Journal of
Bioremediation & Biodegradation

Bhatt, J Bioremed Biodeg 2016, 7:2
DOI: 10.4172/2155-6199.1000329

Short Communication Open Access

Arsenic as Next Global Threat? Role of Biotechnological Approaches

Bhatt SM *

Biotechnology Department, Lovely Professional University, Punjab, India

Abstract

Arsenicosis is about potent toxicity and carcinogenic effect of arsenic but sometime it had been used for medicinal purpose in old times also. Nowadays it has been emerging as a new threat for human community at large because of recent report of arsenic mobilization in food chain. Study reveals presence of high arsenic concentration not only in drinking water but also in in many food crops, meat and other consumables. Many part of world is facing acute crisis such as Bangladesh, china India, and many more countries as depicted in Figure 1 and in more than 70 countries, peoples are severely effected by groundwater arsenic contamination and need urgent interventions. Bangladesh has been declared as one of the worst natural calamities where rural and urban communities are facing severe consequences in form of skin cancer such as keratosis and melanosis. In India, Malwa, Punjab, has been declared as Cancer belt, where intense sign of cancer has been reported in skin and other vital organs.

Keywords: Carcinogenic effect; Arsenate; *P. vittata*; Aqua-glycoporins

Metalloid arsenic has several structural form (Table 1), and can combine with many metals such as iron and molybdenum but Arsenic III (inorganic form) is most toxic form and is accumulating and entering in food chain constantly, escalating arsenic mobility issue more than calculated one. Further environmental condition such as pH, floods (redox condition), are conducive in high mobility and interconversions of arsenic getting complexed with many other compounds, favouring their easy transport in rice and other seeds via multiple transporters e.g., aquaglyceroporins in both plant and animals [1].

Marine organism had exceeding high levels of arsenic accumulation in non-toxic organic form arsenobetain, while rice is reported to have exceeding levels of inorganic arsenic (III). Arsenate As (V) is non-toxic form but it becomes toxic when arsenic (V) combines with phosphate or iron oxide and thus inhibits phosphorylation processes after entering the cells. Arsenate As (III) causes deactivation of enzyme due to its high affinity towards thiol groups. In addition, inorganic arsenic enters the cell via the hexose transporter, phosphate transporter systems (PTS) or aqua-glycoporins, while rice and other plants had different transporter. Arsenic reductase coded by Ars or Arr operon are helpful in conversion of arsenite to arsenate in both prokaryotes and eukaryotes and some microbes has ability to pump out exceeding arsenite after detoxification. Arsenic detoxification in multicellular organisms is based on methylation pattern and further oxidation makes arsenic less toxic basically arsenic (III) is converted into arsenic (V) which is excreted in urine of human being. However, since human has limited capacity of conversion, therefore high accumulation causes various malfunctioning such as keratosis and melanosis.

Figure 1: Countries affected with Arsenic metal in groundwater [15].

Microbial action is thought to provoke high mobilisation of arsenic via arsenic reductases after solubilisation of arsenic complex due to chelation. Methylation is believed to be one of the important mechanisms present in all organism including many microbes such as bacteria, fungi, and even higher plants, other organisms that converts them back in non-toxic form. Mostly, alternative oxidation and reduction is the basis of conversion of one form of arsenic into other. Even though arsenite is more toxic than arsenate, this transformation is essential, since only arsenite can be methylated. Arsenite is methylated to methylarsonate, which is reduced to methylarsonite and further to dimethylarsinate and to dimethylarsinous acid [2].

Arsenic contamination in non-effected area is of great concern today and spreading via food chain. Old strategies for arsenic mitigation were not only costly, but also results in large amount of sludge production, which was difficult to detoxify in one-step. Many worker believes that comprehensive multistep approaches towards escalating problems is essential in mitigation of arsenic means both chemical as well as biotechnological approaches can work in synchronous matter. Therefore, alternative techniques may be helpful in order to prevent the entry of arsenic in the food chain. One of the most relevant strategies seems to be the application of arsenic resistance microbes equipped with both uptake and detoxification machinery for sequestration and introduction of novel genes into food crops. Many endophytes isolated from hyper accumulator's plants have role in mobilization of arsenic. Metagenomics approaches seems to be plausible in finding potential microbes in order to enhanced bioremediation capability of arsenic on the basis of presence of clusters of genes and gene networks present

***Corresponding author:** Bhatt SM , Biotechnology Department, Lovely Professional University, Punjab, India, E-mail: drsmbhatt@gmail.com

