	≤10ppm	MS	0.58	0.53	0.17	6
129	Umorbudhi sel. 1	>10ppm	MT	0.74	0.69	0.26	4
130	Upahaar	≤15ppm	HT	0.89	0.86	0.42	2
131	Zinco rice MS	>10ppm	MT	0.61	0.54	0.20	4
Mean				0.72	0.65	0.27	4.45
Range 				0.39-0.96	0.29-0.95	0.07-0.60	1-9
Significance				**	**	**	**

N.B: STI_S and STI_R denote stress tolerance index based on shoot length and root length respectively, LAD(1-9 scale), **- Significant at $P_{0.01}$

Supplementary Table S2. Details of seedling parameters in a set of rice germplasm under arsenic stress

Sl. No.	Genotypes	Germination % under varying. As-Concentration (ppm)					LD_{50} Conc.	Seedling parameters at 15ppm Arsenic stress									
								Shoot length (cm)		Root length (cm)		Seedling vigor index(SVI)		Relative SVI (RSVI)	Seedling(shoot &Root) tolerance index		LAD Score
		0	5 ppm	10 ppm	15 Ppm (C1)	20 ppm		Con-trol	As-Stress (C2)	Con-trol	As-Stress (C3)	Con-trol	As-Stress (C4)	(C5)	STI_S (C6)	STI_R (C7)	(C8)
1	Ashutosh	100	96	75	55	35	>15ppm	18.2	16.2	18.3	15.8	3650	1760	0.48	0.89	0.86	1
2	Badshabhog	100	90	69	50	30	≤15ppm	16.8	14.2	16.2	13.0	3300	1360	0.41	0.85	0.80	2
3	Basmati 564	98	65	50	30	20	≤10ppm	24.9	16.7	22.4	13.2	4635	897	0.19	0.67	0.59	7
4	Basmatibhog	100	80	59	33	22	>10ppm	23.8	17.4	21.4	14.8	4520	1063	0.24	0.73	0.69	5
5	BasnaParijat	100	47	35	25	15	≤5ppm	25.5	14.3	25.1	13.5	5060	695	0.14	0.56	0.54	8
6	Basnasapuri	100	85	60	32	23	>10ppm	20.8	14.2	18.1	11.5	3890	822	0.21	0.68	0.64	5
7	Basuabhog	100	50	33	25	18	≤5ppm	21.5	10.7	19.4	7.8	4090	463	0.11	0.50	0.40	8
8	Bishnupriya	98	62	48	32	21	≤10ppm	18.9	10.2	17.0	7.8	3518	576	0.16	0.54	0.46	7
9	BRRI Dhan-72	100	100	78	60	38	>15ppm	17.2	15.6	17.3	14.8	3450	1824	0.53	0.91	0.86	1
10	CGZR -1	100	92	70	43	35	≤15ppm	18.8	16.4	18.4	15.2	3720	1359	0.37	0.87	0.83	2
11	CGZR 2	100	60	45	30	26	≤10ppm	18.9	10.4	17.8	8.6	3670	570	0.16	0.55	0.48	7
12	Chandrahasini	98	64	46	32	23	≤10ppm	21.3	14.8	17.9	10.5	3842	810	0.21	0.69	0.59	6
13	Chinikamini	100	65	50	30	20	≤10ppm	20.3	13.5	18.6	11.2	3890	741	0.19	0.67	0.60	6
14	CR Dhan 311	100	93	68	50	33	≤15ppm	16.7	13.3	14.5	10.5	3120	1190	0.38	0.80	0.72	3
15	CR Sug. Dhan 907	97	48	36	25	18	≤5ppm	25.5	14.4	22.6	12.2	4666	665	0.14	0.56	0.54	8
16	CRM 839 sel.-1	100	45	35	20	15	≤5ppm	25.3	12.2	23.6	10.6	4890	456	0.09	0.48	0.45	9
