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Arsenic Uptake, Transport, Accumulation in Rice and Prospective Abatement Strategies - A Review

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Abstract: Recent reports claim that arsenic (As) toxicity affects millions of individuals worldwide. A significant problem for rice output and quality as well as for human health is the high content of arsenic (As), a non-essential poisonous metalloid, in rice grains. Therefore, substantial research has been done on the interactions between rice and As in recent years. As rice plants uptake at the root surface is impacted by factors like radical oxygen loss and iron plaque. The absorption and movement of various As species as well as the transfer to sub cellular compartments include a multitude of transporters, including phosphate transporters and aquaglyceroporins. As III and AsV are transported into the root by phosphate transporters and intrinsic channels that mimic nodulin 26. The silicic acid transporter may have a substantial impact on how methylated As, dimethylarsinic acid (DMA), and monomethylarsonic acid (MMA), enter the root. The issue of As contamination in rice is being addressed by researchers and practitioners to the best of their abilities. Making better plans may be aided by recent research on rice that explains the processes of arsenic ingestion, transportation, and metabolism at the rhizosphere. Common agronomic techniques, such as collecting rainwater for agricultural irrigation, using natural substances that aid in the methylation of arsenic, and biotechnology methods, may be investigated in an effort to lessen the uptake of arsenic by food crops. Innovative agronomic techniques and recent research findings on arsenic contamination in rice crops will be included in this review.

Introduction

Due to arsenic's durability and mutagenicity on living creatures at certain quantities, arsenic pollution on the environment from both natural and human-generated origins is presently a serious environmental issue in many regions of the world (Arslan et al., 2016). Arsenic is a formidable environmental pollutant that has caused one of the largest public health virulent in the history of human civilization (Howladar et al., 2019). Drinking water in regions of India and Bangladesh may possess upwards of 50 g/L of arsenic, however arsenic concentrations in paddy fields may reach 400 g/L due to the consumption of arsenic tainted groundwater for sprinkling (Saha et al., 2017). Rice, the major cereal crop for half of the global consumption, is particularly effective at absorbing arsenic from the soil and thus constitutes a significant health threat to humans (Ye et al., 2017). Arsenic (As) is the world's twentieth highest prevalent chemical exist as metalloid (Kobya et al., 2020). Nevertheless, As is a hazardous metalloid that has been identified as a significant worldwide groundwater contaminant, affecting specific watersheds in the Eastern and Southern parts of Asia and Deltas, in addition to nations in South America (Abedi and Mojiri, 2020).

Arsenic is typically present in soil as both inorganic substances like arsenate As(V) and arsenite As (III). Through microbial action, inorganic arsenic species can be methylated to produce monomethylarsonic acid

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(MMA) and dimethylarsinic acid (DMA). Plant roots system may assimilate both organic and inorganic arsenic species which are present in the paddy soil in solution phase (Bhattacharya et al., 2010). Since As(V) is the predominant form in an oxidized environment and is easily scavenged by iron oxyhydroxide, it serves as a beneficial method for preventing arsenic accumulation during rice cultivation (Ahoulé et al., 2015). On the other hand, under highly reduced conditions, As(V) is converted into As(III), which precipitates out from the solution in sulfur minerals, primarily arsenopyrite (Hele and Moloro, 2023). Anoxic conditions are created in paddy soils as a result of flooding type irrigation, which encourages the release of arsenic from soils and sediments and so enhances the bioavailability of rice plants. Different chemical species of arsenic can be discovered as contaminants in food and drink, which has an impact on the absorption mechanism (Williams et al., 2007). Inorganic arsenic (As) is a contaminant that is poisonous and cancerous and it has long-term effects on both human well-being and environmental quality (Abou-Shanab et al., 2022).

Arsenic may be present in both non-living and natural forms in the surroundings. Arsenite As(III) is the major arsenic form in agricultural field, accounting for sixty three percent of overall arsenic in land, trailed by arsenate As(V) at thirty six percent and methylated arsenic species (Mitra et al., 2017). Each of the following forms of arsenic penetrates the plant cell via unique conveyer proteins. Arsenic, a phosphate analogue, arsenate prevents plants from producing ATP and phosphorylating their own phosphate, whereas coupling arsenite to protein sulfhydryl groups causes disruptions in the formations and/or catalytic functions of proteins (Awasthi et al., 2017). Poisonous effects of arsenic provide impact in plants which has been demonstrated by biological effects such as diminished root elongation, discolouration in foliage, shrinkage and necrosis in those parts that are exposed out in the air and grow above the soil and so on (Carbonell et al., 1998). Arsenic can substantially impede plant development after root-to-shoot translocation by inhibiting biomass buildup and lowering procreative capability via decreased fertility, productivity, and fruit yield (Garg and Singla, 2011). Slower growth, brown spots, and leaf burning are some of the poisoning indicators in paddy plants growing in soils with more than sixty mg kg^{-1} total arsenic are experiencing (Bakhat et al., 2017). The roots are the most vulnerable to arsenic exposure which might impede their expansion and propagation. Arsenic build-up in plants typically reduces from root to above ground portions due to translocation (Mitra et al., 2017). When consumed in large quantities, this compound can interact with crucial metabolic activities, resulting in death (Finnegan and Chen, 2012).

