J. Indian bot. Soc. e-ISSN:2455-7218, ISSN:0019 - 4468 Sp.IssueVol. 100 (A) 2020:105-111

ARSENIC TOXICITY: A BRIEF REVIEW

REKHA BHADAURIA

School of Studies in Botany, Jiwaji University, Gwalior.
A- 46, Sagar Royal Homes, Hoshangabad Road, Bhopal.
E mail: rekhabhadauria@yahoo.com
DOI:10.5958/2455-7218.2020.00047.9

Arsenic is a non-essential, nonmetallic carcinogenic element, occurs in many environments and is highly toxic to all life forms including plants. Arsenic is naturally present at high levels in the groundwater. It is highly toxic in its inorganic form. Arsenic contaminated water has been used for drinking, food preparation and irrigation of crops poses the greatest threat to public health. Arsenic in drinking water may involve one of the longest cancer latencies for a human carcinogen. Long term exposure to arsenic from any source can cause severe health problems to human beings.

Arsenic is a heavy metal with a name derived from the Greek word *arsenikon,* (*meaning=potent).*The earth's crust is an abundant natural source of arsenic. As (Arsenic) is a non-essential, nonmetallic carcinogenic element, occurs in many environments and highly toxic to all life forms including plants (Zhao *et al.* 2009). It is present in more than 200 different minerals; the most common of which is called arsenopyrite. About one-third of the As in the Earth's atmosphere is of natural origin. Arsenic levels vary depending on geological location and arsenic occurs naturally in the environment (Kainth 2015). The elements occur in environment in different oxidation states which are: As (V), As (III), As (0) and As (-III). Some of the most commonly occurring forms of As in the environment include Arsenite (As(III)), arsenate (As(V)), monomethylarsenate, and dimethyl arsenate (Wang and Mulligan 2006, Afton *et al.* 2009, Kim *et al.* 2009, Zhu and Rosen 2009). Out of these arsenate and arsenite are the main forms present in the soil (Harper and Haswell 1988).

Inorganic arsenic compounds are formed in the environment, when arsenic combines with oxygen, chlorine and sulfur. In animals and plants arsenic combines with carbon and hydrogen to form organic arsenic compounds. Arsenic cannot be easily destroyed and can only be converted into different forms or transformed into insoluble compounds in combination with other elements, such as iron (Chooong *et al.* 2007).

Toxicity of widely distributed metalloid depends on the state of the arsenic, solubility, duration of exposure and the individual involved. Most of the anthropogenic activities and natural processes are mainly responsible for worldwide arsenic contamination (Hettick *et al.* 2015). In the past decade, the global input of As to soil by human activities was estimated to be between 52,000 and 112,000 tons per year (Nriagu and Pacyna 1988). Therefore, higher concentrations of heavy metals have been recorded because of agricultural and industrial activities. The genesis of heavy metals may be traced back to 1950s. One of the most famous cases of heavy metal pollution occurred in Minamata, Japan in the 1950s. The cause of this disaster has been traced to the dumping of about 27 tons mercury compounds by the Chisso Corporation into Minamata Bay during the 1950s and 1960s. The people of Minamata consumed fish and shellfish from the Bay in their diet and this lead to an accumulation of toxic methyl mercury in their bodies. Over 3000 victims have been recognized as having "*Minamata Disease*". The episodes of Minamata and *Itai Itai* diseases in Japan have brought to a sharp focus for the far reaching public health (Agrahari 2009).

Most of the essential heavy metals are important constituents of pigments and enzymes, especially Cu, Ni, Zn, Co, Fe and Mo for algae and plants; whilst some of the metals, especially cadmium (Cd), lead (Pb), mercury (Hg) and metalloids such as Arsenic (As), are toxic in higher concentration because of disrupting enzyme function context to many organic compounds, are not decomposed by the microbiological activity (Sharma 2007).