17	CST Sel. 4	100	100	85	65	40	>15ppm	23.2	21.9	23.0	20.5	4620	2756	0.60	0.94	0.89	1
18	Dhalamadhoi	98	93	67	41	35	≤15ppm	22.8	20.4	22.2	19.0	4410	1615	0.37	0.89	0.86	2
19	Dhinkisiali	100	90	69	45	29	≤15ppm	23.8	21.7	23.2	20.0	4700	1877	0.40	0.91	0.86	2
20	Dhoiabankoi	100	50	38	23	18	≤5ppm	25.3	12.3	21.8	9.8	4710	508	0.11	0.49	0.45	9
21	Dimapur local	100	45	34	25	17	≤5ppm	23.5	12.4	21.4	9.8	4490	555	0.12	0.53	0.46	8
22	DRR Dhan 48	100	89	58	30	25	>10ppm	17.7	12.7	15.6	10.0	3330	681	0.20	0.72	0.64	4
23	Dudhamani	100	46	36	20	19	≤5ppm	25.5	14.3	23.8	12.2	4930	530	0.11	0.56	0.51	8
24	Dulhabhog	100	45	35	24	18	≤5ppm	22.5	11.4	20.1	8.5	4260	478	0.11	0.51	0.42	8
25	FR-43-B	100	90	68	40	28	≤15ppm	11.8	9.9	11.4	8.2	2320	724	0.31	0.84	0.72	2

26	Gangabali	98	66	50	33	22	≤10ppm	15.3	8.3	14.2	6.8	2891	498	0.17	0.54	0.48	6
27	Ganjam local -2	100	65	47	35	20	≤10ppm	18.9	10.7	17.4	8.2	3630	662	0.18	0.57	0.47	7
28	Ganjamgedi	100	100	64	42	26	≤15ppm	16.7	13.1	15.5	11.5	3220	1033	0.32	0.78	0.74	3
29	Geetanjali	100	88	57	30	25	>10ppm	13.7	8.8	11.9	6.3	2560	453	0.18	0.64	0.53	4
30	Gelei	98	50	36	27	19	≤5ppm	19.5	8.3	17.8	6.2	3655	392	0.11	0.43	0.35	8
31	Harisankar	100	100	65	43	32	≤15ppm	12.8	10.1	12.7	9.5	2550	843	0.33	0.79	0.75	2
32	Heerakani	100	84	60	29	26	>10ppm	20.8	14.3	18.2	12.0	3900	763	0.20	0.69	0.66	5
33	Heerakhandi	98	47	38	25	20	≤5ppm	25.3	12.3	21.9	8.9	4626	530	0.11	0.49	0.41	9
34	Hundar	100	95	60	43	31	≤15ppm	16.7	13.4	19.2	15.2	3590	1230	0.34	0.80	0.79	3
35	IET 16383	100	85	61	32	25	>10ppm	14.7	9.7	13.1	7.5	2780	550	0.20	0.66	0.57	4
36	IET 24780	100	96	66	42	30	≤15ppm	11.8	9.3	11.4	8.2	2320	735	0.32	0.79	0.72	2
37	IR 15 M 1537	100	85	59	36	27	>10ppm	20.7	15.0	17.8	12.2	3850	979	0.25	0.72	0.69	4
38	IR I5 M 1546	97	50	38	25	20	≤5ppm	29.5	18.8	28.4	16.8	5616	890	0.16	0.64	0.59	8
39	IR 15 M 1633	100	94	64	41	28	≤15ppm	19.8	17.4	19.7	16.5	3950	1390	0.35	0.88	0.84	2
40	IR 15 M 1689	100	65	48	32	23	≤10ppm	25.9	17.8	20.4	11.2	4630	928	0.20	0.69	0.55	7
41	IR 64	100	88	58	30	28	>10ppm	21.7	16.6	19.4	13.8	4110	912	0.22	0.76	0.71	4
42	IR 84847-RIL 195-1-1-1-1	100	96	68	44	27	≤15ppm	17.8	15.3	17.3	14.1	3510	1294	0.37	0.86	0.82	2
43	IR 91143-AC-239-1	96	84	64	33	24	>10ppm	24.8	18.3	21.1	14.5	4406	1082	0.25	0.74	0.69	5
