ISSN: 2320-5407 Int. J. Adv. Res. 11(04), 1670-1679

Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/16838
DOI URL: http://dx.doi.org/10.21474/IJAR01/16838

ISSN NO. 2320-5407

RESEARCH ARTICLE

A REVIEW ON COMPREHENSION AND ACCRETION OF ARSENIC IN RICE (ORYZA SATIVA L.) PLANT

Priyadarshini Basak[1] and Dr. Bhaskar Choudhury[2]

1. Student of M.Sc., Guru Nanak Institute of Pharmaceutical Science and Technology, Kolkata-700114, West Bengal, India.
2. Associate Professor, Guru Nanak Institute of Pharmaceutical Science and Technology, Kolkata-700114, West Bengal, India.

……………………………………………………………………………………………………....

Manuscript Info

……………………..

Manuscript History
Received: 28 February 2023
Final Accepted: 31 March 2023
Published: April 2023

Key words:-
Rice Plant, Arsenic Toxicity, Phytochelatin, Reactive Oxygen Species, Carbohydrate Metabolism

Abstract

………………………………………………………………

Consuming rice exposes you to arsenic (As), which is dangerous for your health. The buildup of As in rice was investigated in this study. According to research, Bangladesh and Taiwan have higher levels of As buildup in their rice than other nations. Furthermore, the key elements affecting the uptake of As into rice crops are described. Additionally, it was investigated if it would be possible to use efficient methods to lessen the buildup of As in rice. Arsenic is a hazardous element that has the ability to harm people's health. In addition to being a source of both amino acids (AAs) and mineral elements, rice is an unwelcome supply of As for the billions of people who eat it as their main source of nutrition. A necessary metalloid called selenium (Se) has the ability to reduce As toxicity by enhancing antioxidant capacity. Through phosphate transporters and intrinsic channels that resemble nodulin 26, As(V) and As(III) are delivered to the root. The entry of methylated As, dimethylarsinic acid (DMA), and monomethylarsonic acid (MMA), into the root may be significantly influenced by the silicic acid transporter. DMA(V) is very mobile in plants and is quickly translocated from root to shoot among As species. The use of microalgae and bacteria is the most effective agronomic strategy for reducing the uptake and accumulation of As in rice.

……………………………………………………………………………………………………....

Introduction:-

A typical metalloid contamination of arsenic (As) that enters the soil-plant system by anthropogenic (mine activity, arsenic-containing pesticides, and industrial waste) and natural (geochemical processes) pathways (1). Bangladesh and Taiwan have higher levels of arsenic accumulation in rice plants than other nations (2). Because rice is extremely effective at absorbing arsenic from paddy soils, although the mechanism has not been fully understood, human arsenic intake through rice consumption can be significant (3). As absorption for a specific plant species is influenced by environmental elements such as soil type, nutrient availability, and medium pH. Therefore, understanding the connections between As and plant nutrients is crucial for creating a productive method of cultivating plants for phytoremediation. Environmental pollutant as arsenic is extremely hazardous to both plants and people and it is built up in rice grain poses a possible risk to human health. It enters soil through mining, burning coal, sewage sludge, and pesticide use then plants absorbs it and moves up the food chain, endangering

Corresponding Author:- Dr. Bhaskar Choudhury
Address:- Associate Professor., Guru Nanak Institute of Pharmaceutical Science and Technology, Kolkata-700114, West Bengal, India.

human health (4). Under anaerobic conditions, arsenate predominates, whereas under aerobic ones, As(V) does. Concerns about agricultural productivity and produce quality have arisen as a result of widespread aspirin overdose in South East Asia (5). Geochemical weathering of rocks and volcanic emissions are the natural sources of arsenic in the environment, but anthropogenic activities like the use of pesticides, wood preservatives, ore mining and smelting, and combustion are what primarily raise the level using fossil fuel. Arsenic's concentration may rise if underground water used for irrigation is used over an extended period of time in crop plants and eventually in agricultural soil (6). Many countries serve as an illustration of As naturally present in alluvial sediments that has been dissolved into groundwater. During the dry season, a large number of people depend on this groundwater for drinking as well as irrigation of paddy rice, which poses extra health problems (7). As rice content and species fluctuate greatly depending on agricultural conditions and rice processing techniques. As in rice grains, for instance, reduced by 41% under occasionally wet situations compared to continuously flooded plots (8) Additionally, samples of white rice that had been polished and washed had much lower As levels. As species and soil bioavailability are linked to the uptake of As by rice plants (8). As is the 20^{th} most plentiful element in the earth crust such as a poisonous metalloid, is noted as a significant global groundwater contamination that affects some rivers and deltas in East and South Asia as well as South American nations (2) One of the most dangerous substances that might be toxic to humans, according to the 2017 list published by the Agency for Toxic Substances and Disease Registry and this metalloid has exposed 200 million people in about 70 different countries (2). Because methylated organic forms of As found in plants are less harmful than inorganic forms, it is necessary to determine As speciation in order to evaluate the danger that As in the diet poses (9). A well-known As hyper accumulator is Pteris vittata, often known as the Chinese brake fern, it is a plant with an outstanding capacity for tolerance, uptake, and translocation of As (10). Understanding how these three elements interact to affect plant development and the uptake of As was anticipated to lead to effective remediation using Chinese brake fern (11). In agricultural fields treated with As-containing insecticides, the average concentration of As ranges from 5 to 2553 mg kg^{-1} and the various cycles of submerged and dry days are used to manage paddy soils for the wet cultivation of rice (2). These cycles lead to alternating oxidising and reducing processes in the soil and the natural sources like rocks, As-enriched minerals, forest fires, volcanoes, and anthropogenic sources including mining, herbicides, phosphate fertilisers, smelting, industrial operations, coal combustion, and timber preservatives are all ways that as penetrates agricultural fields and the environment (2). In many regions of the world, the amount of arsenic in groundwater is so high that it accumulates in irrigated crops. This dangerous substance, which has been linked to cancer and heart disease, is especially concerning in rice since it absorbs arsenic more quickly than other grains and is a staple food for billions of people. Bangladesh, India, and China are among the nations that experience the dual scourge of rice consumption and groundwater contaminated with arsenic (12). Cultural behaviours can be changed to reduce the build-up of As in rice. Therefore, the current research concentrated on the processes of As uptake and accumulation in rice as well as the practical elements that effectively lower As uptake by rice crops. We anticipate that the findings will improve our knowledge of how As is absorbed, transported, and distributed in rice.

