A Review on Arsenic Toxicity in Rice (*Oryza sativa* L.) Seedlings and its Effects on Growth and Metabolism

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Abstract- **Heavy metal pollution is one of the major problems throughout the world. Metalloids such as arsenic is also included in this segment. Due to its high toxicity and cancer-causing potential, Arsenic (As) cause's environmental pollution which is a global hazard for agriculture and the human health. Even at very low concentrations, exposure to as can elicit a variety of morphological, physiological, and biochemical alterations in different plant species. According to a recent study on the interaction between soil and plants, the toxicity of as to plant varies depending on the variable species that are exposed to it and the type of plants and other soil conditions which affect how much as can accumulates in plants. Different plant species have various levels of arsenite or arsenate absorption, toxicity, and detoxification methods. This review highlights the physiological and biochemical changes caused as a result of arsenic absorption in rice plants from the soil.**

***Keywords*: Arsenic toxicity, rice seedling, carbohydrate metabolism, antioxidant enzymes, oxidative stress markers**

INTRODUCTION

As a result of the rising environmental pollution from industrial, agricultural, energy, and municipal sources in recent years, heavy metals have attracted significant attention. They operate as stress factors that disrupt the physiology and biochemistry of plant species. Metalloids such as arsenic are also included in this arena. Arsenic having high density than water, and heaviness and toxicity is directly proportional. So, they can actually induce toxicity at low exposure. Arsenic belongs to Group V of the periodic table and has the atomic number 33. [1] Two stable valence states are created by removal of electrons: As(III), also known as Arsenite, and As(V), also known as Arsenate. Arsenic pollution of groundwater is one of the major problems throughout the world. The people of these countries are facing severe risk due to arsenic poisoning specially in Bangladesh, followed by West Bengal in India.[2] Serious health issues like cancer, hyperkeratosis, lungs cancer, and heart illnesses are all brought on by arsenic exposure.[3] Similar to humans, increased soil levels of arsenic have a negative impact on different plant growth and development, leading to a variety of biochemical and physiological diseases.[4] One of the main crops grown in India, particularly in West Bengal, is rice. Arsenic contamination of rice has only recently come to lime light, and it is a massive calamity which puts millions of people at danger of getting sick from drinking water and consuming contaminated crops like seeds of cereals including rice that has been poisoned with the arsenic due to bioaccumulation.[2] Arsenic levels in the soil also markedly increase when arsenic-contaminated water is used to irrigate the land. It has a negative impact on plant growth and development and is poisonous, leading to a range of biochemical and physiological diseases.[5] Plants exhibit toxic symptoms when exposed to excessive arsenic, either in soil or in solution culture, such as inhibited seed germination, decreased plant height, lower fruit and grain yield, reduced root and shoot growth, wilting and necrosis of leaf blades, and decreased leaf area and photosynthesis. [6,7,8]