Due to its extensive usage, arsenic in rice is becoming a worldwide problem (Meharg et al., 2009). Substantial modern biological research has been revealed how plants react to arsenic induced stress. Modify the other mineral components in the soil, such as iron (Fe), silicon (Si), phosphorus (P), and sulphur (S), to replacement portions of arsenic in order to decrease its fluidity and availability to plants (Bakhat et al., 2017). Due to the fact that both phosphorus and arsenic are the members of group Va in the periodic table, which are chemically alike. As and P compete for same uptake carriers in the plants cell membrane since of their position in same group of periodic table (Begum, 2016). Competitive biogeochemical reaction process between phosphate and arsenate control the fate and bioavailability of arsenic in the environment. In soil, As predominantly exists in the inorganic forms [arsenate, As(V) and arsenite, As(III) with minor concentration of dimethylarsinic acid (DMAA) and monomethylarsenic acid (MMAA)]. Because of their physico-chemical similarity, As(V) and Pi ions interact strongly competing for the same charged surfaces in soil. Arsenate uptake by plants occurs via the similar carrier process with Pi having more affinity for transport sites than As(V) (Strawn, 2018). Attempts have been made to condense knowledge on the bioavailability of arsenic to rice through soil, its absorption, storage, and oxidative stress in rice, as well as realistic, economical agronomic remedies to diminish the contamination of As in rice discussed in this review paper.

Arsenic Ingestion, Transport, and Retention in the Rice Plant

Arsenic (As) pollution exhibits an extensive effect on rice than other agricultural plants. Because of the flooding which occurs during its cultivation, the soil is reduced. The most common As species that exacerbate agricultural soil conditions are organic and inorganic arsenite As(III) and arsenate As(V), which can be discovered in the environment, trailed by methylated As species. Furthermore, some arsenic forms may be specifically absorbed by plant roots system.

Ingestion and Transport of Inorganic Arsenic Species:

There are two processes through which rice roots system absorb inorganic forms of arsenic. Through the high affinity phosphate transporter (PT), As(V) has transported from soil solution to aerial parts of the plants (Gupta et al., 2011). The 13 OsPT genes in rice that code for the transporters OsPT1 through OsPT13 makes up the phosphate transporter gene family (Madrid-Delgado et

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al., 2021). Arsenate is transported from the root to the shoot via OsPT1 (Kamiya et al., 2013). OsPT8 has been demonstrated to significantly impaired root elongation, despite being a necessary carrier protein for taking arsenate through rice roots system. Additionally, plants have accumulated more arsenic as a result of OsPT8 over expression (Wang et al., 2016). The second pathway through which aquaporin channels in root cells take up As(III) (Tang and Zhao, 2021). Lsi1, a major silicic acid inflow carrier that is similar to Nodulin 26 (OsNIP2;1), allows As(III) to enter rice root cells, whereas Lsi2, a silicon exporter, enables As(III) outflow to the xylem (Paola et al., 2014). Due to the Lsi1 protein channel's reversible action, portion of the As(III) received by root cells is quickly released into the rhizospheres (Zhao et al., 2010). In plant tissues, As(V) is converted to As(III), which is then disseminated to various organs by being stored in root vacuoles or moving to shoots (Mitra, 2014). Inorganic arsenic species cannot be methylated by rice, hence methylated arsenic species are mostly obtained from the rhizosphere through microbial methylation (Jia et al., 2013).

Ingestion and Transportation of Arsenic Species (Organic)

Arsenite is a major wetland species and microbial diversity in its inorganic to organic forms, with significant amounts of methyl arsenic forming dimethyl arsenic acid (DMA) and to a lesser extent monomethyl arsenic acid (MMA) is produced in rice soil (Adomako et al., 2011). Methylated arsenic species, as opposed to pentavalent arsenic species, are less dangerous as a result of this change into an organic state. As an inorganic arsenic species, the hypomethylated species absorption mechanism has undergone substantial study. Through the intrinsic macromolecule that resembles nodulin 26, MMA and DMA are jointly involved. While roots digest inorganic arsenic species As(III) and As(V) more effectively than arsenic species that are methylated (DMA and MMA), the pace of inorganic arsenic species transit in plant shoots is much faster. Lower complexity in the synthesis of arsenic species after methylation by ligands (glutathione/phytokeratin) may be caused through better translocation of methylated arsenic species (Raab et al., 2007). The most prevalent individual in the species that are plentiful in rice grains was discovered to be As(III), trailed by DMA (Huang et al., 2012). In rice straw, on the contrary, As(V) is the major species, trailed by As(III) and DMA (Zhao et al., 2013).