Rice Plants' Absorption and Transport of Arsenic:

As pollution has a more significant impact on rice than other agricultural plants. Due to the cultivation being done in flooded conditions, the situation become worsted (2). Natural substances, both organic and inorganic, that can be discovered the predominant As species that improve paddy soil conditions are As(III) and arsenate As(V), followed by methylated As species. In addition, plant roots may preferably absorb particular form of As (13).

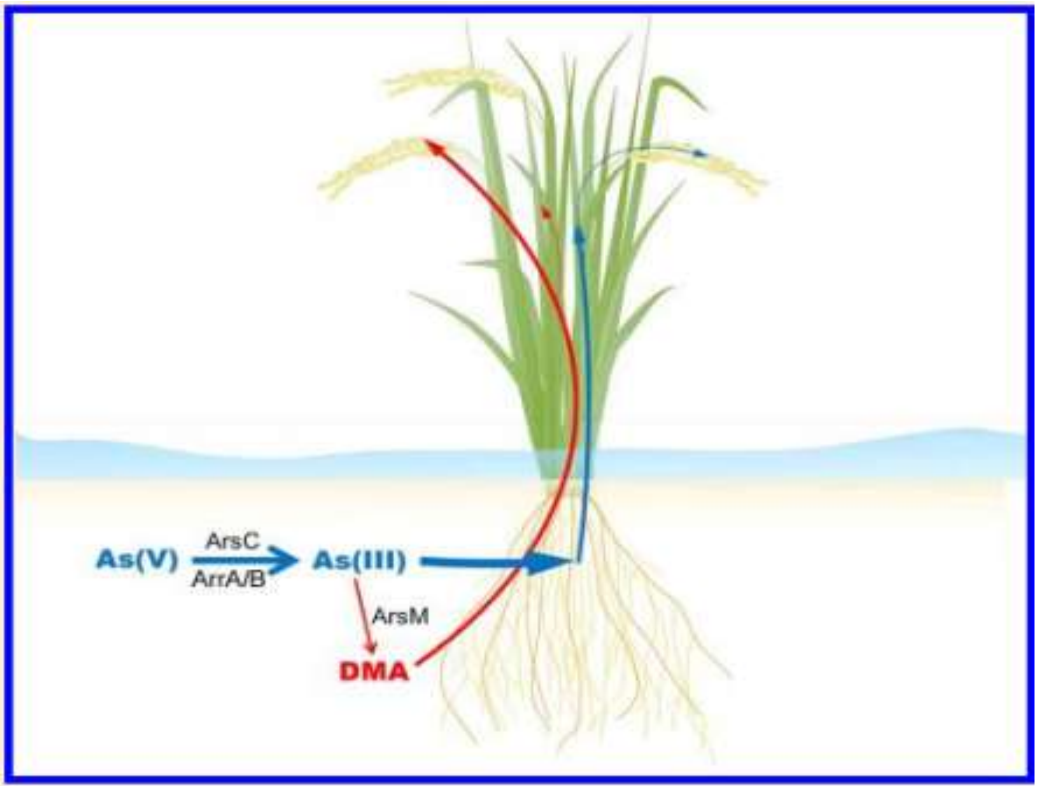

Fig1:- Mechanism of Accumulation of Arsenic (15).

Uptake of Organic Arsenic
Methylation due to microbial activity or previous use of methylated spirits, two species, MMA ($CH_3AsO(OH)_2$) and DMA ($(CH_3)_2AsOOH$), may be present in soil (14). Although plant roots are capable of absorbing DMA and MMA, the levels are lower than those of inorganic As species and decrease as the number of methyl groups increases (15). DMA (V) is easily transferred from root to shoot in plants due to its mobility. (2)

Uptake of Inorganic Arsenic
The predominant form of As in soil and groundwater is inorganic As. While As(V) predominates in aerobic soil conditions, As(III) predominates in submerged environments (16). When inorganic phosphorous (Pi) is being regulated, As(V) can typically enter the roots of rice plants via phosphate transporters (PHTs), particularly PHT1 (phosphate transporter1)-type transporters (17). It has been discovered that a total of 13 PHTs from the PHT1 family in rice (*Oryza sativa* L.) mediate Pi absorption and transport (18) via the incredibly effective silicon (Si) uptake pathway. Additionally, silicic acid and ammonia may also enter through the NIPs aquaporin channels, which are similar to nodulin 26 (14). One of the main intrinsic proteins that make up the family of significant membrane channel proteins are NIP proteins.