Received January 11, 2016; **Accepted** February 01, 2016; **Published** February 10, 2016

Citation: Bhatt SM (2016) Arsenic as Next Global Threat? Role of Biotechnological Approaches. J Bioremed Biodeg 7: 329. doi: 10.4172/2155-6199.1000329

Arsenic form	Sources	Comments	References
Sodium Arsenate	Pesticides and wood		[27]
DMA (also known as cacodylic acid) have been widely used as pesticides and herbicides	Preservatives		[28,29]
Arsenopyrite	Rocks, Soils, Minerals, mines		[15,49]
	Ground water	Arsenite, arsenate	[30]
Arsenobetaine, Arsenocholine, tetramethylarsonium salts		Organic forms (methyl and dimethyl arsenic compounds)	[31]
Arsenosugars	Coal-fired power generation		[32]
	Plants, burning vegetation and also due to eruption of volcano		[33]
Fe- reducing bacteria are linked to the mobilization of As in aquifer of the river delta in Bangladesh.	Tube-wells >1 mg L^{-1}	Bengal Delta region (encompassing Bangladesh and West Bengal)	[34]
Metal-reducing bacteria			
Arsenobetaine	Marine animal		[35]
$[(CH_3)_3As{+}CH_2COOH]$ dimethylarsinic acid	Soil		[36]
arsenobetain MMA, DMA, TMAO	Plants		[37-39]
Arsenic III, DMA, MMA, MA As-cysteine, As_2S_3 and As_2O_5			[40,41]
arsenate, arsenite, MMA and DMA	Soil, rice		[42]
Asbet, Aschol, arsenosugars, arsenolipids	Sea foods	No harm by intake	[43,44]
As(III), DMA,MMA, As(V)	Urine wine club soda		[45]
Legume–rhizobium	Sunflower		[46]
Symbiosis	(*Helianthus annuus* L.), jack bean (*Canavalia ensiformis* L.), velvet bean (*Stizolobium aterrimum* L.), castor bean (*Ricinus communis* L.)		[4,47]

Table 1: Sources and forms of arsenic.

for As sequestration and metabolism [3]. Many hyper accumulators are known to adsorb more than 95% of the arsenic from the soil as evident by the fern (*P. vittata*) [4]. Unfortunately, the plant *P. vittata* grows well only in warm, humid environments with mild winters, therefore they cannot grow everywhere in every environment. Therefore, some scientist are making efforts to increase the ability of plants to pump out arsenic from soil via creating GMO plants which have gene for both mobility and sequestration of arsenic and beside this some more gene required like metal chelator, metallothionein (MT), metal transporter, and phytochelatin (PC) genes [5]. Dhanker and colleagues constructed Arabidopsis plants, where, γ -ECS gene related to mobility was introduced and the arsenate reductase C (ArsC) gene to control the sequestration of arsenic [3,6,7]. Compared to other techniques, biomass based techniques are more useful. Some research on endophytes related to bioremediation and use of arbuscular mycorrhizas (AMs) are also involve absorption of arsenic. Mycorrhizas are vital for some plants since these are fungi associate with plant roots, so an important tools in increasing uptake of nutrients, especially phosphorus. AM fungi may be helpful in increased arsenic uptake along with hyper accumulating fern *P. vittata* The arsenic translocation factor (TF) was reported to increase in AM-inoculated plants as compared with Uninoculated plants, for example in *Glomus mosseae*-inoculated plants TF factor was 730 as compared to 50 as compared to control plants. Since arsenate shares structural similarity with phosphate and thus many hyper accumulator species such as *P. vittata* absorbs arsenate via phosphate transport system (PTS) or with other metal transporter system [8]. Secretion of various chemical chelators also increases rapid uptake of arsenic but mostly plants lacks adequate system to adsorb arsenic rapidly.