44	IR 91143-AC-290-1	100	85	62	30	26	>10ppm	22.7	17.2	18.6	13.0	4130	906	0.22	0.76	0.70	4
45	IR 95044:8-B-5-22-19-GBS	100	44	36	28	23	≤5ppm	26.5	15.0	24.8	13.2	5130	790	0.15	0.57	0.53	8
46	IR 95133 -1-B-16-14-10-GBS-P6-1-5	97	46	33	25	19	≤5ppm	23.5	12.6	21.4	9.8	4355	560	0.13	0.54	0.46	8
47	IR 95133:1-B-16-14-10-GBS-P5-1-3	100	80	59	36	25	>10ppm	22.7	17.9	20.6	15.0	4330	1185	0.27	0.79	0.73	4
48	IR 95133:1-B-16-14-10-GBS-P1-2-2	100	81	60	38	23	>10ppm	17.8	11.2	14.5	7.9	3230	726	0.22	0.63	0.54	5
49	IR 96248-16-3-3-2-B	100	40	38	22	18	≤5ppm	26.5	15.9	25.1	13.5	5160	647	0.13	0.60	0.54	8
50	IR 97443-11-2-1-1-1-1B	100	79	63	36	24	>10ppm	17.7	12.9	19.0	13.4	3670	947	0.26	0.73	0.71	4
51	IR 97443-11-2-1-1-1-3B	100	100	75	50	28	≤15ppm	19.7	16.5	18.3	14.3	3800	1540	0.41	0.84	0.78	3

52	IR 99704-24-2-1	100	92	67	45	29	≤15ppm	17.8	15.0	17.7	14.5	3550	1328	0.37	0.84	0.82	2
53	IR82475-110-2-2-1-2	100	100	75	50	28	≤15ppm	17.8	15.6	17.4	14.2	3520	1490	0.42	0.88	0.82	2
54	Jagabandhu	98	93	70	42	34	≤15ppm	14.8	12.9	14.4	11.2	2862	1012	0.35	0.87	0.78	2
55	Kadalipenda	100	90	75	45	30	≤15ppm	21.7	18.2	20.5	16.5	4220	1562	0.37	0.84	0.80	3
56	Kalamulia	100	89	65	50	36	≤15ppm	16.8	14.9	16.7	13.5	3350	1420	0.42	0.89	0.81	2
57	Kalikati-1	100	68	50	32	22	≤10ppm	17.3	10.3	15.9	8.5	3320	602	0.18	0.60	0.53	6
58	Kanchan	100	100	75	44	30	≤15ppm	18.8	`16.3	18.7	15.5	3750	1399	0.37	0.87	0.83	2
59	Karhani	98	84	59	30	25	>10ppm	23.8	17.2	21.4	14.8	4430	960	0.22	0.72	0.69	5
60	Karpurakranti -1	100	38	32	20	15	≤5ppm	29.3	16.7	27.2	14.2	5650	618	0.11	0.57	0.52	9
61	Karpurakranti -2	100	40	31	27	22	≤5ppm	23.5	12.8	21.6	10.0	4510	616	0.14	0.54	0.46	8
62	Kasturi	100	67	50	35	25	≤10ppm	26.9	18.6	22.3	13.1	4920	1110	0.23	0.69	0.59	7
63	Ketakijoha	100	86	58	36	24	>10ppm	26.8	20.9	24.8	18.2	5160	1408	0.27	0.78	0.73	5
64	Khadiratnachudi	97	93	73	46	31	≤15ppm	17.7	14.2	15.4	11.4	3211	1178	0.37	0.80	0.74	3
65	Khajurikandi	100	89	68	43	32	≤15ppm	19.7	16.6	18.2	14.2	3790	1324	0.35	0.84	0.78	3
66	Labangalata	100	100	75	48	35	≤15ppm	17.8	15.2	17.7	14.5	3515	1426	0.41	0.85	0.82	2
67	Lajakulibadan	100	88	60	35	25	>10ppm	18.7	13.6	16.6	11.0	3530	861	0.24	0.73	0.66	4
68	Lalachounyl	100	40	30	23	19	≤5ppm	20.5	9.8	18.8	7.2	3930	391	0.10	0.48	0.38	8
69	M -48	100	88	70	44	30	≤15ppm	19.8	17.5	19.4	16.2	3920	1483	0.38	0.88	0.84	2