Most of the heavy metals contaminate soil, water, vegetables and fruits. A number of commonly assessed heavy metals in vegetable and soil, are As, Pb, Se, Zn, Cr, Ni, Mo, Fe, Co, Mn, Cu and Cd. Mainly As (V) and As (III) inorganic forms of arsenic occur and plants take up Arsenic as As (V). In plants, arsenic accumulates in the tissues of the different parts of the plant affecting adversely growth and productivity. Its effects are due to the suppression of the high-affinity phosphate / As uptake system (Meharg and Macnair 1992, Smith *et al*. 2010) stress, various physiological disorders in plants, inhibition of growth of the plant (Stoeva and Bineva 2003,Stoeva *et al*. 2005a) and finally death. As (III) reacts with sulfhydryl groups of enzymes and tissue proteins, inhibiting cellular function, causing death (Ullrich-Eberius *et al*. 1989, Smith *et al*. 2010). As is accumulated mainly in the root system and it causes many physiological changes (Marin *et al*. 1992, Wells and Gilmor 1997, Smith *et al*. 2010) interfere with metabolic processes, inhibits plant growth, and ultimately reduction in crop productivity (Miteva 2002 , Stoeva *et al*. 2004).

Arsenic concentrations typically varies from below 10 mg kg^{-1} in non-contaminated soils (Adriano 1986) to as high as 30,000 mg kg-1 in the contaminated soils (Vaughan 1993). Permissible limit of arsenic in agricultural soils is 20 mg/kg soil, while 5- ppm arsenic in soil is found toxic to sensitive crops. Despite its low crustal abundance (0.0001%), As is widely distributed in nature and is commonly associated with metal ores such as copper, lead, and gold (Nriagu 2002, Srivastava *et al*. 2005). Different organic and inorganic As compounds have been identified in the soil–plant environment (Quaghebeur and Rengel 2005, Smith *et al*. 2010).

In aerated soils, used for crops such as wheat, maize and most vegetables, mainly As (V) is present and, as such, is likely to be in the solid phase. Therefore, in such soils As in groundwater, used for irrigation, is quickly adsorbed by iron hydroxides and becomes largely unavailable to plants. In anaerobic soil conditions such as in flooded paddy fields, Arsenic is mainly present as As (III) and dissolved in the soil-pore water (the soil solution) (Xu *et al*. 2008). It is thus more readily available to plant roots.

The literature about the accumulation of heavy metals in food plants shows that both leafy and non-leafy vegetables are good accumulators of heavy metals. It was obsereved that bioaccumulation pattern of heavy metals in non-leafy vegetables is leaf > root ≈ stem > tuber and these heavy metals may manipulate the nutritional values, thus heavy metals have strong influence on nutritional values. Therefore, plants grown on metal-contaminated soil are nutrient deficient and consumption of such vegetables may lead to nutritional deficiency in the population, particularly living in developing countries which are already facing the malnutrition problems (Khan *et al*. 2015).

Arsenic can find its way into the grains of plants, such as rice and wheat, and into vegetables and fruit plants (Raychowdhury 2002, Meharg 2004, Norra 2005, Zhao 2006) through irrigation with As contaminated water. Rice is the major crop in areas where severe arsenic contamination occurs (Williams 2005), and reports indicate the accumulation of Arsenic upto 2 mg kg^{-1} in grains (Islam 2004) and upto 92 mg kg^{-1} in straw (Abedin 2002). The diet of many rice consumers is, therefore, under threat from Arsenic contamination (Raychowdhury 2002). Regarding the route of human exposure to arsenic, rice has been considered as a potentially important source / route in populations with rice based diets (Sinha and Bhattacharaya 2015). Incidences of arsenic contamination in rice grains have also been reported in different rice varieties tested in

