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Review Article

Beneficial traits of chromium resistant bacteria: Mini review

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Abstract

Now a day with advancement of technology, the heavy metals are mainly being generated. These heavy metals have highest toxicity even in low concentration. The chromium Cr (6) produced by industries is one of toxic heavy metals and its removal from the environment is necessary for the safety of all living things including humans. The microorganisms particularly Cr resistance bacteria play an important role in the removal of Cr from environment. The Cr resistance bacteria diminish Cr by different ways e-g by binding with heavy metals Cr, reduction of toxic form to naturally occurring form by using chromium in metabolism forming less harmless by- products etc. This trait of bacteria is considered beneficial for plants as chromium resist the growth of plants and these bacteria promotes the growth of plants by behaving like a bio-sorption surface, substituting noxious chemical ions into less noxious form. These bacteria reside in the roots of plants and produce many products e.g. indole acetic acid, (ACC) aminocyclopropane-1-carboxylic acid deaminase, extracellular polymeric substances and reduction of Cr heavy metal. This review can help researchers to work on these beneficial traits of bacteria in order to discover more about them to produce different beneficial products.

Keywords: ACC deaminase; Chromium reduction; Chromium resistant bacteria; Extra cellular polymeric substances; Indole acetic acid

Introduction

Heavy metals commonly used in industries triggering enhance in disposal of metal substances in water reserves adjoining to industries **[1]**. These heavy metals cause serious significant hazards to land and water ecologies **[2]**. The word "heavy metal" mostly described as metals as metals possessing highest density, atomic-weight, or atomic-number **[3]**. Heavy metals are hazardous for crops leading to different infections in humans due to their consumption **[4]**. Various heavy metals such as Ni, Mn, Cr, Cu, Zn, and Co function as micronutrients and are essential for physiological procedures in microbes. They are mandatory for enzyme activity and in maintaining equilibrium of molecules **[5]**.

Chromium metal (Cr) is among 17 chemicals which cause the utmost risk to health of human in accordance to United States of Environmental Protection Agency (US-EPA). Chromium occurs from +2 to +6 oxidation states, but Cr (III) and Cr (VI) are in core consideration **[7]**. It is a transition element which is present certainly in rocks, plants, animals, soil, gases and in volcanic ash. Chromium is one of the noxious metal

with monitoring checks set at 1.3 mg kg-1 in plants (World Health Organization), 0.1 mg L-1 in water (WHO) and 100 mg kg-1 in soil [2].
Cr (VI) is believed as a human carcinogen because of its mutation, cancer and physical abnormalities causing ability in humans, animals, and plants [8]. Excessive disclosure to Cr (VI) generates major skin problems, ulcers, allergic reactions, necrosis in renal tubules, and promotes threats for cancer of respiratory-system, also promoting noxious effects to genes and even cells (Fig. 1) [9]. The (Table 1) is enlisting properties of chromium's different species.