70	Mahalaxmi	100	93	65	45	36	≤15ppm	16.7	13.2	14.1	10.1	3080	1049	0.34	0.79	0.72	3
71	Mahanadi	100	96	83	53	32	>15ppm	16.2	14.7	16.3	13.8	3250	1511	0.46	0.91	0.85	1
72	Malliphulajhuli	100	83	61	37	27	>10ppm	23.7	18.4	20.2	14.6	4390	1221	0.28	0.78	0.72	4
73	MI 127	100	70	71	48	34	≤15ppm	17.8	15.4	17.4	14.2	3520	1421	0.40	0.87	0.82	2
74	MI 156	100	96	78	52	33	>15ppm	16.2	14.0	16.3	13.8	3250	1446	0.44	0.86	0.85	1
75	Mitimiti	100	45	32	25	15	≤5ppm	23.5	12.5	21.5	11.1	4500	590	0.13	0.53	0.52	8
76	Mrunalini	98	86	60	35	25	>10ppm	14.8	8.3	12.8	6.2	2705	508	0.19	0.56	0.48	5
77	Neelabati	100	87	58	36	26	>10ppm	13.8	7.7	11.8	5.2	2560	464	0.18	0.56	0.44	5
78	Nikipankhia	100	88	71	50	30	≤15ppm	20.8	18.5	20.7	17.5	4150	1800	0.43	0.89	0.85	2
79	Nuachinikamini	100	48	30	25	15	≤5ppm	25.3	12.9	22.8	9.8	4810	568	0.12	0.51	0.43	9
80	OR 1898-2-35-1	100	89	65	43	35	≤15ppm	16.8	14.5	16.7	13.5	3350	1204	0.36	0.86	0.81	2
81	OR-2327-23	100	90	70	44	33	≤15ppm	21.7	18.4	20.9	16.9	4260	1553	0.36	0.85	0.81	3

82	OR(CZ) 48 sel.-1	98	84	58	35	22	>10ppm	21.7	16.0	18.1	12.5	3900	998	0.26	0.74	0.69	4
83	OR(CZ) 48-Sel. 2	100	79	59	38	26	>10ppm	19.7	14.9	16.4	10.8	3610	977	0.27	0.76	0.66	4
84	OR(CZ)- 58	100	98	75	45	32	≤15ppm	17.7	14.9	15.4	12.0	3310	1211	0.37	0.84	0.78	3
85	OR(CZ)-61	97	43	32	20	15	≤5ppm	21.3	8.4	18.2	5.2	3832	272	0.07	0.39	0.29	9
86	OR(CZ)-62	100	90	71	46	30	≤15ppm	12.8	10.8	12.7	9.5	2550	934	0.37	0.84	0.75	2
87	OR(CZ)-63	96	39	35	25	18	≤5ppm	20.5	9.3	18.9	7.3	3782	415	0.11	0.45	0.39	8
88	OR(CZ)- 64	100	67	49	35	24	≤10ppm	22.3	15.3	21.2	13.8	4350	1019	0.23	0.69	0.65	6
89	OR(CZ)-65	100	40	37	28	15	≤5ppm	19.5	8.6	17.1	5.5	3660	395	0.11	0.44	0.32	8
90	OR(CZ)-66	100	98	73	45	33	≤15ppm	15.8	13.2	14.4	11.2	3020	1098	0.36	0.84	0.78	2
91	OR(CZ) 78-1	100	100	80	60	38	>15ppm	18.2	16.5	18.0	15.5	3620	1920	0.53	0.91	0.86	1
92	OR(CZ) 80-1	100	88	68	50	30	≤15ppm	19.8	17.9	19.2	16.0	3900	1695	0.43	0.90	0.83	2
93	OR(T)- 10	100	80	58	37	22	>10ppm	13.7	8.4	11.4	5.8	2510	525	0.21	0.61	0.51	4
94	OR(T) 10-1	95	45	34	25	17	≤5ppm	19.3	12.0	17.8	10.4	3525	560	0.16	0.62	0.58	6
95	OR(T) 10-2	100	89	70	43	32	≤15ppm	19.7	16.3	18.8	14.8	3850	1337	0.35	0.83	0.79	3
96	OR(T) 30	100	82	60	34	26	>10ppm	19.7	14.3	17.9	12.3	3760	904	0.24	0.73	0.69	4
