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Review Article

Arsenic: an alarming global concern

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A B S T R A C T

Arsenic is a potent environmental contaminant and a silent toxin. Presence of high levels of arsenic in the environment may be regarded as a global holocaust and may lead to traumatic effects on human beings. This metalloid finds its way into living systems through inhalation or ingestion. Acute exposure may be fatal, whereas long term exposure to arsenic may lead to cancer. Existing treatment approaches are not effective enough to tackle this problem. Proper strategies therefore need to be adopted to defy arsenic calamity. It is time to adopt effective measures for remediation of arsenic present in soil, water and wastes. This review article aims to explore the potential of plants in remediation of arsenic induced hazards. Holistic approaches may be used to curb this problem, though intense studies are required to establish their role. Arsenic affected people need to be encouraged to get rid of their social taboo and come forward for treatment. Increasing knowledge and awareness among the general public may help to combat this health hazard in the near future.

Keywords

Arsenic, genotoxicity, repair enzymes, arsenicosis, phyto-remediation

Introduction

Arsenic, a metalloid is omnipresent in the environment in both organic and inorganic forms, the most common form being arsenopyrite. Inorganic forms of arsenic namely arsenite and arsenate show more toxicity in humans than their organic counterparts. Arsenic is commonly referred to as "king of poisons" and ''poison of kings'' because it is potent, discreet, easily available, odorless and tasteless; hence it can be easily camouflaged in food (Hughes *et al.*, 2011). This metalloid is mainly present naturally in local bedrocks. It is introduced into the soil during weathering of rocks and minerals, their leaching and run-off or from anthropogenic sources. The source of inorganic arsenic is primarily geological, while organic arsenic is found in abundance in marine life. Surface water gets contaminated when geothermal fluids, rich in arsenic come in contact with it (Garelick *et al.,* 2008). Arsenic released from rocks and sediments or dissolution of arsenopyrite present in sediments contributes to arsenic flux in the environment. Atmospheric contamination with arsenic occurs by coal-fired power generation plants, burning vegetation and volcanism (Gupta and Gupta, 2013). Reduction to arsines also contributes to the same. These particles get dispersed by the wind and they return to the soil. Man-made contaminations do not lag behind. Occupational exposure is another source of arsenic. Different forms of arsenic are used in the treatment of timber, in agriculture, ceramic, glass, semiconductor and pharmaceutical industry, refining of metallic ores, smelting of metals, burning of fossil fuels, pesticide manufacturing, semiconductor etc. However, groundwater arsenic contamination surpasses all other sources. Human arsenic exposure may also come from hazardous waste sites. Exposure to this dangerous element generally occurs by ingestion, inhalation, through direct dermal contact or may be transmitted from the mother to the foetus via the placental route (Tchounwou *et al.,* 2003). Dermal absorption of arsenic is low, therefore washing, bathing and laundry with contaminated water does not seem to affect much.

The famous quote by the physician, alchemist and astrologer Paracelsus (1493–1541) says "all things are poison and nothing is without poison, only the dose permits something not to be poisonous." A growing body of evidence suggests that essential nutrients at small amounts may be a poison at higher doses. Micronutrients are essential part of a healthy diet as they fend off disease and disabilities. Even the obnoxious metal arsenic has a crucial role in the metabolism of the amino acid methionine and in gene silencing. Therefore human life since evolution developed a hunger for these metals. There has been a cut off limit for all elements, beyond which they may lead to disaster, as happened in case of arsenic (Hunter, 2008).

Increased concentration of arsenic often leads to serious health hazards. Arsenic in drinking water poses threat to human health. The safe level of arsenic set by WHO is 10 μg/L, but, for the developing countries because of problem of remediation, this level is 50 μg/L (Huq *et al.,* 2006). Factors that control arsenic concentration and transport in groundwater includes Red-ox potential (Eh), adsorption/ desorption, precipitation/dissolution, arsenic speciation, pH, presence and concentration of competing ions, biological transformation, etc (Gupta and Gupta, 2013). Groundwater in proximity to the surface contains a lower concentration of arsenic than that deep inside.