Transfer of Arsenic Species from Root to Shoot
Arsenic has a translocation factor that is often around 0.8, which is larger than that of other crops like wheat (0.2) and barley (0.8). (19). Similar to how soil water provides rice plants with numerous resources. Depending on the numerous physicochemical factors in the soil environment, one species of As in soil frequently predominates the others in terms of concentration. The As is easily translocated by DMA. Market samples were gathered, and samples from Taiwan Province were used in China. As previously indicated, As(III) is taken up by the Si transporter OsNIP2;1 (Lsi1), and As(III) is released from rice root cells and transported to the xylem by Lsi2 (20). Exodermal and endodermal cells' Lsi1 is found on the distal side of the plasma membranes and is in charge of As(III) 's influx, whereas the same root cells' Lsi2 is found on the proximal side and is in charge of As(III) 's efflux (15). In other words, Si and As(III) are transported into root cells by Lsi1 and Lsi2 working together. After Lsi1 and Lsi2, which are located in the xylem parenchyma cells of leaves, Si and As(III) in the xylem vessel are transferred to the shoot by transpiration flow (21). The Lsi6 gene, (22) is essential for Si or maybe As(III) distribution in rice shoots. Inside

the rice root, As(V) may be converted to As(III), and As(III) may subsequently enter the xylem by a silicic acid/ As(III) effluxes (23). High As content 1 (HAC1) As(V) reductases have the ability to convert As(V) to As(III) fast in plant cells (23). HAC1 is essential for reducing As (V) activity in the inner layer close to the xylem (pericycle) and the outer layer of the root (epidermis). (24)

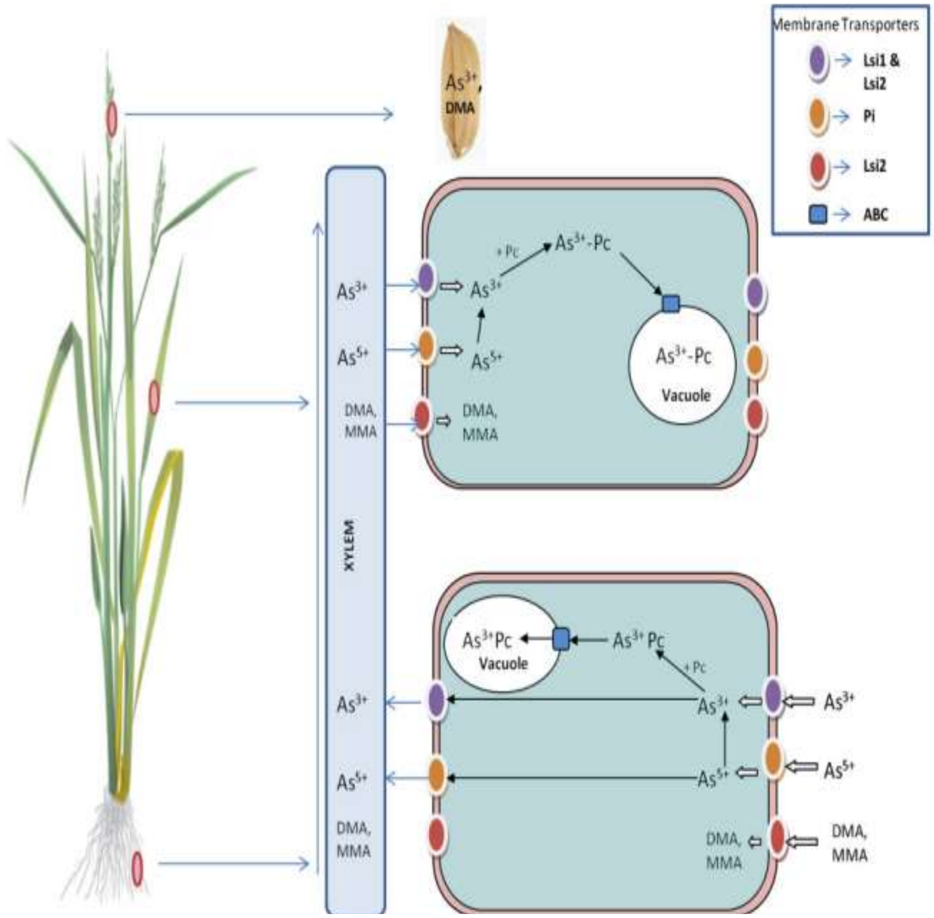

Fig 2:- Transfer of arsenic from root to shoot (19).

Arsenic Phytotoxicity and Arsenic Detoxification in Rice Plants

As it reduces agricultural output and plant growth, it is highly phytotoxic to plants (7). Additionally, it was discovered that As (V) was more hazardous than As (III). The generation of reactive oxygen species (ROSs), including hydroxyl radicals (HO•), superoxide radicals ($O_2^{\bullet -}$), and hydrogen peroxide, are As' hazardous biochemical effect at the subcellular level. ROSs can damage macromolecules and are harmful to plant metabolism (25). As (V) is transformed into As(III) in plants, as was already mentioned. In addition, an essential method of As detoxification in plants is As (III) outflow to the external medium. As (III) may be detoxified within plant cells by complexing with phytochelatins (PCs), which is followed by the build-up of As (III)-PC complexes in vacuoles via OsABCC1 transporters(26). Additional detoxification mechanisms emerge in the vacuole via vacuolar sequestration following the decrease of As (V) to As (III). Sulfhydryl (-SH)-rich protein and As (III) chelate to form a complex that is kept apart by vacuolar transporters (PCs). Two phytochelatin synthase enzymes, OsPCS1 and OsPCS2, have been identified in rice (27).