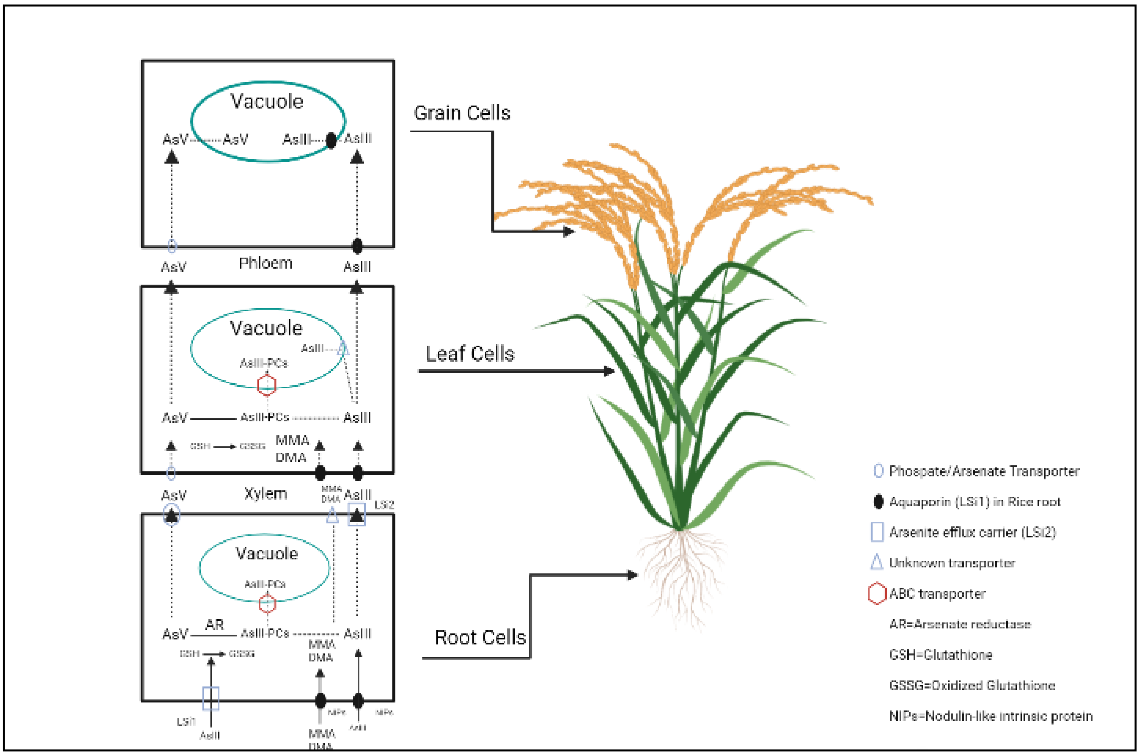

Figure 1: Mechanism of arsenic uptake in rice plant

Variation of arsenic concentration in rice

The ability of rice cultivars to absorb arsenic varies from 3 to 37-fold, and the amount of inorganic arsenic in the grain likewise varies with variety. As a result, arsenic levels in samples of commercial rice vary greatly, depending on the cultivar and growing area. Greater total arsenic concentrations were found in rice grown in the US and Europe in compared to cultivars from India, Egypt, Bangladesh, and Asia. In comparison to rice from Bangladesh or India, US-grown rice had lower percentages of inorganic arsenic and greater levels of total arsenic accumulation. Due to the build-up of inorganic arsenic in the bran layers, brown rice has a higher arsenic content than white rice. [9]

Moreover, the content and bioavailability of arsenic in rice are affected by processing and cooking methods. Arsenic levels in cooking water also affect how much arsenic is in cooked rice. Arsenic's real bioavailability in rice may differ. Between 53% and 102% of the total amount of arsenic in rice is thought to be bioavailable, according to experiments simulating *in vitro* gastrointestinal digestion. These elements make it difficult to determine the amount of arsenic received through contaminated rice intake for epidemiologic research on the effects on health. [10]

Table 1: Arsenic levels (mg kg^{-1}) in raw rice from different countries collected from previous research works. [10]

Country	Max limit (mg kg^{-1})	Min limit (mg kg^{-1})	Average	Survey Range	No of Sample	References
Bangladesh	1.84	0.03	0.49	Field	13	Meharg and Rehman (2003)
	2.05	0.05	0.57- 0.95	Field	-	Islam *et. al.* (2004a)
	0.91	0.04	0.14- 0.51	Field (boro)	133	Williams *et. al.* (2006)
	0.92	0.04	0.08-0.36	Filed (aman)	189	Williams *et. al.* (2006)
	0.27	0.21	0.24	Market basket (boro)	-	Williams *et. al.* (2006)
	0.31	0.18	0.24	Market basket(aman)	-	Williams *et. al.* (2006)
	-	-	0.57- 0.69	Contaminated field	-	Rahman *et. al.* (2006)
	0.58	0.26	0.39	Field	4	Ohno *et. al.* (2007)
	-	-	0.60-0.70	Contaminated field	-	Rahman *et. al.* (2007)
	0.98	0.41	0.73	Contaminated field	4	Sun *et. al.* (2008)
	0.33	0.02	0.13	Market basket	144	Meharg *et. al.* (2009)