Bangladesh. Arsenic levels ranging between 0.04 and 0.92 mg/kg in rice samples obtained from 299 markets in 25 (of 64) districts across Bangladesh; the samples included several different rice varieties from irrigated and rainfed land and from areas with high and low-As tubewell water (Williams *et al*. 2006). Most common symptoms in As-stressed plants are alteration of adenosine triphosphate (ATP), chlorophylls and photosynthesis system by arsenic (As) pollution, interveinal necrotic (Singh *et al*. 2006 and Smith *et al.* 2010) and whitish chlorotic symptoms (Shaibur *et al*. 2008). Arsenic damages the chloroplast membrane and disorganizes the functions of integral photosynthetic process (Stoeva and Bineva 2003). A significant decrease in pigment synthesis due to the lack of adaptive adjustments of pigment synthesis to high As levels and reduced rate of CO2 fixation and functional activity of photo system II (PSII) have been observed in plants growing under As stress conditions (Stoeva and Bineva 2003). Heavy metals at toxic levels have the capability to interact with several vital cellular biomolecules such as nuclear proteins and DNA, leading to excessive augmentation of reactive oxygen species (ROS). This would inflict serious morphological, metabolic, and physiological anomalies in plants ranging from chlorosis of shoot to lipid peroxidation and protein degradation (Emamverdian *et al*. 2015) as well as physiological disorders of rice (*Oryza sativa* L.) characterized by sterility of the florets / spikelet's leading to reduced grain yield (Rahman *et al*. 2008, Smith *et al*. 2010).
Another one of the most widespread important problem is Arsenic contamination of ground water found in many countries throughout the world due to leaching of naturally occurring As into drinking water aquifers. The sources of As include both natural, i.e. through dissolution of As compounds absorbed onto pyrite ores into the water by geochemical factors (Juhasz *et al*. 2003) and anthropogenic (through the use of insecticides, herbicides, and phosphate fertilizers and from the semiconductor industry) (Cozzolino *et al*. 2010, Mondal *et al*. 2006, Verbruggen *et al*. 2009) processes. Arsenic contaminated water contains arsenous acid and arsenic acid or their derivatives. These are merely the soluble forms of arsenic near neutral pH and are extracted from the underlying rocks that surround the aquifer[1].
Arsenic (As) poisoning from drinking water has been called the worst natural disaster in the history of mankind (Kainth 2015). However, the worst As contamination conditions encountered in Bangladesh and West Bengal (India) have been created due to natural processes (Tripathi *et al*. 2007). The intensity of arsenic to contaminate the water varies depending on the geological location. In West Bengal, India, the mud underneath the surface of the earth is particularly thick. This thick mud prevents water from flowing to the sea at a very fast rate. Groundwater is in contact with this mud for hundreds, or even thousands of years. The longer water is in contact with the mud, the higher the concentration of arsenic in water(Kainth 2015). A 2007 study found that over 137 million people in more than 70 countries are affected by arsenic poisoning of drinking water. The problem becomes a serious health concern after the mass poisoning of water in Bangladesh. The acceptable level as defined by WHO for maximum concentration of arsenic in safe drinking water is 0.01mg/L.
WHO has defined the areas under threat are: seven of the twenty districts of West Bengal have been reported to have groundwater arsenic concentration above 0.05mh/L (WHO 2007). In Bihar groundwater in 13 districts has been found to be contaminated with arsenic with quantities exceeding 0.05mg/L. All these districts are situated closest to large rivers Ganga and Gandak**.** Arsenic also finds its way into the food chain, e.g. into rice, through irrigation practices using contaminated ground water (Raychowdhury 2002).

An estimated 200 million people worldwide are exposed to arsenic concentrations in drinking water that exceed the recommended limit of 10 µg/l (Naujokas *et al*. 2013) as set out in the guidelines of the World Health

Organization (WHO 2012). A report of 2015 indicates arsenic as potent carcinogen and is known to cause cancer of the skin, lung, kidney, bladder, and liver (Kainth 2015). It has been reported that if exposure occurs over a brief period time symptoms may include vomiting, abdominal pain, encephalopathy and watery diarrhea that contains blood. Long term exposure can result in thickening of the skin, darker of skin, abdominal pain, diarrhea, heart disease, numbness and cancer (Ratnaike 2003). The majority of this exposed population lives in southern Asian countries such as Bangladesh, Cambodia, India, Nepal and Viet Nam. (George *et al*. 2014).

Hettick *et al.* (2015) have compiled the observations of studies concerning the metalloid and consider the physical and chemical properties of arsenic in perspective to human toxicity and phytoremediation. Mechanism of arsenic toxicity, interaction with plant system have also been discussed. Chatterjee *et al.* (2016) have reviewed and discussed Arsenic toxicity, its major effects of arsenic contamination. They have also stated that Arsenic is highly toxic element and often found in groundwater and contaminated drinking water and can enter the body through various routes like ingestion, absorption and inhalation. Arsenic toxicity can be both acute as well as chronic and can lead to several diseases of the human body (Chatterjee *et al.* 2016).