Retention of Arsenic in Rice Grain

Inadvertently transporting arsenite through the silicic acid transporter, rice is the highest efficient Si transporter of any agricultural plant (Norton et al., 2010). As(III) is transported to the xylem by the Silicon transporter OsNIP2;1 (Lsi1), and Lsi2 drives As(III) out of rice root cells (Ye et al., 2017). In exodermal and endodermal cells, Lsi1 controls the entrance of As(III) and is found on the distal portion of the plasma membrane. The release of As(III) from the proximal surfaces of similar root cells is regulated by Lsi2 (Zhao et al., 2010). In other words, Si and As(III) are transferred inside the root cells via Lsi1 and Lsi2 working together. Prior to Lsi 6, which is found in the xylem parenchyma cells of the leaf, Lsi1 and Lsi2 convey xylem vessels to the shoot via evaporation activity in the Si and As(III) (Lin et al., 2019). As(V) may be transported to the root by 13 Pi transporter genes (OsPT) in rice. Several genes are implicated in the absorption and translocation of Pi in rice, including "OsPT1, OsPT2, OsPT4, OsPT6, OsPT8, OsPT9, and OsPT10 (Cao et al., 2017). OsPT1 is one of these OsPTs, clearly explained in roots serve as Pi's primary regulator. OsPT2 is essential for Pi to transfer from the stem to its roots (Yang et al., 2018). Within the rice root, As(V) may be converted to As(III), and As(III) can then move into the xylem by a silicic acid/ As(III) effluxer (Carey et al., 2009).The beginning of arsenic decontamination in rice seedlings may be indicated by a decrease in arsenate. Rice arsenate reductases, such as OsHAC1;1, OsHAC1;2, and OsHAC4, have been discovered by researchers that help in the regulation and conversion of arsenate to arsenite. The discovery of majority of these genes has been traced in roots. These genes accelerate a process in the exterior cell layer of roots, enabling the outflow of arsenite from the root soil. In contrast to OsHAC1;2 which is prevalent in the pericycle, root hair, and epidermis predominate in the outer cortical layer, endodermis, and epidermis (Shi et al., 2016). OsHAC4 is primarily found in the epidermis and exodermis, there is a root elongation and mutation zone (Xu et al., 2017). Rice arsenic build-up was greatly reduced and arsenite outflow into the external medium was significantly boosted by over expression of OsHAC1;1 and OsHAC;2 (Shi et al., 2016).

As opposed to that, OsHAC1;1, OsHAC1;2, and OsHAC4 mutation increased arsenic build-up in the root and grain and decreased arsenate reduction in the root (Xu et al., 2017). A significant method of arsenic decontamination in different plant species, in addition to arsenate, is phytochelatin-arsenite complexation and consequent sequestration inside vacuoles (Song et al., 2014). Phytochelatin (PC) is synthesized from glutathione (GSH), which is a precursor molecule, tolerance to arsenic. Gly and ɣ-glutamylcysteine (ɣ-EC) undergo an ATP-dependent reaction to produce GSH. Plants produce intermediary ɣ -ECs within the plastid, which are then transferred to the cytosol via a protein that resembles CRT (CLT) (Hernández et al., 2015). OsCLT1, a similar transporter, is responsible for the transfer of ɣ -EC and GSH from plastids to the cytoplasm via GSH homeostasis (Yang et al., 2016). As a result of increased arsenic storage in vesicles caused by the presence of a tonoplast carrier (OsABCC1) in phloem partner cells, the amount of arsenic transported into rice grains is reduced (Song et al., 2014). DMA and other methylated arsenic species, in particular, are mobilised more quickly than inorganic species, and their redistribution in the embryo, endosperm, and aleuronic layers may hinder seed germination and induced less yield and spikelet sterility (Zheng et al., 2013). The kind of rice cultivar, plant physiology, location of cultivation, and manner of rice processing are the key factors that determine arsenic deposition in rice grains. Brown rice species was shown to have greater arsenic contents than white rice species (Bakhat et al., 2017). Specific transporter proteins enable the passage of all As species through the plant cells (Mitra et al., 2017).

Impacts of several factors on lowering the uptake of arsenic by plants

Arsenic uptake by different plant species may be influenced by a number of factors, including pH, the composition of the earth's crust, the amount of decaying matter (OM), and the content of sulfur dioxide (SO_2) (Hossain, 2015). Soil properties may have an effect on As mobility because changes in charges on the soil surface that control the adsorption as well as the desorption processes in soil. Substantial clayey soil has a better potential for As accumulation than soils with a coarse texture. It's also claimed that plants grown in loamy sandy soil absorb and concentrate as more as those cultivated in silt clay loamy soils (Bakhat et al., 2019). Additionally, the toxicity of As is approximately five times greater in sandy and loamy than in clayey soil, and the association between phytotoxicity and As is significantly impacted by its accessible form (Quazi et al., 2011).

Soil pH

As uptake has significantly influenced by pH. As in soil is frequently mobilized when the pH has been raised. Anions, as well as As(V) and As(III), are typically released from their exchange sites when soil pH rises. According to research As species are influenced by redox potential and pH (Islam, 2016). For example, in oxidizing conditions, $HAsO_4^{2-}$ dominates at high pH whereas H_2AsO_4 emerges as the dominant species at a pH of less than 6.9. The dissociation of arsenic from iron oxides and subsequent engagement of arsenic in the root area are made possible by high soil pH (typically pH 8.5), which increases the negative surface charges like hydroxyl ions. As a result, these circumstances encourage As accumulation in plant species (Mitra et al., 2017).