Arsenic scenario

Over the ages, elevated concentrations of arsenic in drinking-water have become a menace in several parts of the world. Initially, arsenic contamination in groundwater was found in Asian countries like Bangladesh, India, and places in China. High arsenic levels in groundwater is found in Chandpur, Comilla, Noakhali, Munshiganj, Brahmanbaria, Faridpur, Madaripur, Gopalganj, Shariatpur, and Satkhira areas of Bangladesh (Huq *et al.,* 2006). Later on it was found that high level of arsenic are also prevalent in other parts of the world like Nepal, Cambodia, Myanmar, Afghanistan, Korea, Pakistan, Chile, Brazil, Bulgaria, Canada, Czech republic, Egypt, Iran, Vietnam, Argentina, Australia and Finland (Mukherjee *et al.,* 2006).

Arsenic contamination is highly prevalent in various regions in India. High level of Arsenic in ground water has been found in the states of Bihar, Uttar Pradesh, Jharkhand, Assam, Tripura, Arunachal Pradesh, Nagaland, Manipur, Chhattisgarh and Andhra Pradesh. Apart from these, arsenic contamination of dug-wells, hand-pumps, and spring-water was reported in Chandigarh and different villages of Punjab, Haryana, and Himachal Pradesh in northern India (Mukherjee *et al.,* 2006). Dwelling beside a river side is always a pleasant experience, but people are often unaware of the fact that something deadly is awaiting. The states in the region of the upper, middle and lower Ganga and Brahmaputra plain are most affected by arsenic (Chakraborti *et al.*, 2003). Like other heavy metals like Iron, Cadmium, Copper etc, Arsenic was found in Gomti River originating in Uttar Pradesh (Kumar *et al.,* 2013). Arsenic poisoning was first detected in West Bengal in July, 1983 (Mukherjee *et al.*, 2006). West Bengal is one of the states in India in which arsenic poisoning is highly prevalent. Surveys conducted showed that the districts like Malda, Murshidabad, Nadia, North-24-Parganas, South-24-Parganas, Bardhaman, Howrah, Hoogly and Kolkata in West Bengal are most affected. However the areas in West Bengal that are mildly affected by arsenic include Koch Bihar, Jalpaiguri, Darjeeling, North Dinajpur and South Dinajpur (Dey *et al.*, 2014). The main cause of this type of contamination in West Bengal and Bangladesh is natural erosion (Gupta and Gupta, 2013). The deltaic plain of West Bengal is one of the areas which are worse affected. Arsenic rich sediments coming from the Chotanagpur Rajmahal Highlands get deposited under reducing condition, thus contributing to the disaster (Chakraborti *et al.,* 2003). The reactions that regulate mobilization and accumulation of arsenic in the environment are oxidation-reduction, precipitation-dissolution, absorption-desorption, and organic and biochemical methylation. Arsenic sulphides get oxidized under moist conditions; these forms are soluble in water and are transported due to washing out of sediment particles by precipitation. The excessive level of arsenic contamination in the Ganges delta may be hypothesized to be oxidation of pyrite and arsenopyrite, reduction of oxyhydroxides, and continuous oxidation and reduction reactions in unconfined aquifers.

Metabolism of arsenic

Arsenic may exist in different forms. The stability, solubility and toxicity of arsenic vary among its various forms. The inorganic forms of arsenic, namely arsenate and arsenite are more persistent and bioavailable; hence they are more hazardous as compared to their organic counterparts (Gupta and Gupta, 2013). Pentavalent arsenate is commonly found in surface water; where as trivalent arsenite is more prevalent in deep anoxic wells (Sinha *et al.*, 2005c). The absorption of arsenic in the body depends on the particle's solubility and size. Arsenic is mainly absorbed in the small intestine at a pH 5.0, through an electrogenic process which involves a proton (H+) gradient (Gonzalez *et al.*, 1997). Liver is the site of arsenic metabolism in the human body. The metabolism of arsenic mainly involves reduction and oxidative methylation reactions and is depicted in Figure 1. More than half of the ingested arsenic may get eliminated through the urine within five days. DMA is the primary urinary metabolite (60%–70%) in comparison to the other organic forms (Hopenhayen-Rich *et al.*, 1993). Though highly toxic, a minute amount of inorganic arsenic is also excreted out of our system. Studies reveal that the maximun concentration of arsenic resides in the kidneys and liver (Benramdane *et al.*, 1999).

