Journal of Experimental Agriculture International

Volume 45, Issue 12, Page 180-185, 2023; Article no.JEAI.111138
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Mitigation of Arsenic Contamination through Biotechnological Approaches in Rice

Bishun Deo Prasad [a*] and Sangita Sahni [b]

[a] Department of AB and MB, CBS and H, Pusa, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, 848125, India.
[b] Department of Plant Pathology, TCA, Dholi, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, 848125, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2023/v45i122276

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/111138

Received: 17/10/2023
Accepted: 22/12/2023
Published: 26/12/2023

Review Article

ABSTRACT

Arsenic poisoning negatively impacts plants, soil, water, and human health, posing a serious threat to sustainable agriculture. Pesticides, fertilizers, and industrial processes that contain arsenic are widely used, which leads to soil contamination and reduces soil fertility and productivity. The drinking of groundwater contaminated with arsenic affects around 300 million people globally. Prolonged exposure to arsenic has been linked to a number of health concerns, including cancer, developmental abnormalities, and skin sores. Concerns have been raised over the possible health effects of arsenic, which is mostly exposed to consumers through the consumption of contaminated food. Because arsenic-contaminated soil and irrigation water affect rice more than other crops, rice is frequently consumed with elevated levels of arsenic in it. In present review, the challenges related to arsenic toxicity and its possible solutions in rice have been discussed.

**Corresponding author: E-mail: bdprasadbau1@gmail.com, bdprasad@rpcau.ac.in;*

Keywords: Arsenic toxicity; soil contamination; Brassinosteroid (BR); RICE.

1. INTRODUCTION

Arsenic toxicity poses a significant threat to sustainable agriculture by adversely affecting soil, water, plants, and human health [1]. The widespread use of arsenic-containing pesticides, fertilizers, and industrial processes contributes to the contamination of soil, compromising its fertility and overall productivity. Moreover, arsenic can leach into groundwater, further contaminating water sources used for irrigation and exacerbating the risk of crop uptake. Crops such as rice, leafy vegetables, and root crops are particularly susceptible to arsenic accumulation, presenting a direct threat to food safety. The consumption of arsenic-contaminated crops can lead to various health issues, including skin lesions, cancer, and neurological problems, underscoring the interconnectedness of environmental and human well-being. Additionally, the economic sustainability of agriculture is at stake due to potential trade restrictions on arsenic-contaminated agricultural exports.

Arsenic is a metalloid ranked first in a list of 20 major harmful materials by the Agency for Toxic Substances and Disease Registry and United States Environmental Protection Agency [2]. It is sometimes referred to as the "king of poisons" because of its extreme toxicity [3]. Groundwater contamination by arsenic exceeds the World Health Organization's (WHO) recommended maximum permitted level of 10 parts per billion (ppb) in nearly 108 countries (https://www.who.int/news-room/fact-sheets/detail/arsenic) [3]. The intake of groundwater contaminated with arsenic affects almost 300 million people globally [4.] The areas of India, Bangladesh, Nepal, Vietnam, and China that make up the South and Southeast Asian Belt are thought to be the most arsenic-polluted [5,3]. Assam, West Bengal, Jharkhand, Bihar, Uttar Pradesh, and four Union Territories are among the twenty Indian states where groundwater has been contaminated with arsenic thus far [3]. There has been a rise in arsenic poisoning cases in Bihar [4].

Chronic arsenic exposure has been linked to detrimental consequences on human health, including a higher risk of cancer, hyperkeratosis, birth abnormalities, cardiovascular disease, neurotoxicity, and diabetes [6] Flanagan et al., [7] Kumar et al., [4]. Skin lesions are a common sign of arsenic poisoning and indicate prolonged exposure. Even more concerning, the International Agency for Research on Cancer, a part of WHO (https://www.who.int/news-room/fact-sheets/detail/arsenic), has categorized arsenic as a Group 1 human carcinogen, connecting it to malignancies of the skin, lungs, bladder, and other organs. Prolonged exposure to arsenic has also been linked to developmental defects, cardiovascular disorders, and neurological impairments Tyler et al., [8] Sharma and Kumar [9]. The negative health effects are more severe in areas where arsenic poisoning is common, which emphasizes how urgently this public health issue has to be addressed.