	0.56	0.02	0.14	Contaminated region	214	Rahman *et. al.* (2009)
	-	-	0.42	Field	40	William *et. al.* (2009)
India	0.66	0.09	0.3	Contaminated field	10	Roychowdhury *et. al.* (2002)
	0.61	0.04	0.23	Contaminated field	11	Roychowdhury *et. al.* (2003)
	0.55	0.08	0.23	Contaminated field	23	Roychowdhury *et. al.* (2003)
	0.66	0.04	0.23	-	34	Roychowdhury *et. al.* (2008)
	0.4	0.02	0.14	-	148	Pal *et. al.* (2009)
	0.36	0.02	0.12	-	30	Chatterjee *et. al.* (2010)
	0.31	0.07	0.07	Market basket	133	Meharg *et. al.* (2009)
	0.81	0.1	0.49	Contamination field	-	Anirban *et. al.* (2011)
	0.78	0.19	0.45	Contaminated area (boro)	-	Bhattacharya *et. al.* (2010a)
	0.6	0.06	0.33	Contaminated area (aman)	-	Bhattacharya *et. al.* (2010a)
China	0.7	0.31	0.49	Contaminated Field	-	Liu *et. al.* (2005)
	-	-	0.93	Contaminated Field	-	Liu *et. al.* (2005)
	1.18	0.46	0.82	Contaminated Field	2	Sun Liu *et. al.* (2008)
	0.46	0.02	0.14	Market Basket	124	Meharg *et. al.* (2009)
Taiwan	-	-	0.76	-	-	Schoof *et. al.* (1998)
	0.63	0.1	0.1	Market Basket	5	Lin *et. al.* (2004)
	0.14	0.1	0.05	-	-	Lin *et. al.* (2004)
Thailand	0.5	0.06	0.15	Market Basket	53	Adomako *et. al.* (2011)
Korea	0.72	0.24	0.41	Mine Site	-	Lee *et. al.* (2011)
Japan	0.42	0.07	0.19	Market Basket	26	Meharg *et. al.* (2009)
Vietnam	0.22	0.19	0.2	Farm Survey	3	Schoof *et. al.* (1998)
	0.17	0.09	0.12	-	18	Adomako *et. al.* (2011)
Philippines	0.25	0	0.07	-	-	Williams *et. al.* (2006)
Pakistan	0.2	0.01	0.09	Market Basket	5	Adomako *et. al.* (2011)
Venezuela	0.46	0.19	9.3	-	4	Schoof *et. al.* (1998)
Egypt	0.08	0.02	0.05	-	108	Meharg *et. al.* (2007)
Spain	0.82	0.05	0.2	Market Basket	76	Meharg *et. al.* (2009)
	0.21	0.07	0.13	-	10	Williams *et. al.* (2007a)
Europe	0.2	0.13	0.15	Market Basket		Williams *et. al.* (2005)
France	0.61	0.12	0.32	-	22	Williams *et. al.*. (2007a)
USA	0.46	0.2	0.3	Market Basket	-	Schoof *et. al.* (1999)
	0.34	0.21	0.28	-	-	Heitkemper *et. al.* (2001)
	0.4	0.11	0.26	Market Basket	-	Williams *et. al.* (2005)
	0.71	0.16	0.29	Market Basket	24	Zavela *et. al.* (2008)
	0.66	0.03	0.25	Market Basket	163	Meharg *et. al.* (2009)
Italy	0.22	0.19	0.2	Market Basket	-	Williams *et. al.* (2005)
	0.24	0.05	0.14		11	Adomako *et. al.* (2011)

				Market Basket		
Ghana	0.15	<LOD	-	Market Basket	7	Adomako *et. al.* (2011)
Australia	0.04	0.02	0.03	Market Basket	5	Williams *et. al.* (2006)
Canada	-	-	0.02	Market Basket	-	Williams *et. al.* (2005)
Lebanon	0.07	0.01	0.04	Market Basket	11	Adomako *et. al.* (2011)

Effects on arsenic in morphology and anatomy of rice seedlings

Root and shoot lengths of rice seedlings significantly reduce as a result of arsenic exposure. Compared to shoot length, this inhibitory effect was more pronounced on the root because of the predominant effect of arsenate.[11] In rice seedling other anatomical features are similarly affected by arsenic exposure. The quantity and length of root hairs become reduced as a result of arsenic pollution.Arsenic damages the epidermal cells and the aerenchymatous cortex, causing form distortion, tissue disintegration, and the appearance of fewer and shorter root hairs.[6]