Organic Content of the Soil

Negative charges such as phosphate, DOC, and silicate, reactions involving redox substances, aggressive retention, and As-organic materials (OM) complexation are just a few of the ways that OM in soil may alter the mobility and accessibility of As. In rice plants, OM may potentially have an impact on As accumulation and plant growth. Theoretically, As can interact with phenol OH, carboxylate, and groups of sulfhydryl chains with or without triad complexes to become insoluble when OM is present in soil (Syu et al., 2019). According to Norton et al. (2013) OM is essential for the mobilization of As from rice fields because of the bacteria that utilizes it consumed oxygen, lowering the redox potential and causing As to dissolve from FeO-OH. Before adding alterations to As-contaminated soils Syu et al., 2019 noted that the characteristics of the soils and OMs should be taken into account. Different impacts on the As accumulation and rice plant growth may result from the application of OM in As-contaminated top soil (Syu et al., 2019). Adding farmyard compost to As-rich soils, for example, decreases plant growth (Norton et al., 2013). However, biochar may enhance As diminution and discharge in waterlogged paddy soils (Qiao et al., 2018). According to Norton et al. OM may also alter the availability of As in soils by removing As species from sites of soil surface swap and combining As species with soluble organic material (DOM).

Nitrogen, phosphorus, and sulphate concentrations in soil

In soils where rice grows, ammonium predominates over other forms of nitrogen (N), with nitrate concentrations just under 10 μM. The roots of this rice plants provide oxygen to the rhizosphere, which in turn prompts bacteria at the root surface to begin nitrifying ammonium (Srivastava et al., 2019). The nitrogen cycling mechanism could have an effect on Iron redox cycling. As in paddy settings, the combination of NO_3^- reduction and Iron(II) oxidation might decrease (Kumarathilaka et al., 2018).

Phosphate transporters help rice plants take up As(V) (Cao et al., 2017). Due to their analogous nature,

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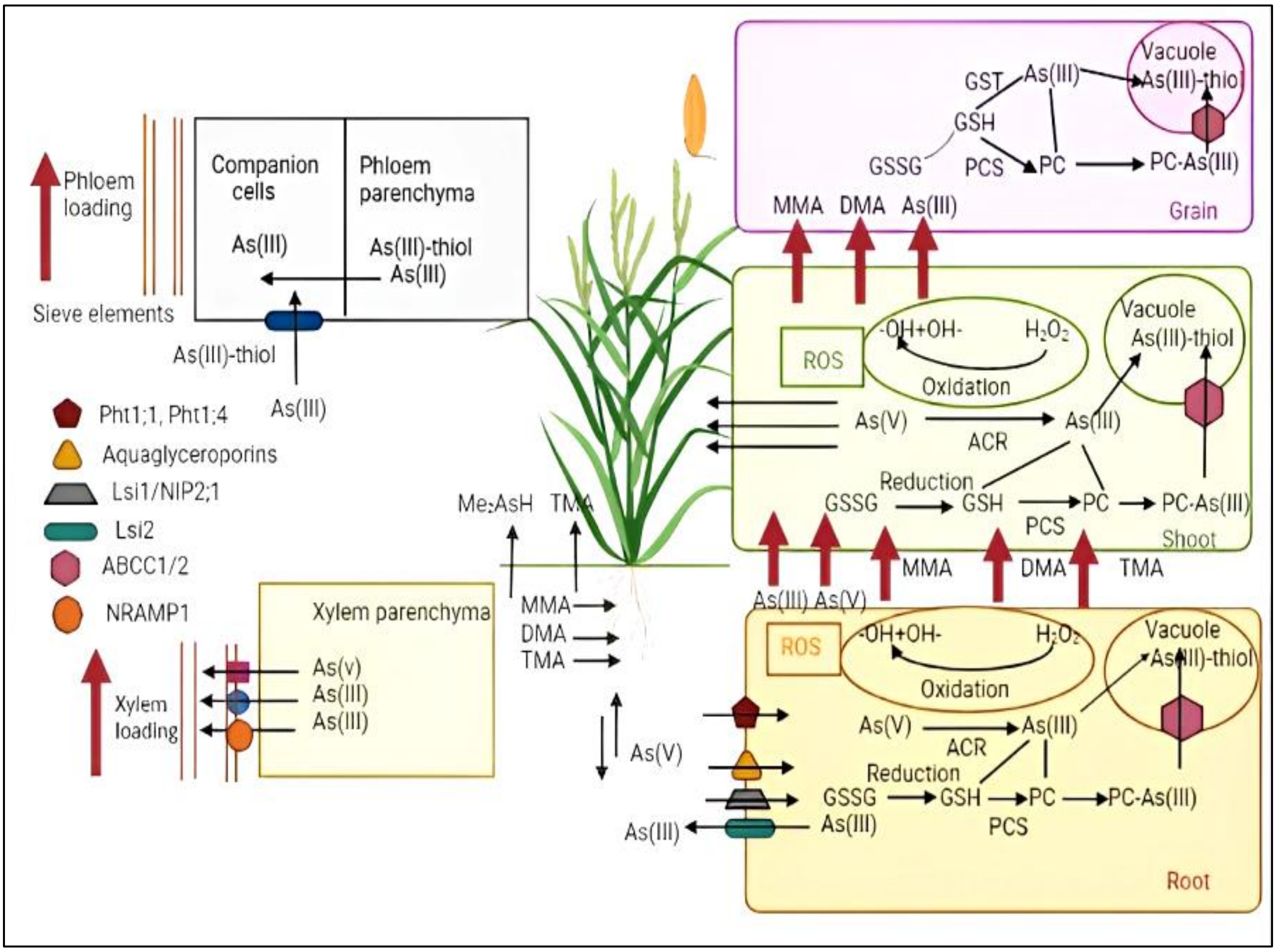