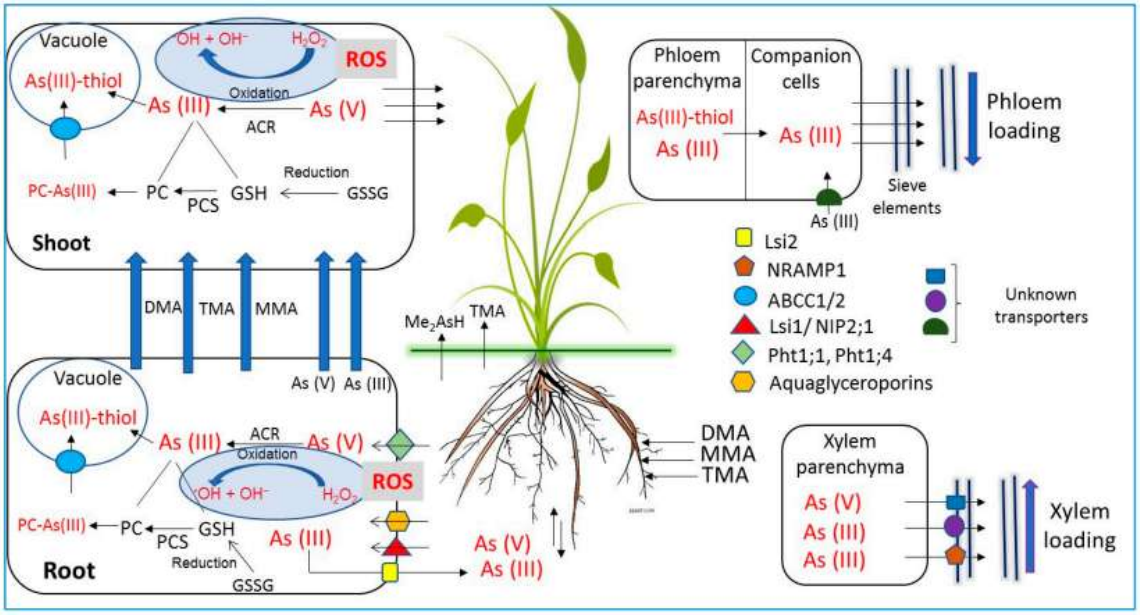

Fig 3:- Diagrammatic illustration of the various As absorption, transportation, and detoxification components (25).

Arsenic Accumulation and Toxicity

The accumulation of As by rice plants causes a variety of harmful reactions and has an impact on the plant's morphological, physiological, and growth processes (19). Due to the retention of As from previous years' polluted irrigation water in the soils, yield reduction has also been noticed along with the increase in As content in soils in subsequent cropping years (28). As^{3+} is the most readily absorbed by roots and DMA is the most readily translocated inside rice plants, according to the research that is currently available about the transportation of various As species in rice plants. The two most noticeable As species that are transferred to the grains are As^{3+} and DMA. However, rice roots also absorb a sizeable amount of As^{5+} from the soil, and its concentration in the plant's above-ground tissues is influenced by mechanisms linked to an As-tolerance response, such as the presence of various arsenate reductases in rice, such as OsHAC1;1, OsHAC1;2, and OsHAC4, which control the conversion of arsenate to arsenite. The differential in accumulation might be brought about by the different levels of As in soils, irrigation water, and genetic makeup (19). Low pH (5) soils offer greater As-binding species, such as Fe-oxyhydroxide complexes, and boost plant uptake of As. When the pH is high, the negative surface charge increases, leading to an increase in hydroxyl ions, which facilitates the desorption of as from iron oxides and causes as to be transported to the area around the roots and accumulate there (19). Furthermore, the amounts of toxicity caused by each As species vary in rice plants.

Effects of Various Factors in Reducing Plant Uptake of Arsenic

Due to variations in charges on the soil surface, which regulates the adsorption and desorption processes in soil, the texture of the soil may have an impact on As mobility. In comparison to soils with a coarse texture, soils with significant clay content have a higher potential for As retention (2). Additionally, studies have shown that loamy sand-growing plants ingest and concentrate As at higher levels than plants grown in silty clay loam soils (29).

Soil pH

As in soil is frequently mobilised when the pH is raised. Anions, as well as As(V) and As(III), are typically released from their exchange sites as soil pH rises (30). For instance, in oxidising conditions, H_2AsO_4 becomes the predominant species at pH 6.9, whereas at high pH, $HAsO_4$ predominates (2).

Soil organic matter

The following procedures were used to analyse the fundamental characteristics of organic materials: The pH was assessed at a 1:5 ratio of organic matter to water, and the quantities of organic matter (OM) and organic carbon were assessed, respectively, using the loss-on-ignition method and the Walkley and Black method (1). In rice plants, OM may potentially have an impact on As accumulation and plant growth. Theoretically, organic matters are insoluble. As in comparison to specific pathways, such as the association of As with phenolic OH, carboxylate, and sulfhydryl groups when ternary complexes are present or not (31) According to Japan's Agricultural Land-Soil Pollution Prevention Law, the soil was not contaminated (31).