It has been observed that lung, bladder and kidney cancer mortality due to arsenic exposure have very long latencies with increased risks manifesting after 40 years exposure reduction. The findings of Smith *et al*. (2018) have suggested that arsenic in drinking water may involve one of the longest cancer latencies for a human carcinogen. Further, the long latency after exposure reduction means the incidence of arsenic –related diseases are likely to remain very high for many years after arsenic exposures have stopped, highlighting the importance of eliminating exposures as soon as possible and to reduce mortality (Smith *et al*. 2018).

According to WHO (2018), Arsenic is a natural component of the earth's crust and is widely distributed throughout the environment in the air, water and land. It is highly toxic in its inorganic form. People are exposed to elevated levels of inorganic arsenic through drinking contaminated water, using contaminated water in food preparation and irrigation of food crops, industrial processes, eating contaminated food and smoking tobacco. Long-term exposure to inorganic arsenic, mainly through drinking-water and food, can lead to chronic arsenic poisoning. Skin lesions and skin cancer are the most characteristic effects.

Regarding the acute toxicity of arsenic, WHO also indicates the occurrence of arsenic at high levels in the groundwater of a number of countries. Long term exposure to arsenic from drinking water and food can cause cancer and other health problems. It has also been associated with cardiovascular diseases and diabetes. In utero and early childhood exposure has been linked to negative impacts on cognitive development and increased deaths in young adults.

In 2019, Costa has reviewed the human exposure to arsenic, and discussed mechanism of its acute and chronic toxicity and mechanism of its carcinogenesis in humans. Arsenic has been considered as a well-established human carcinogen, and its contamination impacts hundreds of millions of people in the world and, and has been shown to cause skin, lung, bladder, liver, prostrate and kidney cancers (Costa 2019).

REFERENCES

Abedin M J 2002 Uptake kinetics of arsenic species in rice plants. *Plant Physiol* **128** 1–9

Adriano D C 1986 *Trace elements in the terrestrial environment*. Springer, New York.

Afton S E, Carton B, Caruso J A 2009 Elucidating the selenium and arsenic metabolic pathways following exposure to the non hyperaccumulating *Chlorophytum comosum*, spider plant. *J Exp Bot* **60 (4)** 1289–1297.

Agrahari K C 2009 Heavy metals in aquatic ecosystem some environmental implications. *Everyman's Science* **XLIV (2)** 88- 93.

Babula P, Adam V, Opatrilova R, Zehnalek J, Havel L, Kizek R 2008 Uncommon heavy metals, metalloids and their plant toxicity. *Environ Chem Lett* **6** 189- 213.

Chatterjee Madhurima, Banerjee R, Bhattacharaya R 2016 Review on Arsenic Tosicity:its treatment and prevention. *J Toxicology* **6 (2)** 17-22.

Choong T S Y, Chauah T G , Robiah Y, Gregory Koay, Azni F C 2007 Arsenic toxicity, health hazards and removal of techniques from water: an overview. *Desalination* **217** 139-166.

Costa M 2019 Review of arsenic toxicity, speciation and polyadenylation of canonical histones. *Toxicol Appl Pharmacol* **375** 1- 4.

Cozzolino V, Pigna M, Di Meo V, Caporale A G, Violante A 2010 Effects of arbuscular mycorrhizal inoculation and phosphorus supply on the growth of Lactuca sativa L. and arsenic and phosphorus availability in an arsenic polluted soil under nonsterile conditions. *Appl Soil Ecol* **45** 262–268.

Emamverdian A, Ding Y, Mokhberdoran F and Xie Y 2015 Heavy metal stress and some mechanisms of plant defense response. *The Scientific World Journal* 2015 18.

George, C M ,Sima L, Jahuira Arias M H, Mihalic J, Cabrera L Z 2014 Arsenic exposure in drinking water: an unrecognized health threat in Peru. *Bulletin of the World Health Organization* **92** 565-572.

Harper M, Haswell SJ 1988 A comparison of copper, lead and arsenic extraction from polluted and unpolluted soils. *Environ Technol Lett* **9** 1271–1280.