Figure 1.Arsenic uptake, translocation and accumulation in rice plant

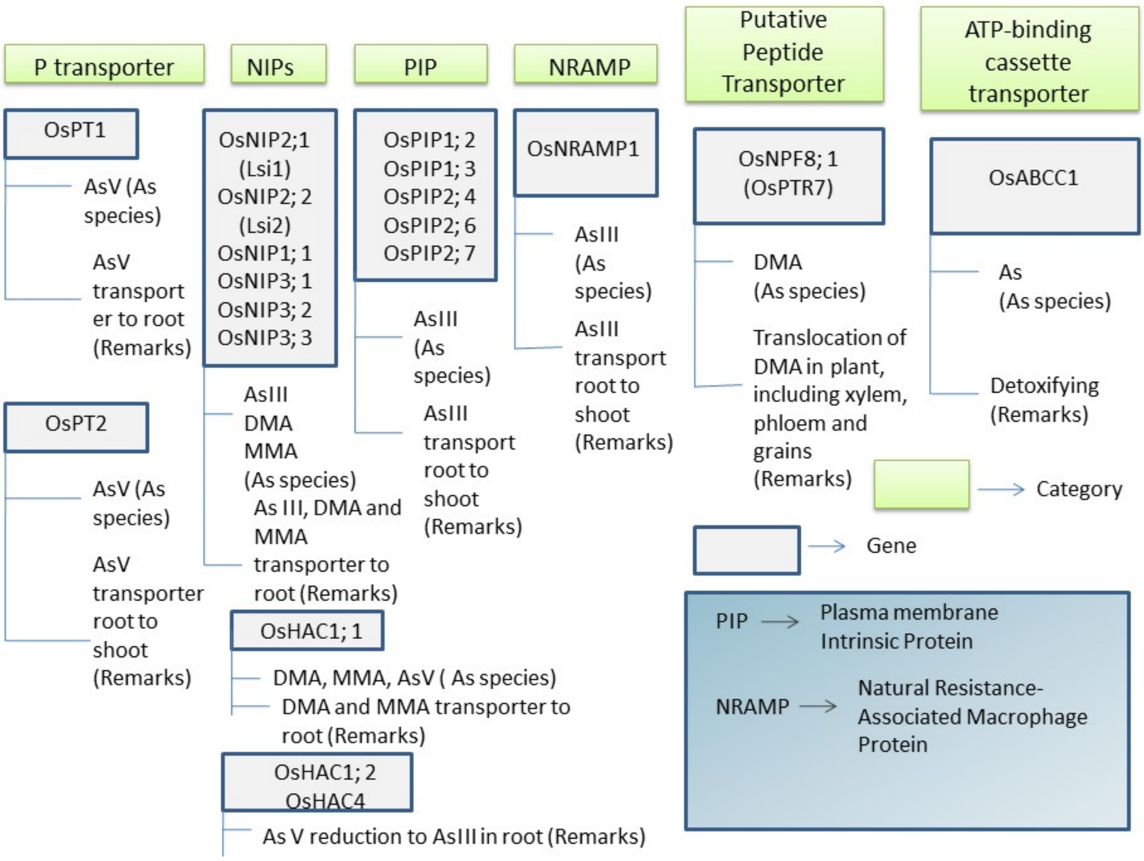

Figure 2.Gene families involved in As uptake, transport and metabolism in rice (Abedi and Mojiri, 2020)

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phosphorus and arsenate are able to compete for identical locations for adsorption on soil particles. The addition of phosphate typically has two effects: (i) increased As leaching from the top soil due to a raised downward movement, and (ii) increased As accessibility in the soil solution. As(V) performs the same role as a phosphate counterpart in terms of travel through the root plasma membrane (Seyfferth et al., 2010). According to Pigna et al. (2010), As toxicity in crops may be common when As pollution coexists with little accessible Pi.

Sulphur (S) is a component that seems to have difficulty in interactions with As, notably when diminished; lowered forms of S can bind to As(III). S controls how effectively plants develop, making it necessary for the development. S-containing ligands like PCs (GSH oligomers) and glutathione (GSH; -Glu-Cys-Gly), which control As tolerance, make As complex and varied according to Srivastava et al., 2016 In high sulphate pre-treated rice plants, Zhang et al., 2011 showed a decrease in the translocation of As from roots to shoots.

Iron and manganese concentration in soil

It has been reported that As(V) substantially consumed by iron and manganese-rich substances including pyrolusite, goethite, smectites, nontronite, ferruginous and birnessite (Anawar et al., 2018). As a result, movement may be limited. On the roots of freshwater plant species, iron plaque, a covering of Fe hydroxides and oxides, commonly develops. When roots oxidize, oxygen and other oxidants have been released into the rhizosphere, causing iron plaque. Iron plaque may prevent plant species from absorbing As because of its adsorption or co-precipitation processes. According to Yu et al., 2016 who also proposed that unstructured Fe oxides may function as a deterrent to the plant's absorption of As, Arsenic in rice grains and unstructured linked to Iron oxide like soil were discovered to be negatively associated. Mn and Fe plaque, in accordance with might lessen rice seedlings' assimilation (Huang et al., 2012),

Rice Plant Response to Arsenic-Induced Oxidative Stress

Countless articles have been written about oxidative stress along with the defence mechanisms in arsenic-stressed plants (Thakur et al., 2016). Arsenic releases reactive oxygen species (ROS) when it converts As(V) to As(III), which is then accompanied via the redox-driven process of methylation, which may also release ROS (Anyanwu et al., 2018). Tetra-methyalarsoniumion and tri-methylarsonium oxide (TMAO) are methylated forms of arsenic that combine with molecular oxygen to produce reactive oxygen species (ROS) in the biological environment (Sharma, 2012). Due to the iron released from ferritin, dimethylarsinic acid (DMA) induces Fe-dependent oxidative stress, which damages the structure of DNA. It is well known that plants produce ROS after being exposed to inorganic arsenic species, including superoxide, the hydroxyl radical, and H_2O_2 (Mallick et al., 2011).