Arsenic may build up in agricultural soils as a result of using contaminated groundwater for crop irrigation; this could eventually reduce crop yields and poorer human health [4,10]. Human health risks from arsenic are often greatest in high-density arsenic countries like those in South and Southeast Asia where groundwater is the main supply of drinking water and agriculture depends significantly on large-scale irrigation. However, the problem of arsenic in groundwater contaminating soils is genuinely worldwide, with different levels of soil pollution occurring in widely separated nations such as the USA, Greece, Chile, Mexico, and Argentina (Smedley and Kinniburgh, [11] Sahoo and Kim, [12] Shaji et al., [3].

Rice arsenic contamination is a pressing concern for global food safety, as rice is known to accumulate greater levels of arsenic than any other staple crop Upadhyay et al., [13] He et al., [14] The rice plant effectively absorbs arsenic from the soil, especially inorganic arsenic (iAs), which results in higher amounts in the grain. Eating rice exposes one to arsenic over time, which has been related to cancer, developmental disorders, and skin sores, among other health problems. Arsenic buildup in rice is caused by a variety of agronomic, geochemical, and hydrological conditions as well as the plant's innate capacity to absorb arsenic [15]. Controlled flooding is a common method of managing rice plants to reduce weed competition, lower the demand for herbicides, and boost yields (IRRI 2015).

The regions where arsenic buildup in rice-paddy soils after irrigation with polluted groundwater is most concerning are South and Southeast Asia.

In the heavily colonized river basins that drain the Himalayas, groundwater poisoned by naturally occurring arsenic has been used extensively for irrigation of dry-season rice Fendorf et al., [16] Chakraborty et al., [17]. In the heavily affected and well-researched Bengal Delta region of India and Bangladesh, arsenic levels in irrigation water used for irrigating rice field can surpass 50 µg/L (Williams et al., [18] Khan et al., [19] Chakraborty et al., [17], reaching as high as 1800 µg/L [20]. As a result, arsenic concentrations in rice grains can reach up to 1835 µg/kg and in polluted areas, soil arsenic concentrations can reach up to 95 mg/kg [19]. Compared to other cereals like wheat, rice can accumulate arsenic up to ten times higher in concentrations [21]. Additionally, rice-based products including those ingested by infants and young children were indicated to contain high quantities of inorganic arsenic [22]. About 66% of the region's calories come from rice, and for certain individuals, it can make up as much as 50% of their daily intake of arsenic [23].

The identification and introgression of QTLs related to arsenic are among the preferred strategies for arsenic mitigation in crop plants Zhang et al., [24] Adeva et al., [25]In rice shoots and grains cultivated under alternate wetting and drying (AWD) and continuously flooded (CF) conditions, genome wide association (GWA) mapping for arsenic has revealed seventy-four distinct QTLs for arsenic, six of which exhibit stability over time and/or water treatments (Norton et al., 2019). Recently, a GWAS (Genome-Wide Association Study) analysis was performed to identify QTL for grain-arsenic and straight head disorder resistance [26]. For each As-associated trait, several QTL (ranging from 9 to 33) were identified [26]. The quantitative trait loci (QTLs) associated with arsenic buildup in rice were mapped using a doubled haploid population produced by anther culture of F1 plants from a hybrid between CJ06, a Japonica cultivar, and TN1, an Indica cultivar (Zhang et al., 2008). The map revealed four QTLs for the concentrations of arsenic. At the seedling stage, a single QTL for arsenic concentrations in roots was found on chromosome 3, and a single QTL for arsenic concentrations in shoots was mapped on chromosome 2 with a 24.4% phenotypic variation. Two QTLs with 26.3 and 35.2% phenotypic variance, respectively, were discovered on chromosomes 6 and 8 at maturity for arsenic concentrations in grains [24].

Phytohormones play a crucial role in arbitrating cellular responses to numerous environmental stimuli (Vos et al., [27] Ku et al., [28]. The protective role of salicylic acid (SA) against abiotic and biotic stress are well documented in crop plants (Prasad et al., [29] Noriega et al., [30] Kumari et al., [31] Sahni et al., [32] Sahni and Prasad [33]. Recent studies showed the modulation of genes related to heavy metal stress in plants (Noriega et al., [30] Singh et al., [34]. Exogenous treatment of SA was found effective in mitigating arsenate (AsV) toxicity in rice by lowering translocation to the shoots [34]. The amount of arsenic in the shoot was directly related with the expression of *Low silicon 2* (*OsLsi2)* gene that moves arsenic from the root to the shoot as arsenite (AsIII) [34].