Factors Affecting Arsenic Intake and Mobilization withinside the Rice Plant

Metal ions from soil are concentrated in part due to the microclimate that exists in the root rhizosphere, which is caused by the connection of microorganisms with roots and root exudates (33). Several parameters, such as the affinity of the metal to the soil particle and the physical, chemical, and biological characteristics of the soil, control metal-metal interaction and their dynamic equilibrium between diverse chemical forms in soil. The soil contains both organic and inorganic types of arsenic. Arsenate As(V) and arsenite As(III) are the most prevalent inorganic species, while monomethylarsonic acid (MMA) and dimethylarsinic acid are the most prevalent inorganic species (DMA) (33).The following is a list of arsenic species in order of their toxicity MMA > AsIII > AsV > DMA (34). Redox chemistry is primarily in charge of controlling the speciation and mobility of arsenic in soil, which results in the accumulation of the metal in paddy. Arsenic predominates in aerobic soil (oxidised conditions) as arsenate As(V) and is adsorbed on Fe-oxyhydroxide phases, which limits the availability of arsenic to plants (33). Arsenite As(III) predominates in reducing environments, such as submerged rice fields, and is more readily absorbed by plants as a result of the dissolution of Fe-oxides and the reduction of As(V) to As(III) by microorganisms (35). Arsenic solubility in soil and the bioavailability of arsenic to rice plants are both significantly influenced by soil texture. Due to the presence of Fe oxides, silt and clayey soils have a finer texture, a lot more surface area than sandy soils, and a higher capacity to scavenge arsenic.As a result, vegetation grown in clayey soils exhibits less arsenic toxicity than vegetation grown in sandy and loamy soils, which exhibits five times more arsenic toxicity (33).

Agronomic Techniques to Reduce Arsenic Build up in Rice

In order to lessen the effects of arsenic accumulation in rice, a number of agronomic techniques may be used. These techniques include aerating the soil and preventing the reduction of arsenic, fostering the formation and precipitation of insoluble arsenic in soil, and increasing the amount of mineral nutrients in the soil that compete with arsenic uptake. Effective treatments are available now that could aid in reducing the risk posed by arsenic in plants (33).

1. Adding minerals to the soil as fertiliser
2. Techniques for irrigation and water management

Fertilization of Soil with Minerals–

By reducing its uptake and translocation in food crops, the addition of specific mineral to the soil, such as Fe, S, P, and Si, can dramatically reduce the accumulation of arsenic in edible plant parts (36).

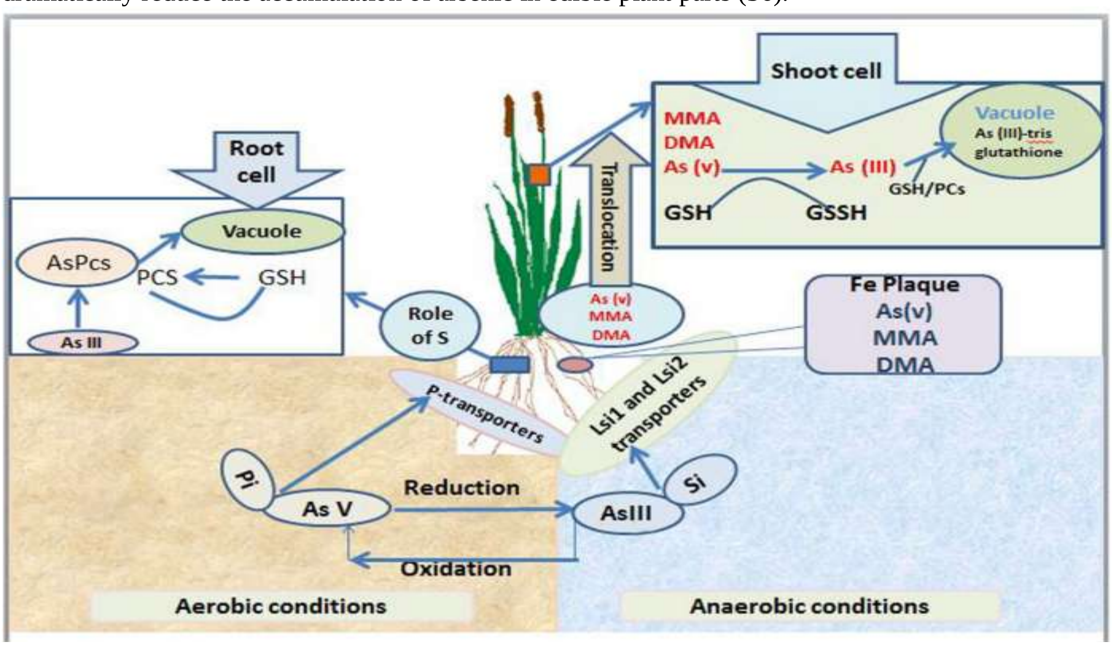

Fig 4:- Factors influencing the assimilation and transport of as in rice plants as well as the plant's root and shoot detoxifying (36).

