Chapter 5

Arsenic Pollution in the Environment:
Role of Microbes in Its Bioremediation

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ABSTRACT

Arsenic (As) pollution in drinking water and soils poses a threat to over 100 million people worldwide, making it one of the largest environmental catastrophes particularly in Bangladesh and West Bengal—where more than one-third of the population are at risk. Microbial As metabolism and mobilization in aqua system is relatively a recent issue. The presence of the arsenic oxidation, reduction, and extrusion genes (aioA, arrA, arsB, and acr3) are explored within microorganisms retrieved from As-contaminated environments. However, the nature of microbiome involved within a certain As transformation environment is still an area of research, specifically how microbial redox transformations occur, that can be exploited to mitigate the longstanding problem. The present chapter overviews the mechanism of As pollution in various environments, microbial diversity in such environment, correlation of their activities to the biogeochemistry of As and finally application of microbes as a bioremediation tool for As detoxification and bioremediation.

INTRODUCTION

Arsenic (As) is chemically classified as a metalloid, having properties of both a metal and a non-metal. The word ‘Arsenic’ is derived from the Greek word arsenikon, meaning ‘potent’. The metalloid arsenic (As) was first discovered in 1250 by the German alchemist Albertus Magnus via heating of soap with orpiment (arsenic trisulfide) (Matschullat, 2000) and later it was classified as a member of group V of...
the periodic table of elements. The element occurs in the environment in different oxidation states and forms various species, e.g. As(V), As(III), As(0) and As (-III). As 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. It is widely distributed in the nature and is commonly associated with the ores of copper, lead, gold, sulfur and iron (C. Palache, 1951).

The predominant forms of As in soils and aquifers are inorganic arsenate [As(V)] and arsenite [As(III)], with the later being more mobile and toxic. Arsenic (As) is introduced into soil and groundwater during weathering of rocks and minerals, followed by subsequent leaching and runoff. Himalayan-derived sediment is the source of groundwater As contamination in large areas of south and southeast Asia. In Bangladesh and West Bengal (India), approximately 60 to 100 million people rely on drinking water containing As in excess of the World Health Organization standard of 10 µg/L (international) and 50 µg/L (Bangladesh). Consequently, people and livestock are being exposed to As via contamination of drinking water and consumption of food grown in As-contaminated soil or irrigated with As-enriched water (Banejad & Olyaie, 2011). So, arsenic distribution and toxicology in the environment is a serious concern, with millions of individuals being affected by As toxicities. Arsenic is known to have mutagenic and genotoxic effects on humans. Chronic exposure to As can cause a wide variety of adverse health effects including dermatological diseases, skin and internal cancers (Choong, Chuah, Robiah, Gregory Koay, & Azni, 2007). The following segments of this manuscript will illustrate the arsenic nature and toxicity, its severity and especially microbes mediated arsenic detoxification mechanisms, to explore the potential role of microbes in arsenic bioremediation.

SPECIATION AND TRANSFORMATION OF ARSENIC

Arsenic exists in the environment mainly in four oxidation states, As(-3) (arsine), As(0) (native or elemental arsenic), As(+3) (arsenite) and As(+5) (arsenate). The first two forms are relatively rare, whereas arsenite and arsenate are the two main forms occurring in aquatic environments (Lièvremont, Bertin, & Lett, 2009). Both biological and chemical parameters especially the redox potential (Eh) and the pH are important for the stability, speciation and distribution of arsenite [As(III)] and arsenate [As(V)] in the environment. As(V) is predicted to be thermodynamically stable form at Eh values > ca. -100 mV at pH 8.0, and > 300 mV at pH 4.0. Below those redox potentials, As(III) is the thermodynamically stable oxidation state, present either as H₃AsO₄⁺ species, as As-S complexes (e.g. H₂AsS₃⁻) or as As(III) solid phases such as As₂S₃ (Inskeep, McDermott, & Fendorf, 2002) (Figure 1). Due to various pKₐ values of arsenate (H₃AsO₄⁻) (pKₐ₁ = 2.19, pKₐ₂ = 6.94 and pKₐ₃ = 11.5), the H₂AsO₄⁻ form predominates in oxidizing environment with pH between 2.5 and ca. 7.0, whereas the HAsO₄²⁻ is the predominant form of As(V) between pH 7.0 and 11.0. For arsenite, the lowest pKₐ value is equal to 9.22. So, H₃AsO₄⁺ is the predominant form of As(III) in slightly reductive environments with a pH level below 9.2 (Figure 1)

As(V) is a stronger oxidant (with potential of +130 mV for As(V)/ As(III) pair) than sulfate (-220 mV for sulfate/sulfide), but weaker than nitrate (NO₃⁻/NO₂⁻: +440 mV) or oxygen (O₂/H₂O: + 818 mV) (Oremland, Saltikov, Wolfe-Simon, & Stolz, 2009). Arsenite has a greater hydrologic mobility and toxicity than As(V). Arsenate tends to adsorb to more mineral surfaces than As(III), thereby making it less mobile than As(III) in aqueous environments (Oremland et al., 2009).