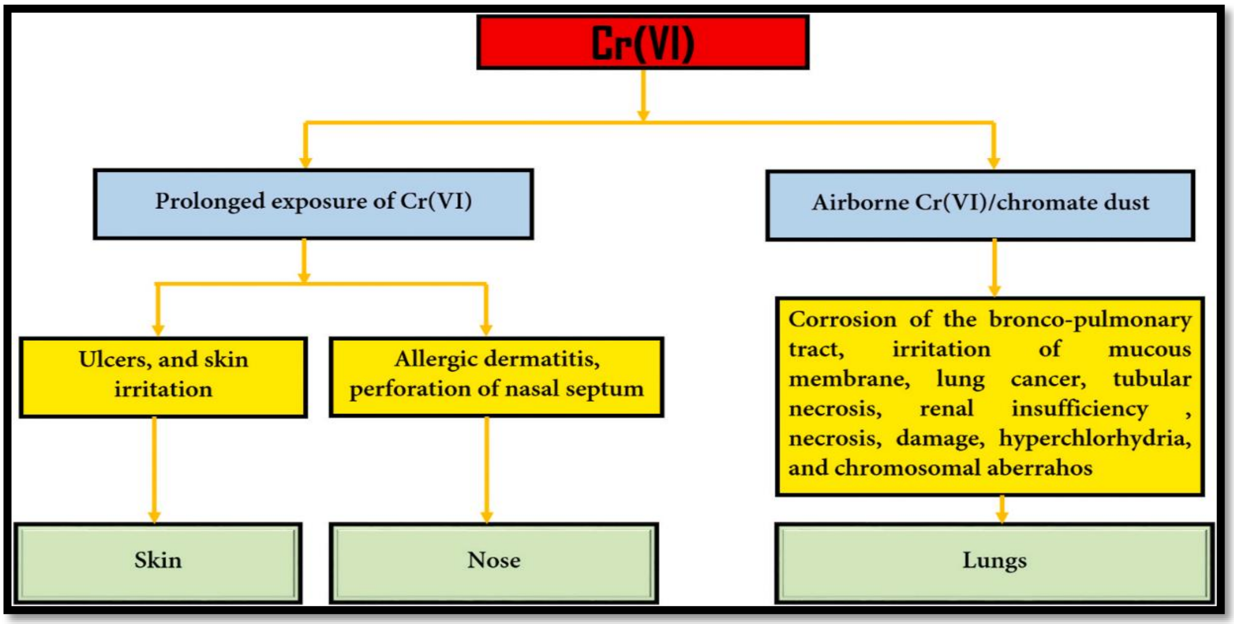

Figure 1: Effects of chromium toxicity on human organs [6]

Table 1: Different chemical species of Cr and their characteristics [10]

Chromium Species	Properties
Cr(0)	Naturally unavailable
Cr(II)	Mostly unbalanced Easily get oxidized to Cr^{3+}
Cr(III)	Present in ores Synthesize unbalanced alloy
Cr(IV)	Naturally not present Short-lived
Cr(V)	Naturally not present Long-lived Derived from chromate
Cr(VI)	Highly balanced Produced by human activity

Cr resistant bacteria

Various microbes can amass or diminish particular heavy-metals effortlessly. Microbes have a high surface area to volume ratio consequently they offer a large area of interaction with the metals in their environments [2]. These microorganisms have acquired the potentials to defend themselves from heavy metal noxiousness by numerous mechanisms such as adsorption, uptake, methylation, oxidation and reduction. Microbes, have potential for utilizing organic waste. When the microbes utilize waste, they transform the surplus into non-hazardous secondary products and in this procedure of transformation the microbes in fact generate numerous metabolites to disintegrate the composite surplus into simple complexes this is because microbes have adopted numerous resistance mechanisms to persist the occurrence of toxic heavy metals in their surroundings [11]. Thus, the first chromate-resistant bacterial strain was named as *Pseudomonas dechromaticans* [12].

Bacteria possess metal binding characteristics, Gram positive bacteria owing positive charge around their cell walls as a consequence of possessing teichuronic acid, teichoic acid and peptidoglycan while gram negative bacteria possess lipopolysaccharides, peptidoglycan, and phospholipids. Metal holding property initiates in consequence of possessing different functional-groups like amine, hydroxyl, phosphonate, and carboxyl group. Bacteria are classified as rods and cocci on the basis of morphological features. The methods for adsorption of metals in bacteria are classified in two, one as fast, indefinite, and ATP independent, while the second is definite, prolonged, ATP dependent and inferential. Tiny size of bacteria makes them able to develop and flourish in diverse ecological situations leading them to become efficacious bio-technological medium to remediate chromium metal. The multiple-covering of bacterial cell envelope performs a crucial function in fastening metallic ions and splits adjacent region from protoplasm of cell (Fig. 2) [6].