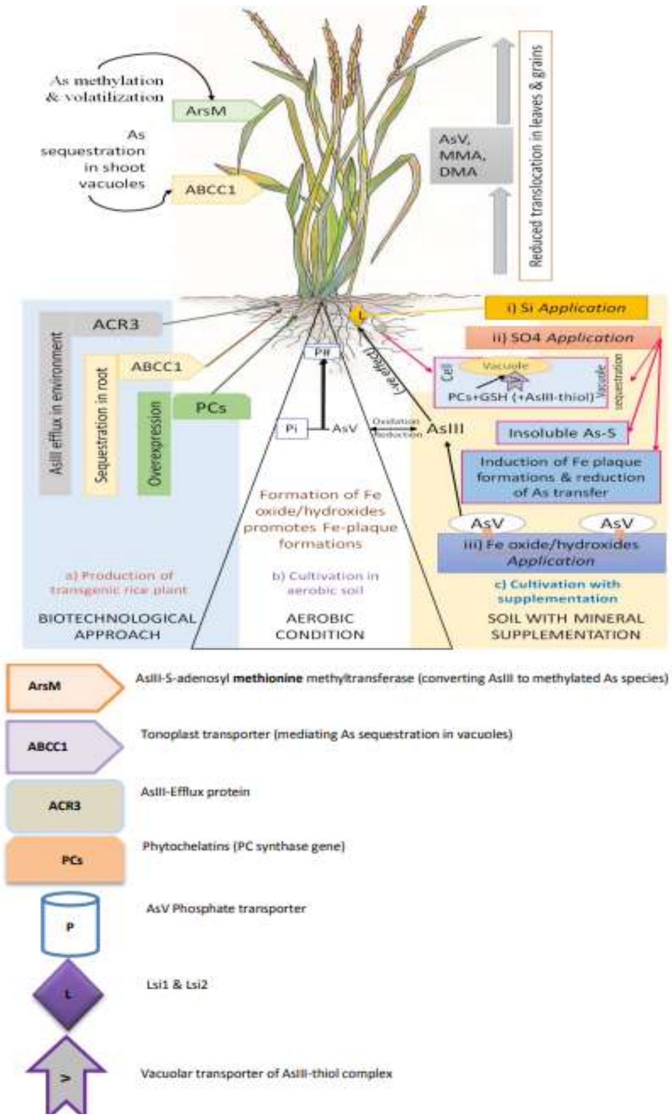

Fig 5:- Diagrammatic representation of the agronomic tactics and biotechnology methods for preventing arsenic build-up in rice (33).

Practices for Water Management and Irrigation

A water-saving regimen has been suggested as an immediate and long-term strategy to reduce the amount of arsenic in rice. As was mentioned in earlier sections, the reductive breakdown of Fe greatly increases arsenic mobility under flooding conditions (33). Water conservation practises alter the soil's redox state and encourage oxidation, which hinders the reduction of the mostdeadly arsenic species, As(V), to As(III), which has noticeably higher solubility, plant availability, and toxicity. Arsenic's affinity for soil minerals increases in aerated or oxidised soil, and the oxidation of iron leads to the production of Fe plaques at the root surface (33).

Arsenic's Biochemical and Molecular Effects on Rice Plants

In general, As affects any biological system in one of two ways: either directly by inactivating important enzymes directly by interacting with sulfhydryl groups or by displacing mandatory ions from their active sites, or indirectly by bursts of ROS, which cause a series of irreparable damages in plants (37). Under normal aerobic metabolism, a number of metabolic pathways that operate in distinct cellular compartments, including chloroplast, mitochondria, and peroxisomes, can continually emit ROSs as their by-products (25).

Reactive Oxygen Species (ROS) Generation Caused by Arsenic

The ROS are oxygen-containing molecules that are extremely unstable, chemically reactive, and short-lived. They also have an unpaired electron in their valence shell. Because PTEs, such as As, are present in chloroplasts, mitochondria, and peroxisomes as a consequence of numerous metabolic pathways operating within a cell, the production of ROS is typically hazardous (25). O_2 is converted to $O_2^{\bullet-}$ at the respiratory chain's ubiquinone cytochrome region. According to certain research, As(V) to As conversion results in increased ROS generation in plants As(III) (38). Following the transformation of As(V) into As (III), a methylation process occurs, one of the redox-driven processes that encourages the creation of ROS (39). According to research on Solanum lycopersicon, Catharanthus roseus, and Agrostis tenuis, the biomethylation of As results in the production of monomethylarsonic acid, dimethylarsinic acid, trimethylarsonium oxide, tetramethyluronium ions, arsenocholine, arsenobetaine, and arsenosugars (40).These active iron species can then undergo Haber-Weiss reactions to release damaging O_2 species. In chloroplasts and/or mitochondria, cytochrome oxidase likely also catalyses the transformation of As (V) into As (III), using O_2 as a final electron acceptor and resulting in the creation of O_2 (25).

Effect of Arsenic on Rice Plant Carbohydrate Metabolism

Under the effect of As, the conversion of non-reducing carbohydrates, primarily sucrose, into reducing sugars (hexoses), has been reported (41). As-induced plant toxicity has also been linked to a significant suppression of the activities of starch-degrading enzymes including α-amylase and starch phosphorylase (41). In contrast, after applying As stress to Oryza sativa and Phaseolus aureus seedlings, a 77–120% increase in starch phosphorylase activity was seen, leading to a greater release of soluble sugars (41). Additionally, under in-situ As toxicity, the increase in activities of the sucrose-hydrolysing enzymes acid invertase and sucrose synthase, as well as the reduction of sucrose phosphate synthase activity, were studied (41). Under the exogenous application of As, the metabolic limitations as stated above will change plant growth and development.

Conclusions:-

More academic emphasis is being paid to the fact that eating rice is a significant source of As exposure for rural communities other than drinking water. For many Bangladeshis, eating rice that contains As poses major health concerns to people. The average amount of inorganic As found in different rice varieties varies greatly between districts and, in some situations, exceeds the Food and Agriculture Organization (FAO)'s recently imposed rice MDL of 200 g kg^{-1}. Most samples above the FAO threshold limits for total As, and they are primarily composed of inorganic As. Since rice is a significant dietary source of as, scientists have worked to limit the as that rice plants take up. In the current study, a number of research articles were examined to look into the journey of arsenic in rice. Even in the presence of arsenic-enriched soil, arsenic accumulation in rice largely depends on its bioavailability, which is influenced by a number of factors including soil types, physicochemical parameters, the presence of other elements, and mineral composition such as iron, phosphorus, sulphur, and silicon in soil. Other factors include the soil-rhizosphere-plant system, rhizospheric microorganisms and their activities, organic matter. Improvements in agricultural methods, such as spray irrigation, have been observed to reduce arsenic build up in rice plants. Although scientists are focusing on various rice plant genes that are in charge of arsenic uptake, transport, and/or detoxification in an effort to produce a more palatable crop, the application of these genes under various field conditions and the ensuing high-quality rice production remain serious issues. Recent advancements in gene-editing technology aid scientists in understanding gene function and enhancing agricultural yield.