Some edible microbes such as Lactic acid bacteria has various special characteristic features such as secretion of antibacterial substances (bacteriocins) presence of arsenic reductase (Ars C). *Lactobacillus lactis* reported to contains GSH which protects bacterium under extreme acidic conditions [9,10]. Use of LAB is limited in adsorption since they requires surface modifications for perfect adsorption of arsenic. There are presence of many secondary transporter Ars A, Ars B, Ars C operon that makes them arsenic resistant bacteria but they fail to adsorb Cobalt, Copper, Nickel, and Iron metals [9]. Bacillus adsorb wide range of metals such as mercury, lead and cadmium, while *Staphylococcus, E. coli, Lactobacillus* are arsenic resistance [11,12]. Known Lactobacillus species for arsenic are *Lactobacillus acidophilus, L. Crispatus,* while *Pseudomonas proteda, Bacillus subtilis, L. rhamnosus, Bifido bacterium* and *Lactobacillus plantarum* [9,13,14]. Both facultative aerobic and anaerobic e.g., bacillus, clostridium reported to remove metal ions rapidly [15-17]. Presence of metal resistance shows microbial capability to survive in the environment, which can be harnessed as an effective mitigation strategy for arsenic [11,18,19]. Arsenite III is mostly dominating in anoxic water such as floods and via root uptake enters in seedlings. DARP (Dissimilatory Arsenate-respiring prokaryotes) [20] is associated with arsenic reduction via electrons exchange via release of chelators such as lactate, acetate and formate. These microbes utilizes 'arr' biomarkers [21] and thrive well in deep sea, deep well and lake or contaminated aquifers [22].

For arsenic detoxification arsenate and arsenite operon is present in both the gram positive as well as gram negative bacteria. arr operon is related to arsenic reductase present in many microbes such as *Shewanella, bacillus* some organism like *E. coli, Staphylococcus, Bacillus, Acidithiobacillus, Pseudomonas,* had well characterised Ars operon linked with As(V) detoxification where. In these organisms, As (V) is converted to As (III) via arsenic reductase, which triggers ars operon. Actually, these operons are linked with efflux and transporter protein, as a result arsenic V enters via phosphate transporter protein while Ars III is efflux after activation of Ars operon [16]. Endophytes are part of plant system and thus may help in mobilisation of nutrients and arsenic along with Arsenic V which is analogous to phosphate while some rhizospheric endophytes stops mobilization of arsenic metals. There is more bioavailability of arsenic or deposits of arsenic. Rather than single microbes to act for decontamination groups of microbes (called as Biome) activates for maintaining balance between toxic metals. Recently, addition of SiO, or iron oxide (Fe_2O_3 or Fe_3O_4) nanoparticle in soil resulted in increasing growth of specific micro-organism specially anaerobic arsenic reducing microbes, which resulted in enhanced uptake, via rapid mobilization and precipitation of arsenic in presence of sodium acetate. This reduction strategies is actually depends on presence of specific operon, such as Arr operon. Treatment of NPs with sodium acetate increases precipitation of arsenic due to electron donating capacity [23,24]. In assisting microbial bioremediation plants may have vital absorptive role in aim to survival strategies, Bayer et al. [25,26] has recently studied a detail mechanism of interaction between plant and microbes via metagenomics study [48]. In conclusion, more research effort is required in pilot scale study which may represent a confirmative mitigation of arsenic from food chain [49,50].