Arsenic normally gets racked up in the

organs like liver, kidneys, heart, and lungs and smaller amounts in the muscles, nervous system, gastrointestinal tract, and spleen (Benramdane *et al.,* 1999). However, it is eliminated from these sites. Keratin-rich tissues like nails, hair, and skin on the other hand retain arsenic. Hence, impact of environmental arsenic on health of humans is detected from their presence in metabolically inactive tissues, hair, and nails. These serve as indicators of arsenic exposure (Samanta *et al.,* 2004, Abbas and Cheema, 2014).

Arsenic induced genotoxicity

Arsenic compounds in the trivalent forms are the most toxic. These compounds exert various biochemical and cytotoxic effects. Arsenic has an affinity towards sulphur containing compounds; it binds to thiol or sulfhydryl groups in tissue proteins of the liver, lungs, kidney, spleen, gastrointestinal mucosa, and keratin-rich tissues (Ratnaike, 2003). Arsenic catastrophe is mainly due to generation of reactive oxygen species (ROS) leading to oxidative damage. This results in interference with cellular enzymatic, respiratory and mitotic machinery. Inhibition of DNA repair is another common phenomenon of arsenic exposure and de-regulation of repair enzymes is responsible for this (Henkler *et al.,* 2010). Arsenic often replaces phosphate in ATP, imparting toxicity.

Some of the other probable mechanisms of action of arsenic involves DNA damage, sister chromatid exchange (SCE), gene amplification, aneuploidy, modification of expression of genes and cellular proliferation. Arsenic is well known to function as a potent clastogen, co-mutagen and co-carcinogen (Tchounwou *et al.*, 2003). They also induce changes in DNA methylation; inhibit enzymes like thioredoxin reductase, pyruvate dehydrogenase etc; modulate levels of proteins like MDM2 and p53 in the cell; induce protein-DNA cross-links; causes altered function of glucocorticoid receptor, and so on. It causes these effects by aberrant modulation of cell signaling pathways. Exposure to arsenic results in induction of heat shock proteins (HSPs 27,60,70,72,90,110) along with metallothionein, ubiquitin, mitogen-activated [MAP] kinases, extracellular regulated kinase [ERK], c-jun terminal kinases [JNK] and p38 (Bernstam and Nriagu, 2000). As a result, c-fos, c-jun and egr-1 get activated (Del Razo *et al.,* 2001; Cavigelli *et al.,* 1996; Ludwig *et al.,* 1998). Arsenic induced oxidative stress disturbs the signal transduction mechanism of PPAR's, AP-1, NF-κB, and cytokines like IL-8 and TNF-α (Vigo and Ellzey, 2006; Hu *et al.*, 2002).

Health effects of arsenic exposure

The harmful effects of arsenic are dependent on the route, dose and duration of exposure, personal habits and presence of other chemicals. Half life of arsenic varies between 10 h and 4 days, therefore the effect of exposure can be reverted by drinking arsenic free water (National Research Council, 2000).

Depending on the span and severity, arsenic exposure may be chronic or acute. The symptoms vary between individuals. "The acute lethal dose of inorganic arsenic to humans has been estimated to be about 0.6 mg/kg/day" (Opresko, 1992). The typical symptoms of chronic and acute arsenic exposure are given in Figure 2.