Acknowledgement:-

I would like to thanks Director Professor (Dr.) Abhijit Sengupta and Principal Professor (Dr.) Lopamudra Datta for providing us this opportunity to work on this review. I am also thankful to Dr. Bhaskar Choudhury, my mentor for his expert advice and encouragement throughout preparation of the manuscript.

Reference:-

1. Syu, C.-H., Wu, P.-R., Lee, C.-H., Juang, K.-W., & Lee, D.-Y. (2018). Arsenic phytotoxicity and accumulation in rice seedlings grown in arsenic-contaminated soils as influenced by the characteristics of organic matter amendments and soils. Journal of Plant Nutrition and Soil Science.
2. Abedi, & Mojiri. (2020). Arsenic Uptake and Accumulation Mechanisms in Rice Species. Plants, 9(2), 129.
3. Ma, J. F., Yamaji, N., Mitani, N., Xu, X.-Y., Su, Y.-H., McGrath, S. P., & Zhao, F.-J. (2008). Transporters of arsenite in rice and their role in arsenic accumulation in rice grain. Proceedings of the National Academy of Sciences, 105(29), 9931–9935.

4. Wan, Y., Camara, A. Y., Huang, Q., Yu, Y., Wang, Q., & Li, H. (2018). Arsenic uptake and accumulation in rice (Oryza sativa L.) with selenite fertilization and water management. Ecotoxicology and Environmental Safety, 156, 67-74.
5. Kumar, A., Dixit, G., Singh, A. P., Dwivedi, S., Srivastava, S., Mishra, K., & Tripathi, R. D. (2016). Selenate mitigates arsenite toxicity in rice (Oryza sativa L.) by reducing arsenic uptake and ameliorates amino acid content and thiol metabolism. Ecotoxicology and Environmental Safety, 133, 350–359.
6. Rahman, M. A., Hasegawa, H., Rahman, M. M., Rahman, M. A., & Miah, M. A. M. (2007). Accumulation of arsenic in tissues of rice plant (Oryza sativa L.) and its distribution in fractions of rice grain. Chemosphere, 69(6), 942–948.
7. Islam, S., Rahman, M. M., Islam, M. R., & Naidu, R. (2017). Geographical variation and age-related dietary exposure to arsenic in rice from Bangladesh. Science of The Total Environment, 601-602, 122–131.
8. Ma, L., Wang, L., Jia, Y., & Yang, Z. (2016). Arsenic speciation in locally grown rice grains from Hunan Province, China: Spatial distribution and potential health risk. Science of The Total Environment, 557-558, 438–444.
9. Lin, S.-C., Chang, T.-K., Huang, W.-D., Lur, H.-S., & Shyu, G.-S. (2013). Accumulation of arsenic in rice plant: a study of an arsenic-contaminated site in Taiwan. Paddy and Water Environment, 13(1), 11–18.
10. Ye, W.-L., Khan, M. A., McGrath, S. P., & Zhao, F.-J. (2011). Phytoremediation of arsenic contaminated paddy soils with Pteris vittata markedly reduces arsenic uptake by rice. Environmental Pollution, 159(12), 3739–3743.
11. Tu, S., & Ma, L. (2003). Interactive effects of pH, arsenic and phosphorus on uptake of As and P and growth of the arsenic hyperaccumulator Pteris vittata L. under hydroponic conditions. Environmental and Experimental Botany, 50(3), 243–251.
12. Meadows, R. (2014). How Plants Control Arsenic Accumulation. PLoS Biology, 12(12), e1002008.
13. Li, N., Wang, J., & Song, W.-Y. (2015). Arsenic Uptake and Translocation in Plants. Plant and Cell Physiology, 57(1), 4–13.
14. Mishra, S., Mattusch, J., & Wennrich, R. (2017). Accumulation and transformation of inorganic and organic arsenic in rice and role of thiol-complexation to restrict their translocation to shoot. Scientific Reports, 7(1).
15. Zhao, F.-J., Ago, Y., Mitani, N., Li, R.-Y., Su, Y.-H., Yamaji, N., … Ma, J. F. (2010). The role of the rice aquaporin Lsi1 in arsenite efflux from roots. New Phytologist, 186(2), 392–399**.**
16. Abedin, M. J., Feldmann, J., & Meharg, A. A. (2002). Uptake Kinetics of Arsenic Species in Rice Plants. PLANT PHYSIOLOGY, 128(3), 1120–1128.
17. Luan, M., Liu, J., Liu, Y., Han, X., Sun, G., Lan, W., & Luan, S. (2018). Vacuolar Phosphate Transporter 1 (VPT1) Affects Arsenate Tolerance by Regulating Phosphate Homeostasis in Arabidopsis. Plant and Cell Physiology.
18. Ye, Y., Yuan, J., Chang, X., Yang, M., Zhang, L., Lu, K., & Lian, X. (2015). The Phosphate Transporter Gene OsPht1;4 Is Involved in Phosphate Homeostasis in Rice. PLOS ONE, 10(5), e0126186.
19. Kalita, J., Pradhan, A. K., Shandilya, Z. M., & Tanti, B. (2018). Arsenic Stress Responses and Tolerance in Rice: Physiological, Cellular and Molecular Approaches. Rice Science, 25(5), 235–249.
20. Ye, Y., Li, P., Xu, T., Zeng, L., Cheng, D., Yang, M., … Lian, X. (2017). OsPT4 Contributes to Arsenate Uptake and Transport in Rice. Frontiers in Plant Science, 8.
21. Lin, Y., Sun, Z., Li, Z., Xue, R., Cui, W., Sun, S., … Song, Y. (2019). Deficiency in Silicon Transporter Lsi1 Compromises Inducibility of Anti-herbivore Defense in Rice Plants. Frontiers in Plant Science, 10.
22. Detmann, K. C., Araújo, W. L., Martins, S. C. V., Sanglard, L. M. V. P., Reis, J. V., Detmann, E., … DaMatta, F. M. (2012). Silicon nutrition increases grain yield, which, in turn, exerts a feed-forward stimulation of photosynthetic rates via enhanced mesophyll conductance and alters primary metabolism in rice. New Phytologist, 196(3), 752–762.
23. Carey, A.-M., Scheckel, K. G., Lombi, E., Newville, M., Choi, Y., Norton, G. J., … Meharg, A. A. (2009). Grain Unloading of Arsenic Species in Rice. PLANT PHYSIOLOGY, 152(1), 309–319.
24. Chao, D.-Y., Chen, Y., Chen, J., Shi, S., Chen, Z., Wang, C., … Salt, D. E. (2014). Genome-wide Association Mapping Identifies a New Arsenate Reductase Enzyme Critical for Limiting Arsenic Accumulation in Plants. PLoS Biology, 12(12), e1002009.
25. Abbas, G., Murtaza, B., Bibi, I., Shahid, M., Niazi, N., Khan, M., … Natasha. (2018). Arsenic Uptake, Toxicity, Detoxification, and Speciation in Plants: Physiological, Biochemical, and Molecular Aspects. International Journal of Environmental Research and Public Health, 15(1), 59.
26. Sun, S.-K., Chen, Y., Che, J., Konishi, N., Tang, Z., Miller, A. J., … Zhao, F.-J. (2018). Decreasing arsenic accumulation in rice by overexpressing OsNIP1;1 and OsNIP3;3 through disrupting arsenite radial transport in roots. New Phytologist, 219(2), 641–653.