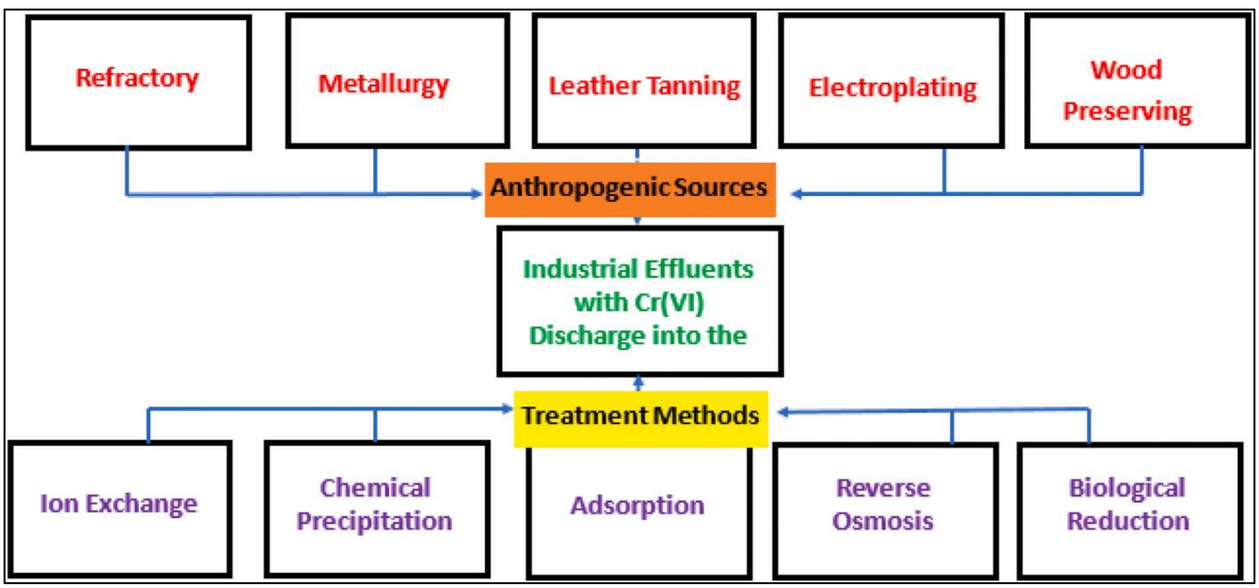

Figure 2: Fate of chromium pollution and the available treatment procedures [6]

Reduction of chromium

Microbial reduction of Cr (VI) to Cr (III) is a considerable and efficient remediation technology, crucial for glucose metabolism, activation of enzymes and DNA and RNA stabilization. Chromium (VI) remediation has been described in both soil and water tainted with metal by bacterium *Pannonibacter phragmitetus* (assigned as strain BB). Chromium eradication each by depletion or via bio-sorption leads to minimal danger towards human life **[13]**.

The first Cr (VI) reduction by bacteria of anaerobic Cr^{6+} reduction was reported in unspecific *Pseudomonas* sp, internationally scientists sequestered and identified chromium resistant bacteria aerobes and anaerobes in nature possess series of genera from various ecosystems. Apparently, microbes breaking down chromium-metal (VI) into chromium-metal (III) are omnipresent in polluted and unpolluted areas like soil, aquatic areas, and on sludge as well. The previously mentioned microbes can eradicate chromium-metal (VI) different aspects influence their reducing efficacy. Eradication of chromium-metal (VI) is performed by different aerobes and anaerobes. Usually, reduction or eradication of chromium-metal in aerobes is done by consuming nicotinamide adenine dinucleotide hydrogen (NADH) and endogenic cell-preserves, while in anaerobes it is performed by using electron transport chain including cyto-chromes for reducing chromium-metal **[14]**.

Chromium reduction methods utilizing microbes lead to synthesis of inoffensive and immoveable products by converting noxious chromium-metal (VI). Moreover, enzymes which reduce chromium-metal (VI) perform some other beneficial functions along with reducing chromium-metal (VI). Like they mainly perform as iron-reductase, nitro-reductase, lipoyl-reductase, glutathione-reductase, ferredoxin-reductase, or any metal-reductase. Substantially, 3 fundamental procedures for reduction of chromium-metal (VI) have been recognized **[14]**.