Effects on arsenic toxicity on pigment contents of rice plants

Increased arsenic concentrations causes the amounts of total chlorophyll, chlorophyll-a, chlorophyll-b, carotene, and xanthophyll to decrease linearly.[12] The production of reactive oxygen species including hydrogen peroxide, superoxide, and hydroxyl radicals, which can harm proteins, nucleic acids, and amino acids involved in the biosynthetic route of chlorophyll synthesis, is one potential reason why chlorophyll synthesis considerably decreases.[13] A noticeable drop in the intensity of chlorophyll fluorescence, which was connected to a sharp decline in pigment levels is also seen.[12]

Effect of arsenic on carbohydrate metabolism

Arsenic exposure builds up sugars in plant tissues with increase in reducing, non-reducing and total sugar content. It has been seen in rice seedlings that the increase in levels of reducing sugars is more compared to non-reducing sugars.[14] α-amylase degrades starch by hydrolysis and it has been found that α-amylase decreases with increased concentration of arsenic.[2] According to available data, arsenic toxicity causes significant increase in the activity of an enzyme starch phosphorylase in both roots and shoots.[14] It has also been observed, when rice is exposed to arsenic, activities of sucrose degrading enzymes, acid invertase and sucrose synthase increase but the activity of sucrose-synthesizing enzyme named sucrose phosphate synthase decreases.[14]

Effect of arsenic on antioxidant enzyme activities

In rice plants that has been exposed to arsenic, substantial differences in the activities of various antioxidant enzymes such super oxide dismutase (SOD), catalase (CAT), ascorbic-acid oxidase (AOx), and carboxypeptidase (CPX) is observed.[15] On an average the SOD activity increases due to arsenic contamination.[16]. Superoxide dismutase, a significant free radical's scavenger, provides the first line of defence against reactive oxygen species and cellular damage brought on by environmental stress factors.[17] The catalysed dismutation of superoxide free radicals into oxygen and hydrogen peroxide is the role of superoxide dismutase. [18] Arsenic toxicity has been found to increase superoxide dismutase activity, which is a sign that superoxide is being broken down into hydrogen peroxide.[19] On an average the CAT activity seems to decrease considerably.

The tetrameric protein catalase, which contains haem, is well recognised for being an enzyme that splits hydrogen peroxide [20,6]. The role of catalase is to detoxify excess hydrogen peroxide that is produced because of superoxide dismutase activity. However, it has been discovered that arsenic exposure significantly decreases catalase activity, indicating that catalase is not at all involved in the body's defence mechanism against arsenic toxicity.[20] The activity of AOx increases with the present of arsenic contamination.[21] But in case of CPx the activity declines considerably.[6]

