Review Article

MITIGATION OF ARSENIC CONTAMINATION THROUGH BIOTECHNOLOGICAL APPROACHES IN RICE

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.

Keywords: Arsenic, Brassinosteroid (BR), CRISPR-Cas9, QTLs

Introduction

Arsenic toxicity poses a significant threat to sustainable agriculture by adversely affecting soil, water, plants, and human health (Prasad et al., 2020). 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 harmfulmaterials by the Agency for Toxic Substances and Disease Registry and United States Environmental Protection Agency (Roy and Saha., 2002). It is sometimes referred to as the "king of poisons" because of its extreme toxicity (Shaji et al., 2021).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) (Shaji et al., 2021).The intake of groundwater contaminated with arsenic affects almost 300 million people globally (Kumar et al., 2021). 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 (McArthur, 2019; Shaji et al., 2021). 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 (Shaji et al., 2021). There has been a rise in arsenic poisoning cases in Bihar (Kumar et al., 2021).

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 (Phan et al., 2010; Flanagan et al., 2012; Kumar et al., 2021). 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., 2014; Sharma and Kumar 2019). 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 (Kumar et al., 2021; Brammer and Ravenscroft, 2009). 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, 2002; Sahoo and Kim, 2013; Shaji et al., 2021).

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., 2020; He et al., 2021). 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 (Zhao et al., 2010). 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., 2010; Chakraborty et al., 2015). 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., 2006; Khan et al., 2010; Chakraborty et al., 2015), reaching as high as 1800 μg/L (Alam et al., 2003). 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 (Khan et al., 2010). Compared to other cereals like wheat, rice can accumulate arsenic up to ten times higher in concentrations (Karagas et al., 2019). Additionally, rice-based products including those ingested by infants and young children were indicated to contain high quantities of inorganic arsenic (Davis et al., 2017). 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 (Liao et al., 2010).

The identification and introgression of QTLs related to arsenic are among the preferred strategies for arsenic mitigation in crop plants (Zhang et al., 2008; Adeva et al., 2023).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 (Pinson et al., 2021). For each As-associated trait, several QTL (ranging from 9 to 33) were identified (Pinson et al., 2021). 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 (Zhang et al., 2008).

Phytohormones play a crucial role in arbitrating cellular responses to numerousenvironmental stimuli (Vos et al., 2015; Ku et al., 2018). The protective role of salicylic acid (SA) against abiotic and biotic stress are well documented in crop plants (Prasad et al., 2009; Noriega et al., 2012; Kumari et al., 2022; Sahni et al., 2021; Sahni and Prasad 2022). Recent studies showed the modulation of genes related to heavy metal stress in plants (Noriega et al., 2012; Singh et al., 2015). Exogenous treatment of SA was found effective in mitigating arsenate (AsV) toxicity in rice by lowering translocation to the shoots (Singh et al., 2015). 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) (Singh et al., 2015).

Brassinosteroid (BR), a plant steroidal hormone, known to play an important role for plant growth and development, modulating stress responses and shieldingfrom heavy metal toxicity (Manghwar et al., 2022; Sahni et al., 2016; Xu et al., 2018; Prasad et al., 2022; Chaudhary et al., 2023). 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 (Chaudhary et al., 2023). Further, BRs has shown the significant reduction in accumulation of arsenic rice grown under naturally arsenic-contaminated soil (Chaudhary et al., 2023).

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., 2020; Kumari et al., 2022). The well-developed rice transformation protocol facilitates faster adoption of gene editing technology in rice (Prasad et al., 2008, 2009; 2016). 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 (Chen et al., 2017; Fiaz et al., 2019; Chaudhary et al., 2023). The role of *OsLsi1* and *OsLsi2* in arsenic translocation in rice plants are well described (Singh et al., 2015; Chen et al., 2017; Chaudhary et al., 2023).

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.

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