Brassinosteroid (BR), a plant steroidal hormone, known to play an important role for plant growth and development, modulating stress responses and shielding from heavy metal toxicity [35-37] Chaudhary et al., [38]. in hydroponic, rice plants treated with BRs prevents arsenic accumulation (Xu et al., 2018), Recently, we have unequivocally demonstrated BRs-mediated suppression of *OsLsi1* and *OsLsi2* that had a beneficial effect on lowering arsenic buildup in the leaves and seeds of the rice [38]. Further, BRs has shown the significant reduction in accumulation of arsenic rice grown under naturally arsenic-contaminated soil [38].

In recent years, Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR-associated protein 9 (Cas9) has become the method of choice for genome editing in crop plants including rice Zafar et al., [39] Kumari et al., 2022). The well-developed rice transformation protocol facilitates faster adoption of gene editing technology in rice [29]. The emerging reports in targeting genes associated with arsenic uptake, translocation and detoxification of arsenic in rice has pave the way of developing low arsenic mitigation in rice using gene editing [40] Fiaz et al., [41] Chaudhary et al., [38-41]. The role of *OsLsi1* and *OsLsi2* in arsenic translocation in rice plants are well described [34] Chen et al., [40-45] Chaudhary et al.,[17]

2. CONCLUSION

A comprehensive strategy is needed to address arsenic toxicity issue in agriculture, which includes the adoption of new biotechnological methods and the development of low arsenic absorbing/accumulating crops mainly rice. The application of phytohormones and other management techniques may be able to dramatically reduce rice's absorption of arsenic. Furthermore, the development of rice free of arsenic will be made possible by plant breeding techniques combined with gene editing technology. The editing of *OsLsi1* and *OsLsi2* genes in rice might be helpful in dipping the arsenic buildup in rice plant without any obvious yield penalties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Prasad BD, Mandal J, Kumar S, Sohane K. Proceedings-cum-Abstract book National Webinar On Arsenic Mitigation: A Nexus Approach. 2020;1-131.
2. Roy P, Saha A. Metabolism and toxicity of arsenic: A human carcinogen. Curr. Sci. 2002;38-45.
3. Shajia E, Santosh M, Saratha KV, Prakasha P, Deepchand V, Divya BV Arsenic contamination of groundwater: A global synopsis with focus on the Indian Peninsula. Geosci. Front. 2021;12(3):101079.
4. Kumar A, Ali M, Kumar R, Kumar M, Sagar P, Pandey RK, Akhouri V, Kumar V, Anand G, Niraj PK, Rani R, Kumar S, Kumar D, Bishwapriya A, Ghosh AK. Arsenic exposure in Indo Gangetic plains of Bihar causing increased cancer risk. Sci Rep. 2021;11(1):2376.
5. McArthur JM. Arsenic in groundwater. In Groundwater Development and Management. 2019;279-308.
6. Phan K, Sthiannopkao S, Kim KW, Wong MH, Sao V, Hashim JH, Mohamed Yasin MS, Aljunid SM. Health risk assessment of inorganic arsenic intake of Cambodia residents through groundwater drinking pathway. Water Res. 2020;44(19):5777-5788.
7. Flanagan SV., Johnston RB, Zheng Y. Arsenic in tube well water in Bangladesh: health and economic impacts and implications for arsenic mitigation. Bull World Health Organ. 2012;90:839-846.
8. Tyler CR, Allan AM. The Effects of Arsenic Exposure on Neurological and Cognitive Dysfunction in Human and Rodent Studies: A Review. Curr Environ Health Rep. 2014;1(2):132-147.
9. Sharma A, Kumar S. Arsenic exposure with reference to neurological impairment: an overview. Rev Environ Health. 2019;34(4):403-414.
10. Brammer H., Ravenscroft P. Arsenic in groundwater: a threat to sustainable agriculture in South and South-east Asia. Environ Int. 2009;*35*(3):647-654.
11. Smedley PL. Kinniburgh DG. A review of the source, behaviour and distribution of arsenic in natural waters. Appl. Geochem. 2002;17(5):517-568.
12. Sahoo PK, Kim K. A review of the arsenic concentration in paddy rice from the perspective of geoscience. Geosci J. 2013;17:107–122.
13. Upadhyay MK., Majumdar A., Kumar JS., Srivastava S. Arsenic in Rice Agro-Ecosystem: Solutions for Safe and Sustainable Rice Production. Front Sustain Food Syst., 2020;4:53.
14. He Y, Zhang X, Shi Y, Xu X, Li L, Wu J-L. () Correction to: PREMATURE SENESCENCE LEAF 50 Promotes Heat Stress Tolerance in Rice (*Oryza sativa* L.). Rice. 2021;14:63.
15. Zhao FJ, McGrath SP, Meharg AA. Arsenic as a food chain contaminant: mechanisms of plant uptake and metabolism and mitigation strategies. Annu Rev Plant Biol. 2010;61:535-59.
16. Fendorf S, Michael HA, van Geen A. Spatial and temporal variations of groundwater arsenic in South and Southeast Asia. Science. 2010;328(5982): 1123-7.
17. Chakraborty M., Mukherjee A., Ahmed KM. A review of groundwater arsenic in the Bengal Basin, Bangladesh and India: from source to sink. Curr Pollut Rep. 2015;1(4):220-247.
18. Williams PN, Islam MR, Adomako EE, Raab A, Hossain SA, Zhu YG, Feldmann J, Meharg AA. Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. Environ. Sci. Technol. 2006;40(16):4903-4908.
19. Khan MA., Islam MR., Panaullah GM., Duxbury JM., Jahiruddin M., Loeppert RH. Accumulation of arsenic in soil and rice under wetland condition in Bangladesh. Plant and Soil. 2010;333(1):263-274.
20. Alam MGM., Snow ET., Tanaka A. Arsenic and heavy metal contamination of