Hettick B E, Canas Carrell J E, French A D, Klein D M 2015 Arsenic: A Review of the Element's Toxicity, Plant Interactions, and Potential Methods of Remediation. *Journal of Agricultural and Food Chemistry* **63 (32)** 7097-7107.

Islam M R 2004 Assessment of arsenic in the water–soil–plant systems in gangetic flood plains of Bangladesh. *Asian J Plant Sci* **3** 489–493.

Juhasz A L, Naidu R, Zhu Y G, Wang L S, Jiang J Y, Cao Z H 2003 Toxicity tissues associated with geogenic arsenic in the groundwater-soil-plant-human continuum. *Bull Environ Contam Toxicol* **71** 1100–1107.

Kainth, GS 2015 Arsenic poisoning in drinking water: Huge Public-Health problem-OpED. *Eurasia Review News and Analysis.*

Khan A, Khan S, Khan M A, Qamar Z, Waqas M 2015 The uptake and bioaccumulation of heavy metals by food plants, their effects on plant nutrients, and associated health risk: a review. *Environ Sci Pollut Res Int* **22 (18)** 13772-99.

Kim K-W, Bang S, Zhu Y, Meharg A A, Bhattacharya P 2009 Arsenic geochemistry, transport mechanism in the soil-plant system, human and animal health issues. *Environ Int* **35** 453–454.

Marin A R, Masscheleyn P H, Patrik J 1992 The influence of chemical form and concentration of arsenic on rice growth and tissue arsenic concentration. *Plant Soil* **139** 175–183.

Meharg A A 2004 Arsenic in rice-understanding a new disaster for South-East Asia. *Trends Plant Sci* **9** 415–417.

Meharg A A, Macnair M R 1992 Suppression of the high affinity phosphate uptake system :a mechanism of arsenate tolerance in Holcus lanatus L. *J Exp Bot* **43** 519–524.

Miteva E 2002 Accumulation and effect of arsenic on tomatoes. *Comm Soil Sci Plant Anal* **33(11)** 1917–1926.

Mondal P, Majumdar C B, Mohanty B 2006 Laboratory based approaches for arsenic remediation from contaminated water; recent developments. *J Hazard Mater* **137** 464–479.

Nriagu J O, Pacyna J M 1988 Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature* **333** 134–139.

Nriagu J O 2002 Arsenic poisoning through the ages. In: *Environmental chemistry of arsenic*, eds. Frank Enberger WT, Marcel Dekker, New York. Pp 1–26.

Norra S 2005 Impact of irrigation with As-rich groundwater on soil and crops: a geochemical case study in West Bengal delta plain, India. *Appl Geochem* **20** 1890–1906.

Naujokas M F, Anderson B, Ahsan H, Aposhian H V, Graziano J H, Thompson C and William A S 2013 The broad scope of health effects from chronic arsenic exposure: update on a worldwide public health problem. *Environ Health Perspect* **121(3)** 295-302.

Quaghebeur M, Rengel Z 2005 Arsenic speciation governs arsenic uptake and transport in terrestrial plants. *Microchem Acta* **151** 141–152.

Rahman M A, Hasegawa H, Rahman M M, Miah M A M, Tasim A 2008 Straighthead disease of rice (*Oryza sativa* L.) induced by arsenic toxicity. *Environ Exper Bot* **62(1)** 54–59.

Ratnaike R N 2003 Acute and chronic arsenic toxicity. *Post Graduate Medical Journal.* **79 (933)** 391-396.

Roychowdhury J 2002 Survey of arsenic in food composites from an arsenic affected area of West Bengal, India. *Food Chem Toxicol* **40** 1611-1621.

Shaibur M R, Kitajima N, Sugewara R, Kondo T, Alam S, Imamul Huq S M, Kawai S 2008 Critical toxicity of arsenic and elemental composition of arsenic-induced chlorosis in hydroponic Sorghum. *Water Air Soil Pollut* **191** 279–292.

Sharma P D 2007 *Ecology and environment* (10th) Rastogi publication, Meerut.