Social issues

Arsenic calamity disrupts social life of an individual. Arsenic related health problems stigmatize civic profile leading to discrimination and isolation of an affected individual or the family. Generally people are sacred of the lesions on hands and feet. These ignorance ruins the social harmony and relationships. Arsenic victims are refused acceptance by community and families. Marriage-related issues very often arise. Men divorce wives and sent them back to their parents' house. Sufferers are debarred from any marital relationships and young generation in the affected families is forced to remain single. These unfortunate women are also come across social evils like dowry, physical torture, and polygamy. It is a myth or superstition among people that arsenic related disorders are contagious. Instead of being kind to them, people treat them as leprosy patients and they lose acceptance to the society. Students are not allowed to attend school, sufferers are denied to social and religious gatherings and above all they are not even allowed to use tube wells and local ponds. Due to all these ridiculous superstitions and prejudices, victims are unable to receive any treatment. Even today, where science has developed so much, people believe that the disease is 'an act of the devil/impure air' or 'a curse of God' or 'the work of evil spirits'. This hostile attitude makes one homeless or a loner (Hassan *et al.,* 2005; Brinkel *et al.,* 2009).

Arsenic remediation

Arsenic exposure results in various adverse health effects. Thus early identification of affected regions having high arsenic content and methods to remove arsenic is of prime importance in the remediation of this crisis. Supply of arsenic free drinking water will solve the problem. There are various methods that can be adopted to remove arsenic from water sources. Some of the commonly adopted technologies are oxidation, co-precipitation, lime treatment, adsorption onto sorptive media, ion exchange resin, reverse osmosis, electrodialysis, nano-filtration and membrane filtration techniques (Cheng *et al.,* 1994; Hering *et al.,* 1997; Kartinen and Martin, 1995; Joshi and Chaudhury, 1996). Harvesting rain water may be another solution to the problem, but rain is seasonal. Modern technologies like use of raised beds and furrow may reduce levels of arsenic in soil. An easy but cheap way of arsenic removal is Sono arsenic filter, where water is passed through three pitchers. The first pitcher contains cast iron turnings and sand; whereas wood activated carbon and sand is present in the second (Munir *et al.,* 2001). Some of the methods used to remove arsenic from soil are vitrification, acid-extraction, in-situ flushing, pyrometallurgical recovery and so on. Various technologies exist to remove arsenic from water, waste and soil like use of permeable reactive barriers, biological treatment using microorganisms to improve precipitation, phytoremediation, and electrokinetic treatment. Phytoremediation is the use of plants for removal of pollutants from water and soil. It is a safe and cost-effective technology to reduce the arsenic burden of soil or water. Such plants may be excluders and non-excluders or accumulators. There are some plants that tend to accumulate the pollutants present in soil or water. Some plants used for phytoremediation should possess tolerance of adjoining conditions, high production of biomass, easy propagation, and they should be able to accumulate the contaminant. Water hyacinths are free floating aqueous plants that are commonly used in remediation of arsenic. These plants possess fibrous roots which help in accumulation of this toxic chemical (Sarker *et al.,* 2012). Some examples of hyper accumulating plants that aid in arsenic removal are Chinese brake fern *Pteris vittata* and *Pityrogramma calomelanos.* They help to remove the heavy metal from soil and may be considered as potent bio-remediators (Huq *et al.,* 2005).

Food and arsenic

The human body needs little amount of this metallic element, but arsenic is harmful in higher concentration. Plants need water to grow; therefore it is important to know about the safety of foods that grow in contaminated area. Mode and extent of transfer of arsenic from soil to plant is very vital. The risk of arsenic entering the food chain via the soil-plant pathway needs investigation. The amount of arsenic uptake by plants depends on arsenic speciation, type and composition of soil, and plant species. Arsenic and Phosphorus belong to the same periodic group and are chemical analogs. They have similar atomic radii; number of valence electrons, and nearly identical electronegativity and orbital configurations and this resemblance makes arsenic dangerous. There is a competition for binding affinity between arsenic and phosphorus; phosphorus very often is replaced by Arsenic (Knodle *et al.,* 2012).

Crops growing in irrigation water contaminated with arsenic are the point of its entry into the food chain. Arsenic substitution affects glycolysis, leading to inhibition of ATP production. Arsenate uncouples glycolysis culminating in major energy consequences. Disruption of conversion of pyruvate to acetyl CoA is facilitated, hindering the Krebs cycle (Knodle *et al.,* 2012). This is the root cause of arsenic toxicity. Presence of high amounts of arsenic hinders photosynthesis via disruption of pentose-phosphate pathway (Tu and Ma, 2002; Adriano, 2001).