vegetables grown in Samta village, Bangladesh. Sci Total Environ. 2003; 308(1-3):83-96.

21. Karagas MR, Punshon T, Davis M, Bulka CM, Slaughter F, Karalis D, Argos M, Ahsan H. (2019) Rice Intake and Emerging Concerns on Arsenic in Rice: A Review of the Human Evidence and Methodologic Challenges. Curr Environ Health Rep. 2019;6(4):361-372.
22. Davis MA., Signes-Pastor AJ., Argos M., Slaughter F., Pendergrast C., Punshon T., Gossai A., Ahsan H, Karagas MR. Assessment of human dietary exposure to arsenic through rice. Sci Total Environ. 2017;586:1237-1244.
23. Liao CM., Lin TL., Hsieh NH., Chen WY. Assessing the arsenic-contaminated rice (*Oryza sativa*) associated children skin lesions. J Hazard Mater. 2010;176(1-3):239-51.
24. Zhang J, Zhu YG, Zeng DL, Cheng WD, Qian Q, Duan GL. Mapping quantitative trait loci associated with arsenic accumulation in rice (*Oryza sativa*). New Phytol. 2008;177, 350–356.
25. Adeva C, Yun Y-T, Shim K-C. et al. Mapping of Mineral Element Contents in Rice Using Introgression Lines Derived from an Interspecific Cross. Agronomy. 2023;13(1):76.
26. Pinson SRM, Heuschele DJ, Edwards JD, et al. Relationships among arsenic-related traits, including rice grain arsenic concentration and straighthead resistance, as revealed by genome-wide association. Frontiers in Genetics. 2021;12. Available:https://doi.org/10.3389/fgene.2021.787767
27. Vos IA, Moritz L, Pieterse CM, Van Wees SC. Impact of hormonal crosstalk on plant resistance and fitness under multi-attacker conditions. Front Plant Sci. 2015;6:639.
28. Ku YS, Sintaha M, Cheung MY, Lam HM. Plant Hormone Signaling Crosstalks between Biotic and Abiotic Stress Responses. Int J Mol Sci. 2018;19(10):3206.
29. Prasad BD, Creissen G, Lamb C, Chattoo BB. Overexpression of Rice (*Oryza sativa* L.) OsCDR1 Leads to Constitutive Activation of Defense Responses in Rice and Arabidopsis. Mol. Plant-Microbe Interact. 2009;22(12):1635-1644.
30. Noriega G, Caggiano E, Lecube ML et al. The role of salicylic acid in the prevention of oxidative stress elicited by cadmium in soybean plants. Biometals. 2012;25:1155–1165.
31. Kumari D, Prasad BD, Dwivedi P. et al. CRISPR/Cas9 mediated genome editing tools and their possible role in disease resistance mechanism. Mol Biol Rep 2022;49:11587–11600.
32. Sahni S, Kumar S, BD Prasad BD Integration of salicylic acid, vermicompost and bioagent for effective management of chickpea wilt disease. Journal of Environmental Biology. 2021;42(5):1274-1280.
33. Sahni S, Prasad B, Liu Q. et al. Overexpression of the brassinosteroid biosynthetic gene *DWF4* in *Brassica napus* simultaneously increases seed yield and stress tolerance. Sci Rep 2016;6:28298.