References

1. Maciaszczyk-Dziubinska E, Wawrzycka D, Wysocki R (2012) Arsenic and antimony transporters in eukaryotes. Int J Mol Sci 13: 3527-3548.
2. Nies DH (1999) Microbial heavy-metal resistance. Appl Microbiol Biotechnol 51: 730-750.
3. Dhankher OP, Elizabeth AH, Pilon-Smits R, Meagher B, Sharon D (2012) Biotechnological approaches for phytoremediation. Plant biotechnology and agriculture. Academic Press, San Diego, CA, USA. pp: 309-328.
4. Brahman KD, Kazi TG, Afridi HI, Naseem S, Arain SS, et al. (2013) Evaluation of high levels of fluoride, arsenic species and other physicochemical parameters in underground water of two sub districts of Tharparkar, Pakistan: a multivariate study. Water Res 47: 1005-1020.
5. Doucleff M, Terry N (2002) Pumping out the arsenic. Nat Biotechnol 20: 1094-1095.
6. Dhankher OP, Li Y, Rosen BP, Shi J, Salt D, et al. (2002) Engineering tolerance and hyperaccumulation of arsenic in plants by combining arsenate reductase and gamma-glutamylcysteine synthetase expression. Nat Biotechnol 20: 1140-1145.
7. Dhankher OP, Om Parkash D, Nupur Shasti A, Barry Rosen P, Mark F, et al. (2003) Increased cadmium tolerance and accumulation by plants expressing bacterial arsenate reductase. New phytologist 159: 431-441.
8. Wang J, Zhao FJ, Meharg AA, Raab A, Feldmann J, et al. (2002) Mechanisms of arsenic hyperaccumulation in Pteris vittata. Uptake kinetics, interactions with phosphate, and arsenic speciation. Plant Physiol 130: 1552-1561.
9. Van KR, Richard van K, Natasa G, Roger B, Rob LJ, et al. (2005) Functional analysis of three plasmids from Lactobacillus plantarum. Applied and environmental microbiology 71: 1223-1230.
10. Wang SX, Wang ZH, Cheng XT, Li J, Sang ZP, et al. (2007) Arsenic and fluoride exposure in drinking water: children's IQ and growth in Shanyin county, Shanxi province, China. Environ Health Perspect 115: 643-647.
11. Halttunen T, Finell M, Salminen S (2007) Arsenic removal by native and chemically modified lactic acid bacteria. Int J Food Microbiol 120: 173-178.
12. Srivastava M, Ma LQ, Santos JA (2006) Three new arsenic hyperaccumulating ferns. Sci Total Environ 364: 24-31.
13. Nagaoka M, Shibata H, Kimura I, Hashimoto S, Kimura K, et al. (1995) Structural studies on a cell wall polysaccharide from Bifidobacterium longum YIT4028. Carbohydr Res 274: 245-249.
14. Burger S, Tatge H, Hofmann F, Genth H, Just I, et al. (2003) Expression of recombinant Clostridium difficile toxin A using the Bacillus megaterium system. Biochem Biophys Res Commun 307: 584-588.
15. Oremland RS, Stolz JF (2003) The ecology of arsenic. Science 300: 939-944.
16. Mateos LM, Ordóñez E, Letek M, Gil JA (2006) Corynebacterium glutamicum as a model bacterium for the bioremediation of arsenic. Int Microbiol 9: 207-215.
17. Richey C, Chovanec P, Hoeft SE, Oremland RS, Basu P, et al. (2009) Respiratory arsenate reductase as a bidirectional enzyme. Biochemical and biophysical research communications 382: 298-302.
18. Gadd GM (2013) Microbial Roles in Mineral Transformations and Metal Cycling in the Earth's Critical Zone. In Molecular Environmental Soil Science. Springer: 115-165.
19. Mukhopadhyay R, Rosen BP, Phung LT, Silver S (2002) Microbial arsenic: from geocycles to genes and enzymes. FEMS Microbiol Rev 26: 311-325.
20. Hollibaugh JT, Budinoff C, Hollibaugh RA, Ransom B, Bano N (2006) Sulfide oxidation coupled to arsenate reduction by a diverse microbial community in a soda lake. Appl Environ Microbiol 72: 2043-2049.
21. Malasarn D, Saltikov CW, Campbell KM, Santini JM, Hering JG, et al. (2004) arrA is a reliable marker for As(V) respiration. Science 306: 455.
22. Lear G, Song B, Gault AG, Polya DA, Lloyd JR (2007) Molecular Analysis of Arsenate-Reducing Bacteria within Cambodian Sediments following Amendment with Acetate. Applied and Environmental Microbiology 73: 1041-1048.
23. Dong G, Huang Y, Yu Q, Wang Y, Wang H, et al. (2014) Role of nanoparticles in controlling arsenic mobilization from sediments near a realgar tailing. Environ Sci Technol 48: 7469-7476.
24. Politi J, Spadavecchia J, Fiorentino G, Antonucci I, Casale S, et al. (2015) Interaction of Thermus thermophilus ArsC enzyme and gold nanoparticles naked-eye assays speciation between As(III) and As(V). Nanotechnology 26: 435703.
25. Brune KD, Bayer TS (2012) Engineering microbial consortia to enhance biomining and bioremediation. Front Microbiol 3: 203.
26. Xiong J, He Z, Van Nostrand JD, Luo G, Tu S, et al. (2012) Assessing the microbial community and functional genes in a vertical soil profile with long-term arsenic contamination. PLoS One 7: e50507.
27. Thangavel P, Subbhuraam CV (2004) Phytoextraction: role of hyperaccumulators in metal contaminated soils. Proceedings-Indian National Science Academy Part B 70: 109-130.
28. Sarkar D, Datta R (2004) Arsenic fate and bioavailability in two soils contaminated with sodium arsenate pesticide: an incubation study. Bulletin of environmental contamination and toxicology 72: 240-247.
29. Woolson EA, Axley JH, Kearney PC (1973) The chemistry and phytotoxicity of arsenic in soils: II. Effects of time and phosphorus. Soil Science Society of America Journal 37: 254-259.
30. Smedley PL, Kinniburgh DG (2002) A review of the source, behaviour and distribution of arsenic in natural waters. Applied geochemistry 17: 517-568.
31. Zhong L, Hu C, Tan Q, Liu J, Sun X (2011) Effects of sulfur application on sulfur and arsenic absorption by rapeseed in arsenic-contaminated soil. Plant Soil Environ 57: 429-434.
32. Kuehnelt D, Lintschinger J, Goessler W (2000) Arsenic compounds in terrestrial organisms. IV. Green plants and lichens from an old arsenic smelter site in Austria. Applied organometallic chemistry 14: 411-420.
33. Zhao FJ, McGrath SP, Meharg AA (2010) Arsenic as a food chain contaminant: mechanisms of plant uptake and metabolism and mitigation strategies. Annu Rev Plant Biol 61: 535-559.
34. Islam FS, Gault AG, Boothman C, Polya DA, Charnock JM, et al. (2004) Role of metal-reducing bacteria in arsenic release from Bengal delta sediments. Nature 430: 68-71.
35. Huang JH, Matzner E (2006) Dynamics of organic and inorganic arsenic in the solution phase of an acidic fen in Germany. Geochimica et Cosmochimica Acta 70: 2023-2033.
36. Schoof RA, Yost LJ, Eickhoff J, Crecelius EA, Cragin DW, et al. (1999) A market basket survey of inorganic arsenic in food. Food Chem Toxicol 37: 839-846.
37. Koch I, Lixia W, Chris OA, William CR, Kenneth RJ (2000) The predominance of inorganic arsenic species in plants from Yellowknife, Northwest Territories, Canada. Environmental science & technology 34: 22-26.
38. González E, Solano R, Rubio V, Leyva A, Paz-Ares J (2005) Phosphate Transporter Traffic Facilitator is a plant-specific SEC12-related protein that enables the endoplasmic reticulum exit of a high-affinity phosphate transporter in Arabidopsis. The Plant Cell 17: 3500-3512.
39. Rahman MM, Ng JC, Naidu R (2009) Chronic exposure of arsenic via drinking water and its adverse health impacts on humans. Environ Geochem Health 31 Suppl 1: 189-200.