In a plant body arsenic is mostly accumulated in the roots. However, stems, leaves and seeds are not spared. Plant cuticles are more prone to arsenite than its pentavalent form. Addition of arsenic in trace amount leads to higher yield of corn, potatoes, rye, and wheat. However, concentration of arsenic above phytotoxic level is harmful for plants, particularly those having high phosphorus demand like rye, pea, maize, soybean, sunflower, rape and tobacco. Grass is also known to accumulate high concentrations of arsenic. High arsenic level in soils is detrimental on soil organisms, plant growth and is a threat for human and animal health as they enter the food chain. The maximum permissible limit of arsenic intake through food may be considered as 3 µg/kg body weight/day (FSANZ, 1999). Livestock fed on arsenic contaminated vegetation like grass are another potential route of exposure to arsenic toxicity in human. Rice is the staple food in many countries including India. Rice plant is grown under water, in an anaerobic condition. Prolong use of contaminated water for cultivation of rice may lead to accumulation of arsenic in rice plants. Rice straw also accumulates high level of arsenic, affecting poultry and livestock. Indirectly this is alarming to humans, who consume such products. Brown rice is produced by removing the outermost layer of a grain of rice. White rice is produced by further processing of the rice grain, i.e. the bran layer and germ are also removed. During this processing step, various essential nutrients like proteins, thiamine, calcium, magnesium, fiber, and potassium are lost. Thus brown rice is nutritionally richer than its white variant. However, due to presence of the germ layer in brown rice, it contains more arsenic than white rice. Irrigation of boro rice needs to be avoided in areas with high arsenic contamination. Maize and wheat are examples of cereals which can grow in lesser quantities of water than rice; therefore compared to rice these cereals can accumulate much less arsenic; thus they may be used as a substitute for rice. Leafy vegetables contain higher amounts of arsenic as the leaves can accumulate more arsenic than grains. Some of the plants that are consumed by human beings like arum, bean, tomato, papaya, cauliflower, cabbage, leafy vegetables, red spinach and stalks of spinach, wheat also contain arsenic. Some vegetables which can be safely consumed are potato, bitter gourd, brinjal, snake gourd (chichinga), kakrol, ladies finger, palwal, large leafy spinach, pumpkin, sweet potato, turmeric, ginger and green chilli. Apart from the above mentioned plants, Indian mustard (*Brassica juncea*), kachu sak (*Colocasia antiquoram*) and Kalmi sak (*Ipomea reptans*), which are common plants found in West Bengal, may also accumulate arsenic in moderate amounts (Dey *et al.*, 2014). Many edible plants like beans, spinach, radish, tomato, cabbage and others are also affected by arsenic. Fruits, cereals, pulses are however safe. Outer layer of these plant products may contain arsenic, but we consume the inner portion.

The influence on marine life is of great importance. Accumulation of arsenic in fish and shellfish is mainly in organic forms like arsenobatiene, which elicit minimal mutagenicity, immune-toxicity, embryogenicity and therefore are harmless. Arsenocholine, the form of arsenic found in shrimp, is similar to arsenobetaine, and is nontoxic. Finfish, crabs and mollusks contain mainly MMA (V) or DMA (V). Toxicity of arsenosugars in seaweeds and marine mollusks and arsenolipids, a component of fish oil needs further study (Hughes *et al.,* 2011).

Milk is also harmed by arsenic; therefore such milk may be hazardous for human consumption. Arsenic concentration in other poultry products like chicken, eggs needs attention. Though arsenic gets excreted through feces, urine, and milk, it is retained in other parts like poultry egg yolk, albumen, and other poultry products. Consumption of edible products from cows and poultry birds reared in arsenic contaminated soil may lead to arsenicosis.