27. Shri, M., Singh, P. K., Kidwai, M., Gautam, N., Dubey, S., Verma, G., & Chakrabarty, D. (2019). Recent advances in arsenic metabolism in plants: current status, challenges and highlighted biotechnological intervention to reduce grain arsenic in rice. Metallomics.
28. Panaullah, G. M., Alam, T., Hossain, M. B., Loeppert, R. H., Lauren, J. G., Meisner, C. A., … Duxbury, J. M. (2008). Arsenic toxicity to rice (Oryza sativa L.) in Bangladesh. Plant and Soil, 317(1-2), 31–39.
29. Bakhat, H. F., Zia, Z., Abbas, S., Hammad, H. M., Shah, G. M., Khalid, S., … Fahad, S. (2019). Factors controlling arsenic contamination and potential remediation measures in soil-plant systems. Groundwater for Sustainable Development, 100263.
30. Moreno-Jiménez, E., Esteban, E., & Peñalosa, J. M. (2011). The Fate of Arsenic in Soil-Plant Systems. Reviews of Environmental Contamination and Toxicology, 1–37.
31. Suda, A., & Makino, T. (2016). Effect of organic amendments on arsenic solubilization in soils during long-term flooded incubation. International Journal of Environmental Science and Technology, 13(10), 2375–2382.
32. Wenzel, W. W. (2008). Rhizosphere processes and management in plant-assisted bioremediation (phytoremediation) of soils. Plant and Soil, 321(1-2), 385–408.
33. Mitra, A., Chatterjee, S., Moogouei, R., & Gupta, D. (2017). Arsenic Accumulation in Rice and Probable Mitigation Approaches: A Review. Agronomy, 7(4), 67.
34. Baig, J. A., Kazi, T. G., Shah, A. Q., Kandhro, G. A., Afridi, H. I., Khan, S., & Kolachi, N. F. (2010). Biosorption studies on powder of stem of Acacia nilotica: Removal of arsenic from surface water. Journal of Hazardous Materials, 178(1-3), 941–948.
35. Islam, F. S., Gault, A. G., Boothman, C., Polya, D. A., Charnock, J. M., Chatterjee, D., & Lloyd, J. R. (2004). Role of metal-reducing bacteria in arsenic release from Bengal delta sediments. Nature, 430(6995), 68–71.
36. Bakhat, H. F., Zia, Z., Fahad, S., Abbas, S., Hammad, H. M., Shahzad, A. N., … Shahid, M. (2017). Arsenic uptake, accumulation and toxicity in rice plants: Possible remedies for its detoxification: A review. Environmental Science and Pollution Research, 24(10), 9142–9158.
37. Finnegan, P. M., & Chen, W. (2012). Arsenic Toxicity: The Effects on Plant Metabolism. Frontiers in Physiology, 3.
38. Talukdar, D. (2013). Arsenic-induced changes in growthandantioxidant metabolism of fenugreek. Russian Journal of Plant Physiology, 60(5), 652–660.
39. Singh, H. P., Batish, D. R., Kohli, R. K., & Arora, K. (2007). Arsenic-induced root growth inhibition in mung bean (Phaseolus aureus Roxb.) is due to oxidative stress resulting from enhanced lipid peroxidation. Plant Growth Regulation, 53(1), 65–73.
40. Sharma, I. (2012). Arsenic induced oxidative stress in plants. Biologia, 67(3).
41. Jha, A.., & Dubey, R. (2004). Carbohydrate metabolism in growing rice seedlings under arsenic toxicity. Journal of Plant Physiology, 161(7), 867–872.