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Research review paper

Adaptive responses and cellular behaviour of biphenyl-degrading bacteria toward polychlorinated biphenyls

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Abstract

Polychlorinated biphenyls (PCBs) are one of the most widely distributed classes of chlorinated chemicals in the environment. For cleanup of large areas of PCB-contaminated environments, bioremediation seems to be a promising approach. However, the multitude of PCB congeners, their low bioavailability and high toxicity are important factors that affect the cleanup progression. Elucidating how the PCB-degrading microorganisms involved in the process adapt to and deal with the stressing conditions caused by this class of compounds may help to improve the bioremediation process. Also specific physiological characteristics of biphenyl-utilizing bacteria involved in the degradation of PCBs may enhance their availability to these compounds and therefore contribute to a better microbial mineralization. This review will focus in the stress responses caused in aerobic biphenyl-utilizing bacteria by PCBs and its metabolic intermediates and will also analyze bacterial properties such as motility and chemotaxis, adherence to solid surfaces, biosurfactant production and biofilm development, all properties found to enhance bacteria–pollutant interaction.

Keywords: PCB; Chemotaxis; Stress; Toxicity; Biosurfactant; Bioremediation; Biofilm; Polyphosphate

Contents

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1. Introduction

In the past decades, a vast range of xenobiotic compounds have been found to be vulnerable to microbial mineralization. In most instances where bioremediation has been demonstrated, the catabolic pathway and its regulation have also been characterized.

Biphenyl is an aromatic compound used as a fungicide for citrus in agriculture and as a chemical feedstock for organic syntheses in industry. It has been used as a model compound to study bioavailability of soil-sorbed chemicals and polychlorinated biphenyls (PCBs) degradation studies (Wu et al., 2003; Pieper, 2005).

PCBs can be produced by the direct chlorination of biphenyl and up to 209 different congeners, containing from 1 to 10 chlorine substitutions, can thus be produced. Usual commercial PCB mixtures, marketed as Aroclor, Kaneclor, Clophen or Delor, generally contain 20–60 congeners, mostly tri-hexachlorinated derivates. Because PCBs have been extensively used for a variety of industrial purposes, these recalcitrant compounds are recognized to be one of the most serious environmental pollutants worldwide (Kimbrough, 1995).

Biphenyl-utilizing bacteria are able to metabolize PCBs into chlorobenzoic acids by using biphenyl-catabolic enzymes via an oxidative route. Bacteria capable of degrading PCBs have been isolated from a range of sites and the pathways and encoding genes (*bph*) have been well studied (for a recent review see Furukawa, 2004). The genes encoding the degradative pathway are organized in an operon structure, *bphA1* to *bphA4*, *bphB*, *bphC* and *bphD*. Genes *bphA1* to *bphA4* encode a multicomponent dioxygenase enzyme complex that converts biphenyl to a dihydrodiol, which is transformed by the *bphB* gene product, a dihydrodiol dehydrogenase, to 2,3-dihydroxybiphenyl. Another dioxygenase enzyme, the *bphC* gene product, cleaves 2,3-dihydroxybiphenyl to yield a yellow colored meta-cleavage product, which is transformed subsequently to benzoate and a pentanoic acid derivative by the product of the *bphD* gene (Furakawa et al., 1990; Furukawa, 1994; Furukawa et al., 2004). *Burkholderia xenovorans* LB400 (formerly known as *B. cepacia* or *B. fungorum* LB400) and *Pseudomonas pseudoalcaligenes* KF707 have been the most extensively studied species with respect to the degradation of PCBs. These two microorganisms show distinct differences in the ranges of PCBs used as substrates. The range of PCB congeners oxidized by the LB400 enzymes is wider than that oxidized by KF707, which has a higher activity for several di-para-substituted PCBs (Bopp, 1986; Gibson et al., 1993). Also, novel isolates such as *Pseudomonas* sp. B4 (Elbe River) have been studied and compared at molecular and physiological levels with the model PCB-degraders (Bartels et al., 1999; Chavez et al., 2004).

Studies with different biphenyl- and PCB-degrading bacteria, including both gram-negative and gram-positive strains, have created the biochemical and genetic bases for PCB bioremediation (Abramowicz, 1990; Brenner et al., 1994; Furukawa, 1994). Recent extensive reviews are available concerning the microbial advantages, limitations and economics of PCB bioremediation (Abraham et al., 2002; Ohtsubo et al., 2004; Pieper, 2005).

Responding to changes in the environment is a fundamental property of a living cell. It is particularly important for unicellular organisms, which interact directly with the changing microenvironment. Through evolution, microorganisms have developed useful mechanisms that help them to regulate their cellular function in response to changes in their environment (Storz and Hengge-Aronis, 2000).

The high toxicity of the many PCB congeners and their low bioavailability, which are significant factors that influence the bioremediation process in the contaminated environments, have not been extensively addressed. Therefore, the present article reviews some of the specific physiological characteristics of biphenyl-utilizing bacteria that enhance the bioavailability of PCBs. Cell adherence and surface hydrophobicity, biosurfactant production, motility and chemotaxis processes are bacterial abilities that reduce the distance between cells and solid substrates, and thus may enable biphenyl-utilizing bacteria to actively seek new substrates once they are depleted in a given contaminated area.

In this communication, we also review the stress response induced in microorganism grown in these pollutants with particular focus on the versatile possible role of inorganic polyphosphate as a protective agent against stress and as an essential factor in microbial mobility and biofilm formation.

2. Motility and chemotaxis

Mobility (swimming, swarming and twitching) serves the planktonic organism in seeking nutrients, avoiding toxins and finding a suitable surface for aggregation. Bacteria swim using flagella and move on surfaces by a gliding movement. They may respond directly to ambient conditions or, more frequently, to temporal changes in stimulus intensity. Bacterial chemotaxis, a movement under the influence of a chemical