Cure for arsenic toxicity

There are some antidotes for arsenic remedy. The present treatment modalities for patients suffering from arsenicosis include thiol containing chelating agents such as meso 2,3-dimercaptosuccinic acid (DMSA), 2,3 dimercaptopropane-1-sulfonate (DMPS) or British Anti Lewisite (BAL; 2,3-dimercaprol). Chelating agents may be useful as it helps to eliminate the metalloid through urine. BAL has low therapeutic index and has a tendency to redistribute arsenic to brain and testis. The other two antidotes DMPS and DMSA, which can be administered orally or intravenously, elicit relatively low toxicity and high therapeutic index. DMPS and DMSA therefore can be used in placed of BAL for the treatment of chronic arsenic poisoning (Muckter *et al.,* 1997). Arsenic related diseases still lacks a definite and specific treatment regime. Ointments possessing salicylic acid may provide temporary relief in keratosis (Bhattacharya *et al.*, 2002; Smedley and Kinniburgh, 2002; Mandal and Suzuki, 2002). The metal chelators are very often used as life-saving drugs. They can be used as a last resort. DMPS rapidly excretes arsenic from the organs to the kidney via blood stream. Side effects include dizziness, weakness, lowering of blood pressure etc. DMSA, however, is a better alternative than DMPS in terms of side effects, though it is not free from toxicity. The side effects of DMSA are diarrhoea, nausea, vomiting, appetite loss and rashes. Therefore kidney and liver function needs to be done during treatment. A natural cure may pave a way to solve the problem.

Phytochemicals and arsenic

Existing treatment protocols are insufficient to tackle the catastrophe due to chronic arsenic exposure. Treatment options advocated are vitamin and mineral supplements and antioxidant therapy. Presence of dietary nutrients like vitamins, antioxidants or micronutrients provided protection from arsenic induced toxicity in humans. Ascorbic acid, thiamine and methionine contribute to the removal of heavy metals. Hence the clinical importance of herbal drugs has gained popularity. Thus an alternative and safe option is required to counteract the situation.

Studies show that socioeconomic conditions and nutrition status of the people may be responsible for the variation in symptoms of arsenic toxicity among individuals. People having lower amounts of essential nutrients like methionine, choline, proteins etc in diet suffer from malnutrition. Such individuals have altered arsenic metabolism in their body. They have decreased arsenic methylation, reduced excretion of DMA in urine and increased retention of arsenic in tissues. Thus malnutrition may be regarded to have a direct impact on arsenic toxicity and disorders (Milton *et al.,* 2004). Therefore it is good to have a healthy diet to cope with the calamity.

Many plant derived products show efficacy in counteracting arsenic problem. Seeds of *Moringa oleifera*, a tropical plant contain coagulating/flocculating compounds and are good alternatives for removal the toxic compounds like arsenic from drinking water (Gupta *et al.,* 2007). Sodium oleate and saponin have been reported as surfactants for arsenic removal. For remediation of arsenic sodium oleate has been found to have a better efficacy than saponin (Valdez *et al.,* 2013). These compounds are more capable of removing arsenic than other heavy metals like Chromium, Copper and Lead (Valdez *et al.,* 2013). The problem of arsenic toxicity can be tackled by spirulina treatment as its use may help to combat arsenicosis (Rahman *et al.,* 2006).