97	Palaka	100	86	65	43	35	≤15ppm	17.7	14.1	15.3	11.3	3300	1092	0.33	0.80	0.74	3
98	PB-1	100	100	76	58	32	>15ppm	14.2	12.5	13.7	11.2	2790	1375	0.49	0.88	0.82	1
99	PusaSug. 3	100	98	73	53	30	>15ppm	16.6	16.0	14.6	13.8	3120	1579	0.51	0.96	0.95	1
100	Pimpudibasa -1	100	80	63	35	25	>10ppm	18.7	13.5	15.5	10.3	3420	833	0.24	0.72	0.66	4
101	Poornabhog	100	100	74	45	33	≤15ppm	10.8	8.9	10.2	7.0	2100	716	0.34	0.82	0.69	2
102	PusaSug. 3-1	100	100	81	62	41	>15ppm	16.2	14.4	16.3	13.8	3250	1748	0.54	0.89	0.85	1
103	Ramachandi	96	82	61	37	26	>10ppm	18.8	12.3	16.4	9.8	3379	818	0.24	0.65	0.60	5
104	Rasapanjari	100	88	71	44	31	≤15ppm	24.8	22.8	23.2	20.0	4800	1883	0.39	0.92	0.86	2
105	R-RHP-MI 30	100	84	60	35	24	>10ppm	15.7	10.9	13.6	8.0	2930	662	0.23	0.69	0.59	4
106	R-RHZ -IB-80	100	87	70	44	30	≤15ppm	10.8	8.3	10.1	6.9	2090	669	0.32	0.77	0.68	2
107	R-RHZ –LI- 23	100	86	65	47	34	≤15ppm	14.7	11.4	12.6	8.6	2730	940	0.34	0.78	0.68	3
108	R-RHZ -MI -93	100	89	68	48	30	≤15ppm	14.8	12.5	14.4	11.2	2920	1138	0.39	0.84	0.78	2
109	R-RHZ-SD 94	100	81	62	36	25	>10ppm	15.7	10.2	13.8	8.2	2950	662	0.22	0.65	0.59	4
110	R-RHZ-SM 14	100	90	69	50	34	≤15ppm	10.8	8.8	10.6	7.4	2140	810	0.38	0.81	0.70	2
111	Sakaribanki	100	83	60	34	23	>10ppm	20.7	15.8	18.8	13.2	3950	986	0.25	0.76	0.70	4
112	Sankarchini	97	81	61	30	25	>10ppm	25.7	20.4	22.1	16.5	4637	1107	0.24	0.79	0.75	4

113	Sanwal Basmati	100	65	48	34	23	≤10ppm	23.3	16.2	19.6	12.2	4290	966	0.23	0.70	0.62	6
114	Saragadhuli	100	87	59	31	25	>10ppm	20.7	15.5	18.4	13.2	3910	890	0.23	0.75	0.72	4
115	Saragadhuli Sel. 1	100	79	58	35	20	>10ppm	18.7	13.2	16.8	11.2	3550	854	0.24	0.71	0.67	4
116	Sarubhajana	100	68	50	36	25	≤10ppm	25.3	18.7	20.6	13.2	4590	1148	0.25	0.74	0.64	6
117	Savitri	98	86	60	32	26	>10ppm	17.7	12.7	16.6	11.0	3361	758	0.23	0.72	0.66	4
118	Sheetalkani	100	50	34	20	15	≤5ppm	23.5	12.7	19.7	8.1	4320	416	0.10	0.54	0.41	8
119	Sunapani	100	86	62	31	25	>10ppm	21.8	15.3	19.6	13.0	4140	877	0.21	0.70	0.66	5
120	Swarna sel.-1	100	90	67	42	30	≤15ppm	11.8	9.9	11.0	7.8	2280	743.4	0.33	0.84	0.71	2
121	Swarna Sel.-2	100	67	47	33	22	≤10ppm	28.3	21.6	22.8	16.2	5110	1247	0.24	0.76	0.71	6
122	Swarna Sub-1	100	89	72	44	30	≤15ppm	13.8	11.0	13.7	10.5	2750	946	0.34	0.80	0.77	2
123	Tanmayee	100	86	74	50	30	≤15ppm	16.8	14.0	16.4	13.2	3320	1360	0.41	0.83	0.80	2