Arsenic toxicity in plants has been mitigated by a number of intrinsic mechanisms, including phytochelatin (PC) dependent detoxification (Lakshmanan et al., 2015). By increasing PC-synthase activity and coordinating thiol metabolism, rice is able to tolerate arsenic by synthesizing more PCs (Chatterjee, 2013). Additionally, the transport of arsenic from rice leaves to grains has been decreased by PC-arsenite complexation in rice leaves (Chatterjee, 2013). Fe also aids in lowering rice plant arsenic build-up. In soil, iron is typically found insoluble and oxidized Fe(III) form, but after flooding in a rice field, iron undergoes a chemical shift to ferrous Fe(II) form, which quickly leaches out of the ground and traps arsenic (Stroud et al., 2011). In addition to preventing the accumulation and speciation of arsenic, Fe has an enhancing effect on regulating oxidative stress responses.

Risk of Arsenic to Human Health from Rice Diet

Research has been revealed that rice is a staple crop and arsenic contaminated rice has negative effects on human health. Rice is a leading source of arsenic exposure in many countries throughout the world. According to a study by Banerjee et al., 2013, consumption of 500 grams of boiling rice daily that contains arsenic more than 200 mg kg^{-1} which causes human genotoxic effects.

Due to the tight relationship between thiol groups and As(III), Rahman et al. (2014) revealed that some rice cultivars with high protein contents increase arsenic bio-accessibility. However, owing to variations in how quickly arsenic is metabolized, consuming a diet rich in vegetables lowers the risk of developing skin lesions brought on by arsenic (Koch et al., 2013). However, how much arsenic speciates and enters the blood has also greatly influenced by the quantity of bacteria in the stomach. In the digestive tract, arsenic can be transformed biologically by oxidation, reduction, methylation, and thiolation processes. The endosperm cells of rice seeds have a higher propensity for thiol-containing amino acids to bind to inorganic arsenic species. Numerous research back up the idea that actual exposure to arsenic via food relies on the item's processing, cooking temperature, cooking time, and cooking medium. Arsenic level in rice can be decreased by cooking it for a long time in a lot of water (Rahman et al., 2014). To reduce arsenic in rice, studies must concentrate on the mechanisms of bioavailability, root ingestion, rhizosphere, transit, storage, and grain unloading (Wang et al., 2015).

been shown that bacteria or algae can decrease plants' uptake of As. By regulating because of the accessibility of nutrients through precipitation, redox reactions, complexation, and availability, flooded rice fields provide the ideal environment for the growth of microbes and algae (Srivastava et al., 2018).

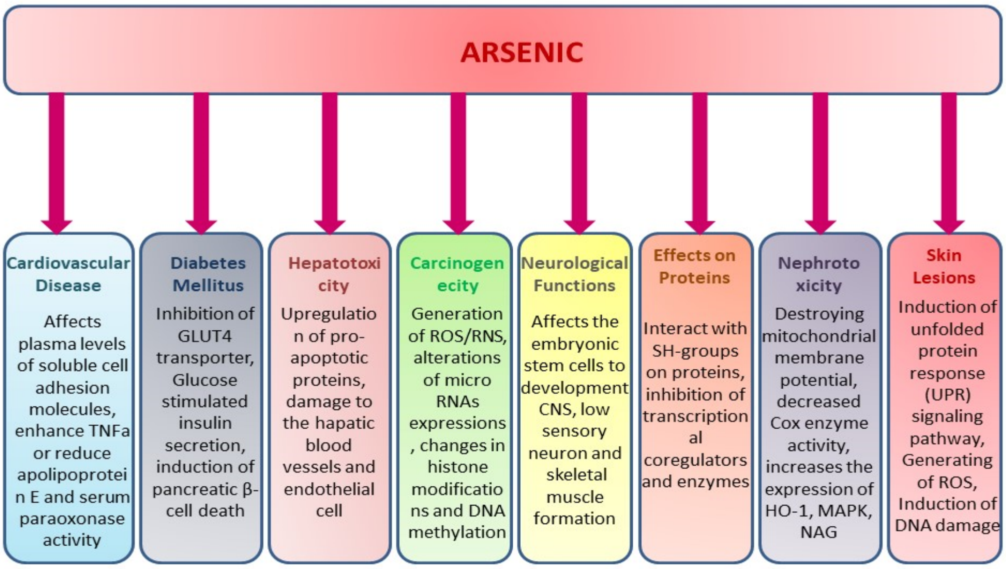

Figure 3. Schematic Diagram represents the toxic effects of arsenic in human

Agronomic Techniques for Lowering Arsenic Ingestion and Retention by Plants

Three main strategies were outlined by Awasthi et al. (2017) to reduce As absorption through rice: (1) agricultural methods; (2) altering the carriers resulting in acquisition and (3) regulating the transportation of Arsenic by affecting the development of chelators.

