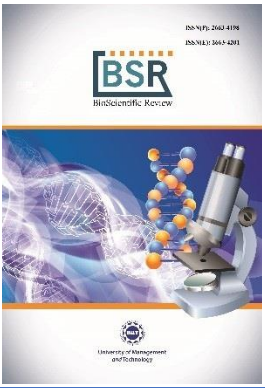

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Insights into the Chemical Interaction between Plants and Microbes and its Potential Use in Soil Remediation

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Abstract

Soil bacteria are very vital and they are frequently used in production of crop. Chemical dialogues between bacteria and plant roots result in the proliferation and biofilm formation of plant growth promoting and contaminant degrading bacteria. Plant-bacterial interactions in the rhizosphere are the determinants of plant health and soil fertility. Plant growth promoting rhizobacteria (PGPR) which is also known as plant health promoting rhizobacteria (PHPR) or nodule promoting rhizobacteria (NPR). It can benefit the host plant directly by enhancing plant growth or indirectly by producing hydrolytic enzymes and by priming plant defence. This review elaborates the effect of plant and bacterial products on the remediation of contaminated soil.

1. Introduction

Terrestrial ecosystem comprises numerous niches among which the association between plants and microbes plays an integral role [1]. Plant-microbe interactions are of various types and include mutualism, commensalism, parasitism and antagonism [2]. The most common interactions include mutualism and commensalism, where one or both participating organisms benefit from them [3].

Rhizosphere contains the root system of plants. It exhibits a flexible morphology and structure that help to respond to any change in the surrounding environment. The health and productivity of plant is influenced by its rhizosphere [4]. The root system provides anchorage, helps in nutrients uptake and facilitates many underground interactions [5]. These interactions comprise a mutualistic relationship with plant associated bacteria, such as rhizobia, mycorrhizae, endophytes, and PGPR [6, 7, 8]. Besides these interactions with beneficial microorganisms, plant roots also interact with pathogenic microbes [9]. The roots of plants release a variety of chemicals in a large amount which help to attract beneficial bacteria and in the fight against pathogenic ones, such as *Azospirillum*, *Bacillus*, *Pseudomonas* species [10, 11]. The aim of this article is to explore the hidden mechanism of key root exudate components responsible for the accelerated rhizodegradation of organic pollutants. It also intends to indicate the responses of soil microorganisms to different root exudate components.

2. Chemical Communication between Plants and Microbes

Rhizosphere is the narrow region of soil where the root exudates of plants drive an intense microbial activity [12, 13]. Rhizobacteria colonize the roots of plants and stimulate their growth. Inoculation and colonization of plant roots with PGPR has been used as a way to enhance the growth of plants [14]. The signalling between plants and bacteria influence the bacterial colonization of plant roots which is a complicated multistep process [15, 16]. Bacterial traits that affect the process of root colonization include motility and components of bacterial surface, such as flagella and pili [17, 18]. The growth and physiology of rhizobacteria is influenced by specie specific exudates secreted by plants. These exudates contain various biochemical components such as carbohydrates, proteins, vitamins and different organic acids [19, 6, 20]. The composition of these exudates and the ability of bacteria to catabolize these chemicals are the key determinants of primary colonizers [21, 22, 23]. *Pseudomonas* is a bacterial specie which can compete for limited carbon source and is capable of catabolizing a wide range of plant root exudates. This ability has made *pseudomonas* one of the most successful root colonizers [24, 25].

Quorum sensing is a mechanism which is utilized by bacterial communities to sense and communicate with environment [26, 27]. It is a sensing mechanism based on cell population density. Bacterial cells, particularly the gram negative bacteria, release molecules such as N-acyl homoserine lactone (AHL) which can sense quorum [28, 29]. Plants have evolved various methods to identify and respond to AHLs. This helps in the establishment of symbiotic associations between bacteria and plants [30, 31, 32]. Plants perceive surrounding AHL molecules and modify their genetic expressions accordingly, which in turn changes their protein profile and finally adjust development based on the nature of signals [30, 33].