These phytochemicals not only remove arsenic from water, but may prevent onset of carcinogenesis caused due to arsenic. Tannins, which are rich in flavonoids are one such compounds. Tannins in cocoa have been reported to counter the oxidative stress caused by arsenic by scavenging free radicals (Chandranayagam *et al.,* 2013). Main constituents of cocoa are polyphenols like catechins or flavan-3-ols, anthocyanins and proanthocyanidins. These are also found to be present in tea, a popular beverage consumed worldwide. Polyphenols in tea have antioxidant properties and can counteract arsenite induced DNA damage, lipid peroxidation and formation of protein carbonyl groups in animal model. This was achieved by quenching of ROS and enhancing the expression of antioxidant enzymes (Sinha *et al.,* 2010). This unique property of combating arsenic toxicity is attributable not only to green tea (EGCG), but also to black tea (Theaflavin) (Sinha *et al.,* 2003). Mode of toxicity of arsenic includes induction of cytotoxic and genotoxic changes like chromosome breakage, chromosomal aberrations, micronuclei formation, sister chromatid exchange among many. DNA damage is the stepping stone of the carcinogenic process. Arsenic is a known inhibitor of DNA repair mechanism. Loss of repair potential by arsenic can be counteracted by induction of repair enzymes by tea polyphenols (Sinha *et al.,* 2005a). The antioxidant rich intoxicating drink may serve as an effective strategy in combating the health hazard caused by Arsenic (Sinha *et al.,* 2005b). Caffeine protects DNA from adversity caused by arsenic (Gulbhile and Zambare, 2013). Arsenic exerts its action mainly via ROS generation, therefore fruits having anti-oxidant property may be effective in combating arsenic toxicity; pomegranate (Mekni *et al.,* 2014), emblica officinalis (amla) (Singh *et al.,* 2013), guava, cherries, strawberries, citrus fruits, apricots etc (Roy *et al.,* 2008) may be useful in this respect.

Phytochemicals are shown to suppress carcinogenesis selectively, sparing the normal cells (Sarkar *et al.,* 2014). Capsaicin from capsicum and green chillies, curcumin from turmeric, ellagic acid from guava, fisetin from strawberries, gallic acid from ginger, limonin from citrus fruits, lycopene from tomato, quercetin from onions and red grapes, resveratrol from grapes, rutin from apricots, cherries showed chemopreventive potential against arsenic induced toxicity (Roy *et al.,* 2008). Of all phytochemicals mentioned above, curcumin gave much better protection when treated simultaneously with arsenic. However, the same study revealed that treatment with resveratrol prior to arsenic was also very effective. Similar studies conducted with Swiss albino mice indicated a protective role of curcumin against arsenic induced toxicity by virtue of its antioxidant potential and quenching free radicals (Biswas *et al.,* 2010b). Hydro-alcoholic extract of *Ocimum sanctum* leaves protected arsenic treated Wistar rats by scavenging free radicals induced by the heavy metal (Mundey *et al.,* 2013). A study was conducted in arsenic affected areas in West Bengal to elucidate the potential of curcumin to combat arsenic induced carcinogenesis. Results demonstrated that curcumin induced repair enzymes both at protein and genetic levels (Roy *et al.,* 2011). A field trial was conducted in Chakdah area of West Bengal to shed light on the potential of curcumin against the genotoxic effects induced by arsenic. It revealed that intervention by curcumin decreased damage to DNA, generation of ROS, peroxidation of lipids and thereby upregulated the extent of antioxidant activity (Biswas *et al.,* 2010a). Garlic also shows protection against high ROS levels produced by arsenic in hepatic tissue (Flora *et al.,* 2009). The benefits of these holistic approaches need further investigation and validation, so that they can be used on a wider basis.

Conclusion

Millions of people around the universe are facing a threat of arsenic contaminated ground water. Thus urgent and fruitful strategies need to be adopted to tackle this devastating situation before it goes beyond control. Development of surface water resources needs exploration. This calamity has resulted as a consequence of human exploitation of nature. Abuse of nature is like signing a pact with the devil and this has culminated in accumulation and biomagnifications of arsenic in the environment and food chain. Arsenic cannot be destroyed easily, therefore remedial measures needs to be taken on an urgent basis. More emphasis needs to be given on preventive measures to control the situation. Provision of safe water for drinking and cooking warrants immediate development of water purification systems. World Health Organization defines health as “a state of complete physical, mental and social well being”. In a poor country like India, social taboo is a big problem, therefore proper education and raising awareness among general public is a must. One should lend a hand to these ill fated sufferers so that they can come forward and get best possible treatment. Therefore, this acute social problem leaves a serious impact and trauma on an individual. Malnutrition has a direct implication on arsenic related health issues, therefore it is necessary for the community to shed off the taboos and come forward to the rescue of these sufferers.