In anaerobes, several elements perform as electron-donors in ETC (electron transport chain) like nucleotides, vitamins, amino acids, nicotinamide adenine dinucleotide (NADH), glutathione, carbohydrates, organic-acids, flavor-proteins, heme-proteins while chromium-metal (VI) performs as electron- acceptor.

2. Soluble reductases

In aerobes, NAD (P) H-dependent extracellular soluble-reductases synthesis occurs deliberately for reduction of Cr (VI) into Cr (III) eliminated by functional-groups persisting on surface of cell. It has been reported that, *Pseudomonas putida*, *Pseudomonas ambigua*, *Desulfovibrio vulgaris*, and *E. coli* synthesize soluble Cr metal (VI) reductases consuming various electron-donors and can be situated both internal and external to the bacteria. The aforementioned enzymes are generated essentially due to more energy consumption and distinctly managed reduction-process. Extracellular reduction is beneficial and protects cell from chromium stimulated DNA-damage due to its independency on transport of chromium-metals **[14]**.

3. Membrane-associated reductases

In anaerobes chromium-metal reduction includes membrane linked reductase-enzymes comprising of H_2 or glucose as electron-donors. Furthermore, it is reported that chromium-metal eradication can occur by electron transport chain where chromium-metal (VI) acts as electron-acceptor molecule. As stated previously, aerobes consume cytosol-soluble reductase-enzymes **[14]**.

Plant growth enhancing/ promoting bacteria (PGP) and their beneficial traits

PGPB (Plant-growth enhancing/promoting bacteria) possess ability to promote growth of plants and the aforementioned bacteria usually present at rhizospheric region of soil surface where roots are in abundancy. In rhizospheric region of soil major microbial activity is performed as it occupies relatively good nutritional amount and a source of essential micro as well as macro nutrients **[10]**. PGPR strains sustain the detrimental consequences of noxious heavy-metals in plants producing in polluted areas and also induce influence on growth as well. They can enhance plant-growth by providing essential elements (nutrients) to their plant hosts. In existence of contaminated environments, these bacteria protect their hosts by acting as metallic bio-sorption entities or substitute noxious elements into slightly noxious elements. These bacteria can control plant-growth either directly or indirectly, creating chelating-agents, extended root-system, resistance influenced by stress contrary to a-biotic stress, and by providing improved accessibility to essential nutrients. Furthermore, they can also promote other bacterial developments via biofilm formation **[15]**.

Symbiotic plant-growth enhancing/ promoting rhizobacteria (PGPR)

Named as intra-cellular PGPR for example, bacteria living in nodules. They can also enter inside cell and reside there for example rhizobacteria. Extra-cellular bacteria including *Bacillus sp.*, *Burkholderia sp.*, and *Pseudomonas sp.* reside outer to root-cells. Abundant amount of bacteria present in rhizobacteria due to easy availability of essential nutrients near root-exudates **[10]**. The favorable features of PGPR (Plant-growth enhancing/promoting rhizobacteria) for plant-growth are mentioned below:

(a) Indole acetic acid (IAA)

Indole-acetic acid is responsible for regulation of plant-growth which is a growth-hormone **[10]**. Auxin being a chief plant hormone, has growth promoting properties and can be perfect for natural plant growth promotion **[16]**. Auxin shows an eminent function in modulation and defense for metabolism of plants in pressurized environments **[10]**. Indole-acetic acid (IAA) most important growth-hormone and almost eighty percent is synthesized by microorganisms living in the root of plants that stimulate plant-growth **[17]**. Indole-acetic acid increases growth of plants by improving osmotic-contents, cell water-permeability, protein and cell-wall production. Reducing excision of plant-leaves, promoting flower and fruit development is achieved by indole-acetic acid **[18]**.