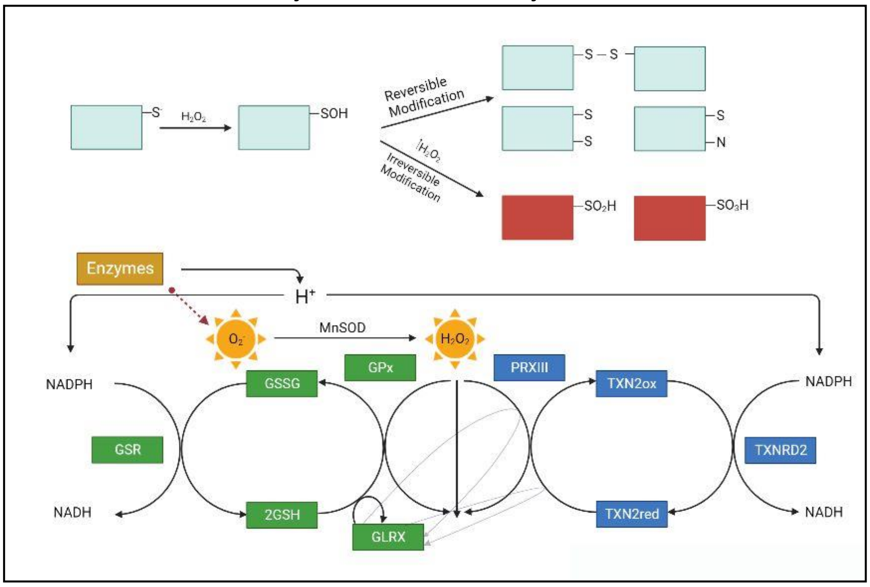

Figure 2: ROS scavenging mechanism in Plants

Effect of arsenic on oxidative stress markers

Proline, an amino acid, protects protein from denaturation and serves as a cytoplasmic osmoticum [22]. Proline concentrations in rice seedlings increased after exposure to arsenic, indicating an increased impact of oxidative stress.[6] Malondialdehyde is formed during membrane lipid peroxidation as a result of the breakdown of polyunsaturated fatty acids and is a useful marker of oxidative damage [23]. It has been observed that malondialdehyde content rises in rice seedlings when arsenic is applied, a sign of membrane damage brought on by peroxidation, which in turn causes an increase in reactive oxygen species and, ultimately, oxidative stress.[24] Hydrogen peroxide acts as a signalling molecule and acts as a defence mechanism for rice plants during stress conditions. Arsenic contamination increases the level of hydrogen peroxide. [25]

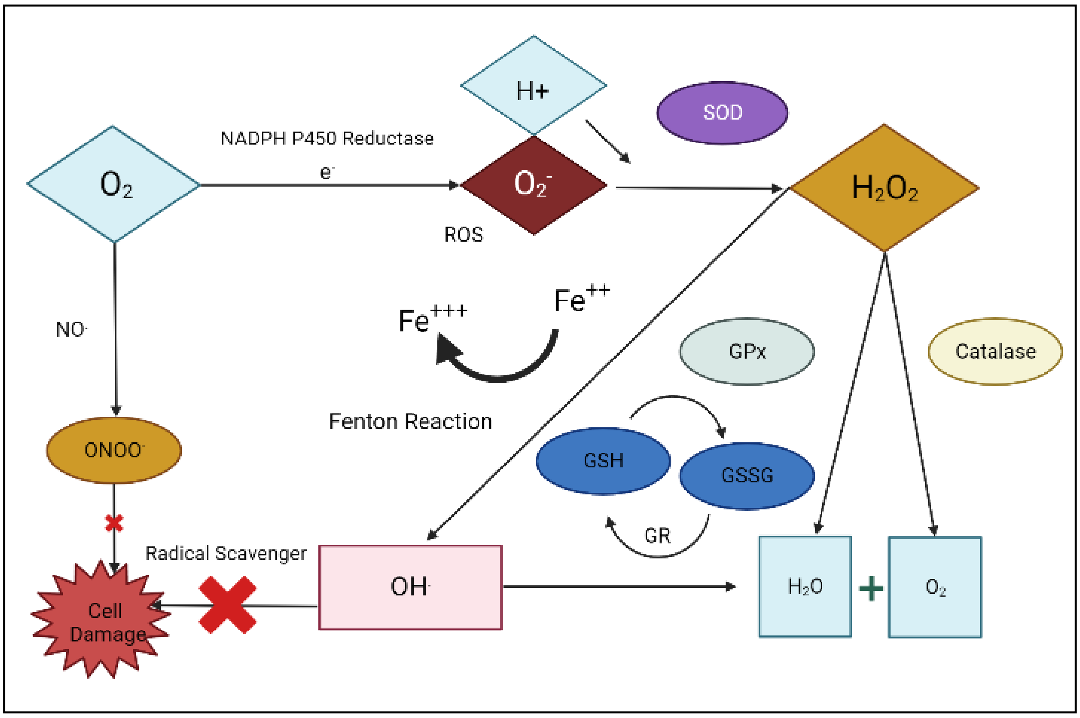

Figure 3: Arsenic induced oxidative stress in plants

CONCLUSION

Rice can take up arsenic more readily than other crops or plants as they grow under flooded conditions. Rice is the staple food in Asia, Lain America some parts of Africa i.e. more than 3 billion people around the world consume rice. So arsenic contamination is a major issue of concern considering the huge amount of physiochemical and biochemical degradation it causes. Extensive study will be required to develop different arsenic tolerant varieties of rice and other cereals to combat this global problem.

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