Researchers have experimented with various mitigation techniques to minimize As ingestion by rice for the agronomic strategy. Over breeding, biodegradation, transgenic and advanced fertilization are some of the methods used to reduce As contamination; nevertheless, each of these approaches has time, ethical, and practical restrictions (Srivastava et al., 2018). One method of reducing As uptake by plants is to use Fe oxides or hydroxides. According to Ultra et al., 2009, Am-Fe-OH soil additives can alter how readily As can be absorbed by rice plants that have been irrigated with As-contaminated water.

As a result, rice has been grown alongside accumulator plants including *Pteris vittata*, *Vetiveria zizanioides*, and *Phragmite saustralis*". It has also

Several agronomic strategies may be utilized to mitigate the consequences of arsenic build-up in rice. These methods include aerating the soil to stop arsenic from being reduced, promoting the development and settlement of arsenic that are not soluble in the soil, and boosting the amount of mineral elements that compete with arsenic absorption. Plants containing arsenic represent a danger that can be reduced by using effective remedies (Bakhat et al., 2017).

1. Adding minerals to the soil as fertilizer.
2. Techniques for irrigation and water treatment.
3. The use of bioremediation.

ACR3 gene in root cell [enhances As(III) efflux], Ars M gene (leads to arsenic methylation and volatilization) are the basis of the technology. Another alternative is to use cultivation techniques in aerobic soil, where Fe plaque formation at the root surface and enhanced arsenic affinity for soil minerals restrict arsenic mobility and bioavailability, and where oxidative conditions prevent As(V) to As(III) conversion (having higher solubility, plant availability, and toxicity). The application of silicon (Si) inhibits the expression of the Lsi1 and Lsi2 transporters and competes with arsenic for the same

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transporter (L) during uptake, which has a negative impact on arsenic

