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Review

Actinobacteria: Current research and perspectives for bioremediation of pesticides and heavy metals

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HIGHLIGHTS

- Pesticides and heavy metals are prevalent contaminants found around the world.
- Bioremediation using actinobacteria is a better option for cleanup polluted sites.
- Actinobacteria have physiological and metabolic properties useful for bioremediation.
- Successful bioremediation techniques are developed using actinobacteria.
- Multi-omics analysis will enable to design new strategies using actinobacteria.

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ABSTRACT

Actinobacteria exhibit cosmopolitan distribution since their members are widely distributed in aquatic and terrestrial ecosystems. In the environment they play relevant ecological roles including recycling of substances, degradation of complex polymers, and production of bioactive molecules. Biotechnological potential of actinobacteria in the environment was demonstrated by their ability to remove organic and inorganic pollutants. This ability is the reason why actinobacteria have received special attention as candidates for bioremediation, which has gained importance because of the widespread release of contaminants into the environment. Among organic contaminants, pesticides are widely used for pest control, although the negative impact of these chemicals in the environmental balance is increasingly becoming apparent. Similarly, the extensive application of heavy metals in industrial processes lead to highly contaminated areas worldwide. Several studies focused in the use of actinobacteria for cleaning up the environment were performed in the last 15 years. Strategies such as bioaugmentation, biostimulation, cell immobilization, production of biosurfactants, design of defined mixed cultures and the use of plant-microbe systems were developed to enhance the capabilities of actinobacteria in bioremediation. In this review, we compiled and discussed works focused in the study of different bioremediation strategies using actinobacteria and how they contributed to the improvement of the already existing strategies. In addition, we discuss the importance of omic studies to elucidate mechanisms and regulations that bacteria use to cope with pollutant toxicity, since they are still little known in actinobacteria. A brief account of sources and harmful effects of pesticides and heavy metals is also given.

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1. Introduction

In the last two decades ecofriendly methods have emerged for cleaning up contaminated environments using different microbial species. This approach, known as bioremediation, is generally considered to be less invasive and more restorative of soil functions compared to conventional physicochemical methods (Kidd et al., 2009). Bioremediation as sustainable technology becomes important analyzing the high release of anthropogenic chemicals into the environment.

Pesticides are chemicals used for pest control, and are probably the most widely distributed contaminants in the environment. The disposal of obsolete pesticide stocks has also resulted in many long-term contaminated sites with very high levels of these compounds. Officially recognized sites, typically dominated by organochlorine (OC) pesticides, have been reported in Brazil, Argentina, Chile (Barra et al., 2006), Poland (Gałuszka et al., 2011), Spain (Concha-Graña et al., 2006), The Netherlands (van Liere et al., 2003), China (Zhu et al., 2005), Canada, USA (Phillips et al., 2006), and India (Singh et al., 2007), among others. However, these reports underestimate the real situation because of the presence of illegal contaminated storage sites. For instance, the most important known illegal disposal of more than 30 tons of OC pesticides [lindane (γ-HCH), chlordane (CLD), methoxychlor (MTX), aldrin, DDT] and several heavy metals [Cr(VI), Cu(II), Cd(II)], has been found in the southeast of Santiago del Estero, Argentina (Chaile et al., 1999; Fuentes et al., 2010). Meanwhile, pollution arising from agricultural activities is considered diffuse since the compounds are distributed over large areas and at low concentrations. Residues of pesticides have been reported for many countries in air (Lammel et al., 2007), water (Kumari et al., 2007), soil (Fuentes et al., 2010), food commodities (Bajpai et al., 2007), milk (Zhao et al., 2007), fishes (Malik et al., 2007), and even in human blood and adipose tissue (Ridolfi et al., 2014).

Heavy metal pollution is also one of the most significant environmental problems today. Contaminated sites can be remediated by a wide range of technologies, however, in case of metal contamination, only a few technologies can be applied because of the immutable and generally immobile character of metals (Dávila Costa et al., 2011a,b). The wide use of heavy metals in several applications leads to their worldwide distribution in soil, silt, waste, and wastewater. The pollution of the environment by toxic metals arises as a result of several human activities, largely industrial, although sources such as agriculture, municipal landfill, and sewage disposal also significantly contribute (Fernández et al., 2014).

Mixed pollution caused by the presence of organic and inorganic compounds tends to be concentrated in industrial zones, oil storage areas, waste recycling sites, and soils and sediments near roads (Mansour, 2012). For instance, several heavy metals and OC pesticides were found in water and silt samples from a major river basin from Northern Argentina ("The Salí basin"), at concentrations up to 10 times higher than allowed by law (Polti et al., 2007). Co-pollution is a very important problem because more than one third of polluted sites have more than one type of contaminant (Mansour, 2012).

Actinobacteria are a group of bacteria present in high concentrations in soils. They play an important role in recycling substances, since they are able to metabolize complex organic matter (Kieser et al., 2000). The important ecological role played by actinobacteria is demonstrated by their capability to remove xenobiotics compounds such as pesticides, and heavy metals, among others substances (Albarracín et al., 2005; Benimeli et al., 2003, 2006, 2007; Polti et al., 2009, 2011a,b, 2014). Because of their metabolic versatility, actinobacteria have received great global interest for several biotechnological applications.

This review focus on how different techniques/strategies using actinobacteria can contribute to improve the bioremediation of pesticides and/or heavy metals. We will present evidence about biotransformation of these pollutants by free or immobilized single or mixed cultures, providing information about the ecotoxicological risks of byproducts of the process. In this context, attention will be paid to omics as they provide invaluable tools for answering what mechanisms and genetic/physiological regulations are behind the degree of resistance to different pollutants. This review compiles and updates information available on the role of plant-associated

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