Chapter 1
Metal Toxicity in Microorganism

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ABSTRACT

An awful consequence of metal contamination in environment is one of the global problems posing severe hazardous and toxic impacts in microorganisms. The objective of the present chapter is to elucidate how metals cause toxicity at biochemical and molecular levels in microorganisms. The excess concentration of metals is responsible for causing various toxicity reactions in microbial cell, such as, over production of reactive oxygen species; protein and enzyme dysfunction, destruction of thiol and iron-sulfide cluster, metal substitution and inhibition of nutrient assimilation; lipid peroxidation; and DNA damage. Consequently, toxicity causes mutagenicity effects and/or cell death that lead to immeasurable damage in microorganisms and microbial community. The biochemical and molecular mechanisms of metal toxicity may be helpful to depth metal toxicity study in microbes and other organisms for controlling and treating the metal toxicity in further. Moreover, metal-resistant microbes have potential significance in environmental and human health perspectives.

INTRODUCTION

Fast progress technologies are primarily responsible for causing tremendous environmental pollution. Metal pollution is one of the prime problems worldwide posing severe damage in environmental and human health. Metals[1] are naturally occurring major constituting elements in the earth's crust. Although, many of them play vital role in daily human life and various physiological process of organisms, it becomes potential contaminant in the environment under certain condition. Anthropogenic and geogenic activities generate massive amount of metals and its derivative chemicals and discharge as pollutants, which are awfully responsible for causing the environmental metal pollution. Therefore, metal pollution is a growing concern worldwide during last few decades due to posing severely hazardous and toxic impacts in all forms of life on earth especially microorganisms by bioconcentration, bioaccumulation and biomagnifications phenomena through food chain and food web (Jillian, Robert, & Rajakaruna, 2015, Bhakta, 2016). Microorganisms (such as bacteria, protists, fungi, yeast, algae, etc.) are omnipresent vital ecosystem components playing pivotal roles in various biogeochemical cycling process of environment (Gadd, 2010). Microbial communities are tremendously affected and intoxicated by environmental metal contamination (Bhakta, Ohnishi, Munekage, & Iwasaki, 2010; Bhakta, Munekage, Ohnishi, &

DOI: 10.4018/978-1-5225-2325-3.ch001

Jana, 2012a; Bhakta, Ohnishi, Munekage, Iwasaki, & Wei, 2012b; Olaniran, Balgobind, & Pillay, 2013; Lenart-Boroń & Boroń, 2014; Bhakta, Munekage, Ohnishi, Jana, & Balcazar, 2014; Kuperman, Siciliano, Römbke, & Oorts, 2014).

Certain metals are crucial for structure and function of cell, and hence indispensable for the biochemical process of life. Approximately half of all known proteins are predicted to be dependent on metal atoms for their structure and their participation in key cellular processes, such as electron transfer and catalysis (Waldron & Robinson, 2009; Andreini, Bertini, & Rosato, 2004). Several metal elements e.g. Na, Mg, K, Ca, Mn, Fe, Co, Ni, Zn, Mo, etc. are essential for functioning the life. These "essential metal" elements are present in a certain concentration range in biological systems and take part in various biochemical reactions in cell. They act as essential cofactors for structural and catalytic roles in enzymes and proteins such as, metalloenzyme and metalloproteins and for stabilizing biological molecules. They are also used in electron transfer and utilization of dioxygen and osmotic balance (Bruins, Kapil, & Oehme, 2000). The essential metal elements can alter (decrease/increase) metabolic activity and lead to develop an adverse situation at too low or insufficient/high concentrations. Besides, there are a number of metals, for example Al, Au, Ag, Bi, Cd, Cr, Hg, Pb, Sn, Ti etc. (metals) and As, Sb, Te (metalloids), those have no known positive biological role and showed hazardous toxic impacts on life are commonly known as "non-essential" metals. In addition, there are some other metals those have no known biological role and may be toxic to microbes with little known biological interactions, these are Be, Cs, Li and Sr. Non-essential metals are generally toxic at very low concentrations and inhibit metabolic activity at certain concentrations in organism. Some of them are referred to as "heavy metals". These metals are generally called as "toxic metals" under certain conditions. Such, different conditions of metals, (i) insufficient levels of essential metal ions, (ii) excess levels of essential metal ions and (iii) the presence of toxic metal ions, can cause cellular stress conditions.

Paradoxically, although the lists of essential, non-essential and toxic metals appear straightforward, many essential metals can be toxic to bacteria if their intracellular concentration becomes too high (Lippard & Berg, 1994; Nies, 1999).

However, it is apparent that all metals can accumulate and exert lethal toxicity impacts to cell when present in excess or above certain threshold concentrations. At high or specific concentrations, all metals can act in a deleterious manner by blocking essential functional groups, displacing other metal ions, or modifying the active conformation of biological molecules (Collins & Stotzky, 1989). These adverse effects of metals for both higher organisms and microorganisms are generally termed as metal toxicity. Such, the mechanism of adverse interactions between metals (and/or its derivatives) and microorganisms resulting in the development of deleterious impacts in microorganism can be defined as "metal toxicity" of microorganism. It alters various biochemical metabolic processes and may damage the microbial cell.

On the basis of different natures of metals available and exposed for experiencing a complex metal-microbial interactions and ultimately toxicity to microbes, the metal toxicity can be characterized into two following categories:

1. **Mono-Metal Toxicity:** One type of metal present over the threshold level in ambience is responsible for causing the metal toxicity to microbes. Microbes can easily tackle this toxicity by improvising responses of mono-metal resistance and
2. **Multi-Metal Toxicity:** When more than one type of metals are present in environment in higher concentrations compared to that of the threshold level, microbes are suffered by critical toxicity of numbers of metals.