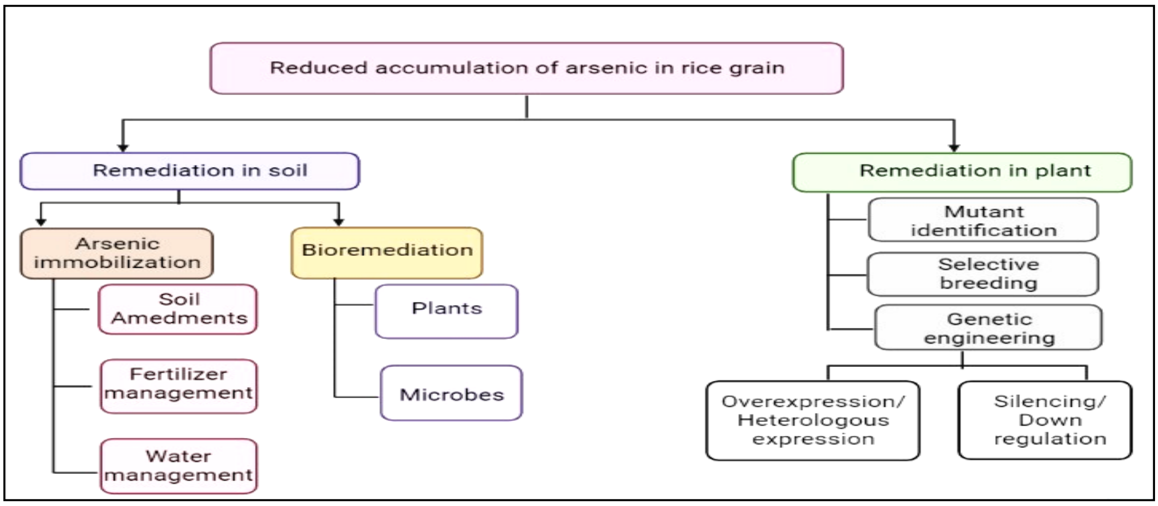

Figure 4.Schematic diagram represents the reduced accumulation in rice grain

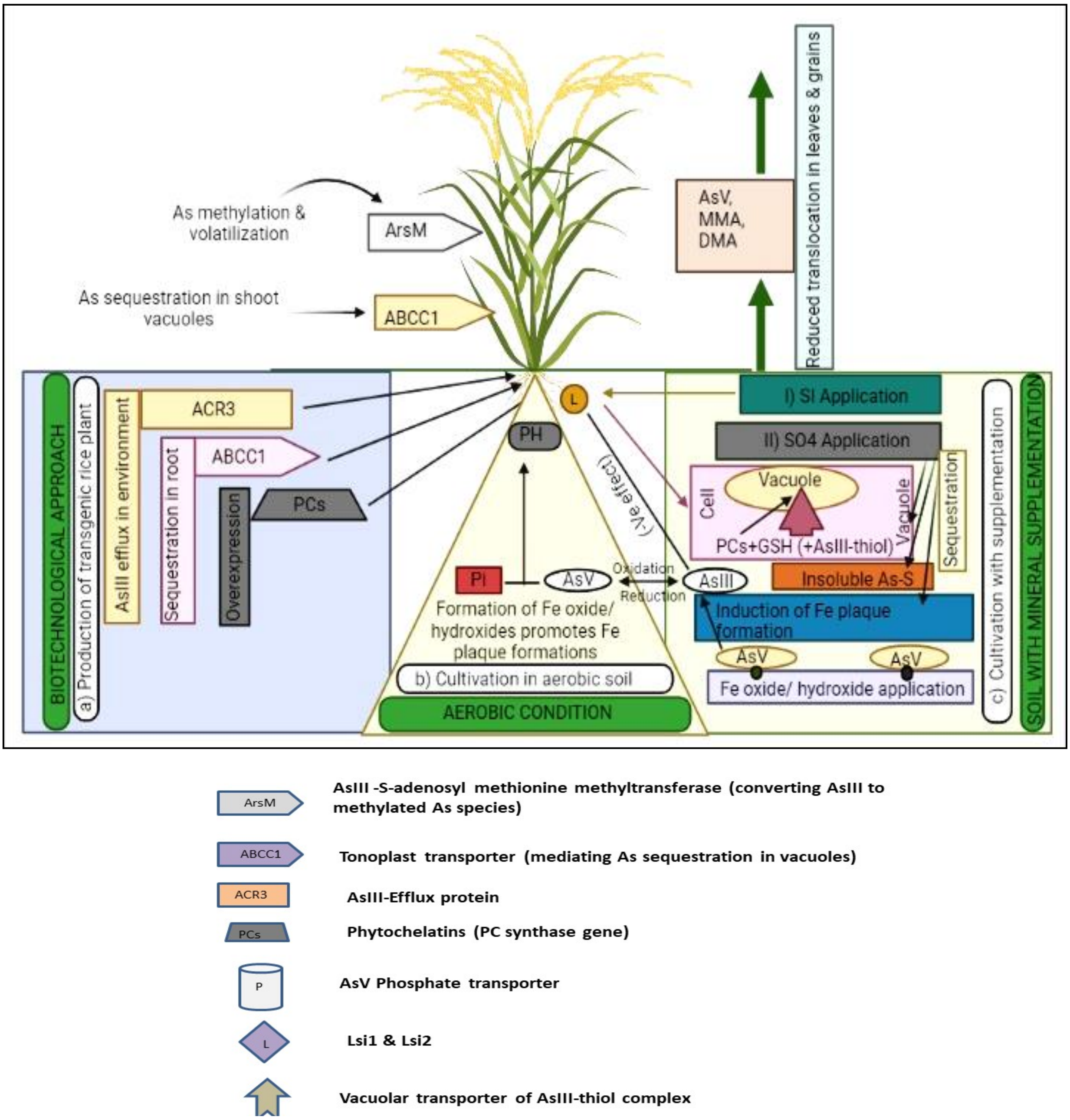

Figure 5. Diagrammatic representation of the biotechnological and agronomic methods for reducing arsenic accumulation in rice. (a) Using biotechnological methods, it is possible to produce transgenic plants that produce rice with low arsenic levels by over expressing one or more genes in plants, the ABCC1 transporter protein (in roots and shoot leads to arsenic vacuolar sequestration within roots and nodes

uptake. The application of SO_4 has a few benefits, including the induction of Fe plaque formation, enhancement of the synthesis of thiol ligands (GSH/PC), increased arsenic-thiol complexation, and production of insoluble arsenic-S complex due to strong affinity to arsenic under reducing environment.

Conclusions

Researchers have tried to limit the ingestion of As by rice plants because rice is a significant dietary source of As. Regarding the amount of arsenic in rice and the variables affecting its bioavailability, absorption, accumulation, and toxicity, a variety of problems are now in existence. In the current study, a number of research articles have been examined to look at how arsenic travels into rice. All the variables, including potentially efficient biotechnological and agronomic methods to reduce arsenic ingestion, translocation, and retention in rice, have also been reviewed. While As(III) is more poisonous than As(V) among the arsenic species which are inorganic, arsenic after methylation are less dangerous. In the presence of soil rich in arsenic, the amount of arsenic that accumulates in rice largely depends on its bioavailability, which is controlled by a number of factors, including the properties of the soil, its physic-chemical makeup, the presence of numerous other components, and the mineral composition of the soil, including its iron, phosphorus, sulphur, and silicon contents. Other factors include the relationship between the soil, rhizosphere, and plants, as well as rhizospheric bacteria and their activity, organic matter, and associated microorganisms. Rice arsenic build-up may be reduced through the use of bioremediation techniques and changes to agricultural practices. Although scientists are focusing on various rice plant genes that are in charge of arsenic ingestion, transport, and/or detoxification in an effort to yield a more palatable crop, the usage of these genes under various field conditions and the ensuring high-quality rice production remain serious issues. Recent advancements in gene-editing technology aid scientists in understanding gene function and enhancing agricultural yield. Precise gene-editing is being attempted with the RNA-guided CRISPR/Cas9 system based on the CRISPER-Cas (Cluster Regularly Interspaced Short Palindromic Repeats -associated nuclease) of bacteria, in addition to other technologies like Transcription Activator— Like Effector Nucleases (TALENs) and Zinc-Finger Nucleases (ZFNs). By minimizing arsenic accumulation, there are now numerous potential to make rice grain safer due to the development of molecular biology technology. It is necessary to start with agricultural methods and work toward possible rice plant development and subsequent field deployments. To find a long-term solution for cleaning up arsenic-polluted soil and to ensure that economically significant crops are used wisely to decrease the amount of bioaccumulation and meet human food demand, in-depth multidimensional integrated investigations are required.

Conflict of Interest

None

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