Singh N, Ma L Q, Srivastava M, Rathinasabapathi B 2006 Metabolic adaptations to arsenic induced oxidative stress in Pteris vittata L. and Pteris ensiformis L. *Plant Sci* **170** 274–282.

Sinha B, and Bhattacharaya K 2015 Arsenic toxicity in rice with special reference to speciation in Indian grain and its implication on human health. *Science of Food and Agriculture*. **95 (7)** 1435-1444.

Smith S E, Christophersen H M, Pope S, Smith F A 2010 Arsenic uptake and toxicity in plants: integrating mycorrhizal influences. *Plant Soil* **327** 1–21.

Smith A H, Marshell G, Roth T, Ferreccio C, Liaw J, Steinmaus C 2018 Lung, bladder, and kidney cancer mortality 40 years after arsenic exposure reduction. *J Natl Cancer Inst* **110 (3)** 241-249.

Srivastava M, Ma L Q, Singh N, Singh S 2005 Antioxidant responses of hyper-accumulator and sensitive fern species to arsenic. *J Exp Bot* **56** 1335–1342.

Stoeva N, Bineva T Z 2003 Oxidative changes and photosynthesis in Oat plants grown in As-contaminated soil. *Bulg J Plant Physiol* **29 (1–2)** 87–95.

Stoeva N, Berova M, Zlatez Z 2004 Physiological response of maize to arsenic contamination. *Biol Planta* **47 (3)** 449–452.

Stoeva N, Berova M, Vassilev A, Zlatev Z 2005a Effect of arsenic on some physiological parameters in bean plants. *Biol Planta* **49 (2)** 293– 296.

Tripathi R D, Srivastava S, Mishra S, Singh N, Tuli R, Gupta D K, Maathuis F J M 2007 Arsenic hazards: strategies for tolerance and remediation by plants. *Trends Biotechnol* **25 (4)** 158–165 .

Ullrich-Eberius C, Sanz A, Novacky A 1989 Evaluation of arsenic and vanadate-associated changes of electrical membrane potential and phosphate transport in *Lemna gibba* GL. *J Exp Bot* **40** 119–128.

Vaughan G T 1993 The environmental chemistry and fate of arsenical pesticides in cattle tick dip sites and banana land plantations. *CSIRO Division of Coal Industry, Centre for Advanced Analytical Chemistry, NSW, Melbourne.*

Verbruggen N, Hermans C, Schat H 2009 Mechanisms to cope with arsenic or cadmium in Plants. *Curr Opin Plant Bio* **12** 1–9.

Wang S, Mulligan C N 2006 Occurrence of arsenic contamination in Canada: sources, behavior and distribution. *Sci Total Environ* **366** 701–721.

Wells B R, Gilmor J 1997 Sterility in rice cultivars as influenced by MSMA rate and water management. *Agron J* **69** 451–454

Williams P N 2005 Variation in arsenic speciation and concentration in paddy rice related to dietary exposure. *Environ Sci Technol* **39** 5531-5540.

Williams P N, Islam M R, Adomako E E, Raab A, Hossain S A, Zhu Y G, Feldmann J and. Meharg A A 2006 Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. *Environ Sci Technol* **40** 4903–8

World Health Organization 2007 Arsenic in drinking Water. Xu XY, McGrath S P, Meharg A A, Zhao F J 2008 Growing rice aerobically markedly decreases arsenic accumulation. *Environ Sci Technol* **42 (15)** 5574–9.

Zhao R 2006 Arsenic speciation in moso bamboo shoot – a terrestrial plant that contains organ arsenic species. *Sci Total Environ* **371** 293–303.

Zhao F J, Ma J F, Meharg A A, McGrath M P 2009 Arsenic uptake and metabolism in plants. *New Phytol* **181** 777–794

Zhu Y-G, Rosen B P 2009 Perspectives for genetic engineering for the phytoremediation of arsenic-contaminated environments: from i https://en.wikipedia.org/wiki/Arsenic _contamination of ground water.
"*Arsenic in drinking water seen as threat*" USAToday.com August 30, 2007.
"*Groundwater in 13 Districts of Bihar contaminated with Arsenic*" Biharprabha News.magination to reality. *Curr Opin Biotechnol* **20** 220–224.
.