Microbial Strategies for the Bioremediation of Arsenic in Polluted Water

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Objectives
The aim of this review is to know bacterial strategies against high concentrations of arsenic in water and which of these mechanisms are useful for bioremediation. Also, it compares natural and genetically modified bacteria for their application in bioremediation.

Background
Arsenic contamination is a global problem. According to WHO, arsenic is one of the most dangerous substances for public health. In addition, inorganic arsenic is considered carcinogenic.

It is estimated that 150 million people are exposed to this metalloid and the most affected regions are Bangladesh, West Bengal and Taiwan. In these zones the arsenic levels in groundwater are higher than WHO’s recommendation, which has established a recommended limit of 10 μg/L (10 ppb) of arsenic in drinking water.

Arsenic as a Contaminant
Arsenic is found in more than 200 minerals and it reaches the water due to the erosion of rocks and several anthropogenic activities that have intensified arsenic contamination in water too.

In natural waters, inorganic arsenic is found as arsenite As\(^{3-}\) and arsenate As\(^{5-}\). The trivalent form is considered the most toxic. Bacteria play an important role in arsenic biogeochemical cycle due to the oxidation and reduction reactions with inorganic arsenic.

Thus, arsenic is a causative of severe epidemiological, cytotoxic and genotoxic affections.

Pathways of Arsenic Uptake and Resistance

As\(^{3+}\) and As\(^{5+}\) uptake
- By non-specific phosphate transporters GfpF and Pst or Pst respectively
- Arsenate uptake is increased in low phosphate concentrations

Oxidation
- By Aio/Ars arsenite oxidase
- As\(^{5+}\) oxidation to As\(^{3+}\)
- Ochrobactrum tritici, Gallionella ferruginea and Leptothrix ochracea

Reduction
- By Arr arsenate reductase
- As\(^{3+}\) reduction to As\(^{5+}\)
- Geosporillum arenosophilus, Bacillus arenoselenatii and Cytophaga arenatis

Isolation of Arsenic Resistant Bacteria

Abbas et al. (2014). Samples of contaminated water from Pakistan
- Three bacterial species isolated: Enterobacter sp., Klebsiella pneumoniae 1 and Klebsiella pneumoniae 2
- All were arsenic oxidizing bacteria

Sarkar et al. (2013). Samples of contaminated water from West Bengal
- 64 arsenic-resistant bacteria were isolated, with a predominance of Agrobacterium, Ochrobactrum and Achromobacter
- Resistant to concentrations of 40 mM of As\(^{3+}\)

Paul et al. (2015). Samples of contaminated water from West Bengal
- Bacterial community formed by Pseudomonas, Flavobacterium, Brevundimonas, Polaromonas, Rhodococcus, Methylovorans and Methylophaga

Development of Genetically Modified Bacteria

Corynebacterium glutamicum modification by Mateos et al. (2006)
- Increase of arsenate uptake
- Low phosphate concentrations
- Mutation on the efflux pump gene
- Arsenic resistance
- Ability to extrude arsenite
- Accumulation of arsenite
- Resistant to 60 mM of As\(^{3+}\)

Ochrobactrum tritici modification by Sousa et al. (2015)
- 6 different mutants were obtained
- Double mutant on ArsB/Acr3.1 accumulates more arsenite than the others
- Useful as a biofilter for bioremediation

Future Prospects & Conclusions

Most studies are made in laboratories need to prove them on an industrial scale to verify their economic viability.

Difficulties to implement microorganisms, Branco et al. proposed a method for the immobilization of O. tritici double mutant obtained in Sousa’s et al. study to use as source of arsenic for bioremediation processes

Biological treatment is promising option due to many advantages of bacteria

- Specificity
- Economical
- Environmentally friendly
- Safe
- Reduction of waste

Table 1. Summary of the most important arsenic affections in humans

<table>
<thead>
<tr>
<th>Arsenic</th>
<th>Epidemiology</th>
<th>Cytotoxicity</th>
<th>Genotoxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dermal disease</td>
<td>Problems in cell differentiation</td>
<td>Apoptosis</td>
<td>Chromosomal aberrations</td>
</tr>
<tr>
<td>Cardiovascular disease</td>
<td>Excessive cell proliferation</td>
<td>Autophagy</td>
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<tr>
<td>Skin and bladder cancer</td>
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References

Discussion
A large group of bacteria is naturally resistant to high concentrations of arsenic in water. Arsenite oxidizing bacteria are useful for bioremediation, since they transform As\(^{3+}\) to As\(^{5+}\) biotransformation assembled to a conventional As\(^{5+}\) absorbent method.

It is also proposed a water treatment based in bacteria with H. arsenicoxydans biofilm: the arsenic is sequestered due to the segregation of exopolymers.

On the other hand, genetically modifications in the arsen oxyanion allows the achievement of improved bacteria capable to optimize the assimilation, resistance and accumulation of inorganic arsenic to be a bio-tool for bioremediation.

Genetically modified organisms are more effective as arsenic bioreaccumulators and they can resist higher arsenic levels than autochthonous bacteria.