At distinct places, various microbes show a varied number of indole-acetic acid synthesis due to accessibility of substrate-elements, indole-acetic acid producer-elements, and physicochemical parameters in culture-medium. Use of chemical-manure and other procedures for nutrient-uptake can be minimized by using indole-acetic producing bacteria and increase in plant-growth can also be achieved **[9]**. Indole-acetic acid, a valuable plant-hormone acid, has an indole-ring attached to acetic-acid in its structure. Indole-acetic acid usually synthesizes in developing parts of plants like roots, shoots and leaves **[9]**. Plants in metal-contaminated areas have rhizobacteria which promote their development. Metal-resistant rhizobacteria increase plant-growth in different ways including amino cyclopropane- carboxylate deaminase-activity, synthesis of indole-acetic acid and different siderophore-elements **[19]**. Indole-acetic acid is a natural hormone synthesized by different organisms and improves plant-growth. Indole-acetic acid performs a pivotal function in regulating plant development. Precursor-element for indole-acetic acid is tryptophan-molecule **[20]**. Tryptophan dependent pathway is crucial method in which amino-group and carboxyl-group is removed to produce oxidized end-production indole acetic-acid (IAA) **[10]**.

(b) ACC deaminase

1-aminocyclopropane-1-carboxylate ACC deaminase an enzyme initiating cessation of converting ACC into its products (ammonia and *a*-keto-butyrate). Ethylene-stress lessen down due to drop in amount of amino cyclopropane carboxylate deaminase **[21]**. Moreover, certain plant-growth promoting/enhancing bacteria manage ethylene-formation in roots of plants leading to enhanced plant-growth. PGP bacteria have ACC deaminase that controls the synthesis of ethylene in the plant roots and consequently results in improved root growth. Consequently, the amino cyclopropane carboxylate deaminase moderated plant-growth stimulates efficiency of phyto-remediation procedures in infected/polluted soils **[10]**. PGP bacteria having ACC deaminase activity can provide benefit in plants to resist salt stress eventually promoting ion channels and membrane transport systems **[22]**.

(c) EPS extracellular polymeric substances

It has been confirmed that in metal-infected atmospheres, synthesis of EPS possesses different protective method for the persistence of bacteria **[15]**. Extracellular polymeric substances (EPS), which are the complex biomolecules are comprised of a mixture of proteins, polysaccharides, lipids and their derivatives. These are constantly produced by the microorganisms during their growth and metabolism. The arrangement of the EPS found from various microbial masses has been described to be varied. They play a crucial function in the aggregation of microbial cell, in the production of biofilms, in immunomodulation, in food industries as gelling agents, in the sequestration of heavy metal contaminants, etc. The ionizable functional groups of EPS, for example, carboxyl, amine and hydroxyl support them in the metal ion sequestration. Numerous microorganisms have been formerly recognized and described in terms of their EPS production. Preceding investigations have exposed shown that the ability of microorganisms to eliminate metals may be linked to their EPS production **[23]**.

Extra-cellular polymeric substances comprise nucleic acids, polysaccharides and polypeptides discharged by bacteria. The negative charge due to presence of carboxyl-group and hydroxyl-groups on extra-cellular polymeric substances enables them to minimize contact of noxious metal-elements to cells or any other chelating metal-cations. Extra-cellular polymeric substances discharged by bacteria act to create hinder between bacterial-cell and outer environment. It is reported that extracellular polymeric substances synthesized in stressed environments impede metal bonding to components of cells **[15]**.

EPS inhibits the entrance of metallic ions in the cell disrupting metallic balance inside cell. EPS are immense molecules and performs essential function of interlinkage among cells, for example biofilm-formation, aggregation of cells, synthesis of inorganic molecules and adsorption of organic molecules **[15]**.

Conclusion

It is concluded that chromium resistant bacteria use their innate ability to diminish Cr, thus playing an important role in the de-contamination of environment and promotes plants growth as well. The review also concludes that favorable features of chromium resistant bacteria make them able to utilize as superb bio-fertilizer leading to enhancement of better plant development. Moreover, researchers can learn more favorable features of aforementioned bacteria for betterment of plant as well as human life.

Authors' contributions

Conceived the idea: S Mazhar, Wrote the paper: S Mazhar & A Abid. Corresponding author: S Mazhar.

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