34. Singh AP., Dixit G, Mishra S, et al. Salicylic acid modulates arsenic toxicity by reducing its root to shoot translocation in rice (*Oryza sativa* L.). Front. Plant Sci. 2015;6. Available:https://doi.org/10.3389/fpls.2015.00340
35. Manghwar H., Hussain A., Ali Q., Liu F. Brassinosteroids (BRs) role in plant development and coping with different stresses. Int J Mol Sci. 2022;23(3):1012.
36. Xu B., Yu JY., Xie T., Li YL., Liu MJ., Guo KX., Li LH., Yu Y., Zheng CY., Chen YH., Wang G. (2018) Brassinosteroids and iron plaque affect arsenic and cadmium uptake by rice seedlings grown in hydroponic solution. Biol Plant., 62:362–368.
37. Prasad BD, Sahni S, Krishna P. et al. De Novo Transcriptome Assembly and Identification of Brassinosteroid Biosynthetic Pathway in Safflower. J Plant Growth Regul. 2022;41:1854–1870.
38. Chaudhary B, Prasad BD, Sahni S. *et al.* Brassinosteroid mediated modulation in the gene expression analysis of genes associated with arsenic uptake and transport in rice (*Oryza sativa* L.) for Effective Mitigation of Arsenic. J Plant Growth Regul; 2023. Available:https://doi.org/10.1007/s00344-023-11073-1
39. Zafar SA, Zaidi SSEA, GabaY, Singla-Pareek SL, Dhankher OP, LiX, Mansoor S, Pareek A. Engineering abiotic stress tolerance via CRISPR/Cas-mediated genome editing. J Exp Bot. 2020;71(2):470-479.
40. Chen Y, Sun SK, Tang Z, Liu G, Moore KL, Maathuis FJM. et al. The nodulin 26-

like intrinsic membrane protein OsNIP3;2 is involved in arsenite uptake by lateral roots in rice. J Exp Bot. 2017;12:e0173681.

41. Fiaz S, Ahmar S, Saeed S, Riaz A. Mora-Poblete, F.; Jung, K.-H. Evolution and Application of Genome Editing Techniques for Achieving Food and Nutritional Security. Int. J. Mol. Sci. 2021;22:5585. Available:https://doi.org/10.3390/ijms22115585
42. Norton GJ, Deacon CM, Xiong L, Huang S, Meharg AA, Price AH. Genetic mapping of the rice ionome in leaves and grain: identification of QTLs for 17 elements including arsenic, cadmium, iron and selenium. Plant Soil. 2010;329: 139–153.
43. Prasad BD, Jha S, Chattoo BB Transgenic indica rice expressing Mirabilis jalapa antimicrobial protein (Mj-AMP2) shows enhanced resistance to the rice blast fungus *Magnaporthe oryzae.* Plant sci. 12008;75(3):364-371.
44. Prasad BD, Kumar P, Sahni S, et al. An improved protocol for agrobacterium-mediated genetic transformation and regeneration of indica rice (*Oryza sativa* l. Var. Rajendra kasturi). J Cell Tissue Res. 2016;16(2):5597–5606.
45. Sahni S, Prasad BD.Salicylic acid induced resistance against mungbean yellow mosaic virus (MYMV) and enhanced seed yield in resistant and susceptible urdbean [*Vigna mungo* (L.) Heper] genotypes. Legume Res. 2022;45(1):97-103.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/111138