Various direct and indirect mechanisms are used by certain AHL producing bacterial strains to stimulate the growth of plants. Such mechanisms include nitrogen fixation, synthesis of phytohormones, siderophores, removing toxic chemicals and fighting pathogenic microbes [33, 34, 35]. Besides this, these bacterial strains also enhance the bioavailability of mineral nutrients such as iron and phosphorous through the decomposition and mineralization of organic matter [25]. Various chemicals produced by these bacteria may also help to enhance the plant community. Roots contain epidermal extensions called root hairs which directly participate in nutrient and water absorption [7, 20]. The development of primary roots, root hairs and adventitious roots is strongly induced by AHL molecules. The acyl chain length of AHL molecules may influence the thickening of root hairs. Small chains of these molecules (C6-C8) do not modify the development of root hairs [36, 32]. Long chains of these molecules (C8-C12) attenuate the development of root hairs in a dose dependant manner [37, 31]. For example, C10- AHL molecule has been reported to stimulate the lateral root hair formation on the tip region. When these quorum signal molecules are exogenously applied on root hairs, they may produce a response similar to auxins. Their role in cell division is evident by the regulation of lateral root hair formation [38].

The array of signalling metabolites produced by microbe assemblages present in the soil have become an interesting and important subject for investigators. These metabolites affect the genetic expression of host plants [39]. Volatile organic compounds (VOCs) are among the very well-documented signalling molecules produced by bacterial communities. These lipophilic compounds with low molecular weight serve as a chemical window to release information. These compounds are synthesized by various metabolic pathways [26]. Recent findings suggest a more crucial role of VOCs in microbial communication than their other volatile equivalents. For example, numerous VOCs are produced by rhizobacteria that may contain alkanes, alkenes, ketones, alcohol, terpenoids and sulphur compounds [39, 32].

3. Role of Root Exudates in Biodegradation

Recently, root exudation has gained significant attention as the process used for the biodegradation of hydrocarbons occurs in the rhizosphere. As shown in Fig. 1, root exudates act by enhancing the hydrocarbon degrader population of the rhizosphere and serve as a carbon source for microorganisms, thereby enhancing hydrocarbon degradation [11]. The concentration of root exudates was found to be negatively correlated with the concentration of hydrocarbons, that is, the higher the root exudate concentration the lower the concentration of hydrocarbons in that area. As the distance from the root increases, the biodegradation of phenanthrene also decreases [16]. Biodegradation reportedly remains 86% in the first 3mm from the roots and gradually decreases to 48% between 3-6mm. It declines to 36% between 6-9mm [26]. A number of external factors influence the chemical complexity of exudates including the size of plant, condition of soil and photosynthetic activity [40]. These factors are also species specific or genotype specific. These exudates can be differentially modified depending on the source of secretion. The potential of root exudates to cover the information about the events that mediate the communication events in rhizosphere is evident from their strong specificity and complexity.

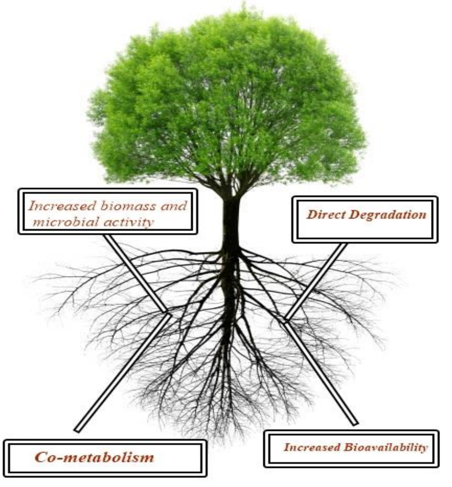

Figure 1. Improvement of petroleum hydrocarbon degradation by root exudates

4. Conclusion

Plants are environmentally safe, economically advantageous, and a robust renewable resource of *in situ* reduction of contaminants. Their root systems are generally extensive and provide a conducive environment for microbial propagation and activity, both within and outside of plant tissues. The combined use of root exudates, contaminant degrading rhizosphere and/or endophytic bacteria provides an effective approach for the remediation of contaminated soil.

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