Figure.1 Metabolism of arsenic

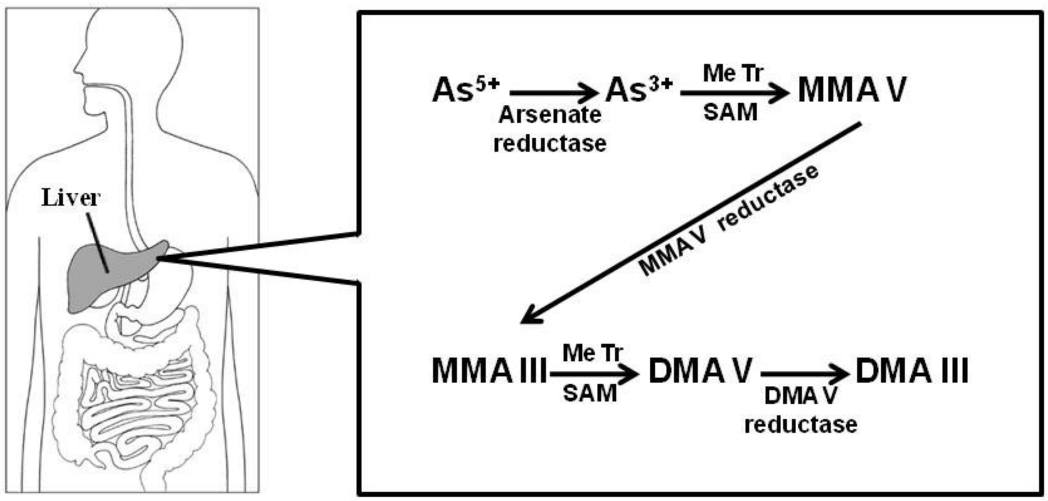
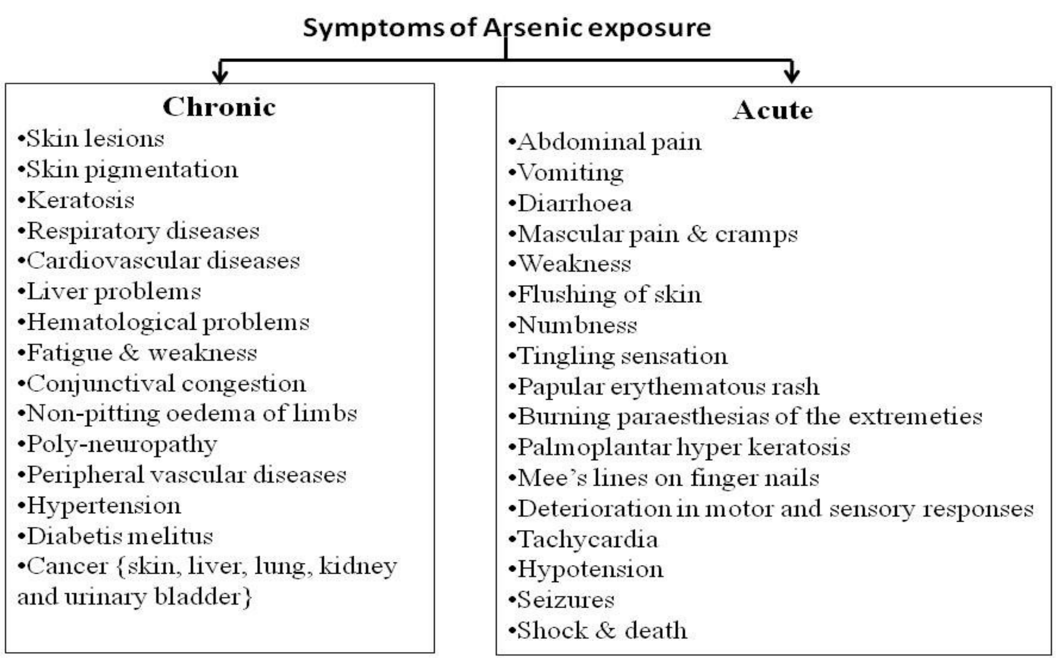


Figure.2 The typical symptoms of chronic and acute arsenic exposure



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