40. Ruiz-Chancho MJ, López-Sánchez JF, Schmeisser E, Goessler W, Francesconi KA, et al. (2008) Arsenic speciation in plants growing in arsenic-contaminated sites. Chemosphere 71: 1522-1530.

41. Rahman MA, Hasegawa H, Rahman MM, Rahman MA, Miah MA (2007) Accumulation of arsenic in tissues of rice plant (Oryza sativa L.) and its distribution in fractions of rice grain. Chemosphere 69: 942-948.

42. Abedin MJ, Feldmann J, Meharg AA (2002) Uptake kinetics of arsenic species in rice plants. Plant Physiol 128: 1120-1128.

43. Goessler W (1997) Arsenic compounds in a marine food chain. Fresenius' journal of analytical chemistry 359: 434-437.

44. Greene R, Crecelius E (2006) Total and inorganic arsenic in mid-atlantic marine fish and shellfish and implications for fish advisories. Integrated environmental assessment and management 2: 344-354

45. Sheppard BS, Caruso JA, Heitkemper DT, Wolnik KA (1992) Arsenic speciation by ion chromatography with inductively coupled plasma mass spectrometric detection. Analyst 117: 971-975.

46. Dwivedi S, Mishra A, Tripathi P, Dave R, Kumar A, et al. (2012) Arsenic affects essential and non-essential amino acids differentially in rice grains: inadequacy of amino acids in rice based diet. Environ Int 46: 16-22.

47. Reichman SM (2007) The potential use of the legume-rhizobium symbiosis for the remediation of arsenic contaminated sites. Soil Biology and Biochemistry 39: 2587-2593.

48. Trotta A, Falaschi P, Cornara L, Minganti V, Fusconi A, et al. (2006) Arbuscular mycorrhizae increase the arsenic translocation factor in the As hyperaccumulating fern Pteris vittata L. Chemosphere 65: 74-81.

49. Aldrich MV, Peralta-Videa JR, Parsons JG, Gardea-Torresdey JL (2007) Examination of arsenic (III) and (V) uptake by the desert plant species mesquite (Prosopis spp.) using X-ray absorption spectroscopy. Science of the total environment 379: 249-255.

50. Huang JH, Scherr F, Matzner E (2007) Demethylation of dimethylarsinic acid and arsenobetaine in different organic soils. Water, air and soil pollution 182: 31-41.