124	Taraori Basmati	100	85	63	30	27	>10ppm	14.8	8.6	11.3	5.1	2610	411	0.16	0.58	0.45	5
125	Thakurabhoga	100	43	33	25	18	≤5ppm	21.5	10.4	20.1	8.5	4160	473	0.11	0.48	0.42	8
126	Thakurasuna	98	46	32	20	17	≤5ppm	22.5	11.0	19.1	7.5	4077	370	0.09	0.49	0.39	8
127	Tulasikanthi	96	42	30	25	20	≤5ppm	25.3	12.6	22.7	9.7	4608	558	0.12	0.50	0.43	9
128	Tulasiganthi	100	66	45	30	23	≤10ppm	17.3	10.1	14.1	7.5	3140	528	0.17	0.58	0.53	6
129	Umorbudhi sel. 1	100	84	60	36	23	>10ppm	21.7	16.0	18.1	12.5	3980	1026	0.26	0.74	0.69	4
130	Upahaar	100	90	69	48	30	≤15ppm	22.8	20.4	22.6	19.4	4540	1910	0.42	0.89	0.86	2
131	Zinco rice MS	100	83	58	35	26	>10ppm	13.7	8.3	12.1	6.5	2580	518	0.20	0.61	0.54	4
Mean		99.5	77.3	57.7	37.1	26.0	-	19.7	13.9	18.0	11.7	3749.9	978.8	0.27	0.72	0.65	4.45
Range		95-100	38-100	30-85	20-65	15-41	-	10.8-29.5	7.7-22.8	10.1-28.4	5.1-20.5	2090-5650	272.0-2756.0	0.07-0.60	0.39-0.96	0.29-0.95	1.0-9.0
ANOVA Result	G	**					-	**	**	**	**	ND	ND	**	**	**	**
	T	**					-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	G x T	**					-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NB: SVI- Seedling vigor index, RSVI- Relative seedling vigor index, G-Genotype, T-As stress treatment, ND- Not determined, NA –Not applicable, **- Significant at $P_{0.01}$

Supplementary Table S3. Descriptive statistics for seedling parameters under 15ppm As-stress

	C1	C2	C3	C4	C5	C6	C7	C8
Mean	37.13	13.98	11.76	978.93	0.27	0.72	0.66	4.45
Standard Error	0.88	0.30	0.31	38.13	0.01	0.01	0.01	0.21
Median	36	14.2	11.5	912	0.24	0.74	0.69	4
Mode	25	8.3	11.2	662	0.11	0.84	0.69	2
Standard Deviation	10.06	3.44	3.49	436.38	0.12	0.14	0.15	2.44
Sample Variance	101.25	11.84	12.19	190423.68	0.01	0.02	0.02	5.97
Kurtosis	-0.39	-0.41	-0.43	0.99	-0.58	-0.95	-0.86	-1.09
Skewness	0.36	0.23	0.18	0.87	0.40	-0.40	-0.38	0.42
Range	45	15.1	15.4	2484	0.53	0.57	0.66	8
Minimum	20	7.7	5.1	272	0.07	0.39	0.29	1
Maximum	65	22.8	20.5	2756	0.6	0.96	0.95	9
Sum	4864	1830.8	1540	128240.4	35.24	94.19	86	583
Count	131	131	131	131	131	131	131	131
Confidence Level(95.0%)	1.74	0.59	0.60	75.43	0.02	0.02	0.03	0.42

C1-Germination %, C2-Shoot length(cm), C3-Root length(cm), C4- Seedling vigor index(SVI), C5-Relative seedling vigor index (RSVI) over control, C6&C7-seedling stress tolerance indices (STIs & STI_R) respectively.