Poll Res. 40 (1) : 21-26 (2021)

ISSN 0257–8050

PLANT-MICROBE INTERACTIONS IN ATTENUATION OF TOXIC WASTES IN THE ECOSYSTEM

IKPONMWOSA O. EVBUOMWAN[1], EHI G. STAN-LABO[1] AND OGHENEROBOR B. AKPOR[2*]

[1]*Department of Microbiology, College of Pure and Applied Sciences, Landmark University, Omu-Aran, Nigeria*
[2]*Department of Biological Sciences, Afe Babalola University, PMB 5454, Ado-Ekiti, Ekiti State, Nigeria*

(Received 18 July, 2020; accepted 22 August, 2020)

ABSTRACT

Several toxic compounds, both organic and inorganic,which are produced as by-products, have the ability to contaminate the environment through either anthropogenic activities or natural processes leading to environmental pollution. The accumulation of these compounds has been associated with adverse human and animal health conditions including cancer. Plant-associated microorganisms (usually bacteria) such as endophytes and rhizospheric microbes have been reported to aid biodegradation of certain toxic compounds and show the potential to enhance phytoremediation technologies. There is a mutualistic relationship between plants and microbes in the rhizosphere - plants have the ability to provide root exudates which serve as nutrients for the microbes thereby aiding chemo taxis while rhizospheric microorganisms contribute to the growth of plants directly and indirectly. Conventional remediation techniques which usually involve excavation and transportation, are labour-intensive bringing about the need for eco-friendly and less laborious techniques. Inoculation of microorganisms with pollutant-degrading capabilities (either autochthonous or genetically engineered) working in conjunction with plants in contaminated environments has been considered a promising technology for remediation and in turn, has positive indications on human and animal health. The aim of this paper was to review the interaction of microbes and plants in the attenuation of toxic wastes.

KEY WORDS: Microbial interaction, Rhizosphere, Microorganisms, Toxic wastes, Ecosystem

INTRODUCTION

Environmental pollution poses a serious threat to public health and has become a global issue of great concern. The sources of environmental pollution are diverse, ranging from gradual increment of numerous human activities such as industrialization, modernization, oil spillage and agricultural activities to naturally occurring activities including forest fires and volcanic eruptions which have led to the production of substances e.g radio active compounds, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, dyes andheavy metals (Malchi *et al*., 2014; Hussain *et al*., 2018). These pollutants have contaminated many terrestrial and aquatic environments and have adverse effects on the ecosystem, animal and human health due to their toxicity, mutagenicity and carcinogenicity (Teng *et al*., 2014; Copaciu *et al*., 2016; Sepehri and Sarrafzadeh, 2018). They are capable of penetrating soil, groundwater and air in their immediate environment and can diffuse and be found far from the source of pollution (McGuinness and Dowling, 2009).

Conventional remediation techniques usually involve excavation, transportation or use of complex machinery. The magnitude of the effects of toxic waste pollution necessitated the need to establish sustainable methods of remediation which require less labour and do not eventually lead to production of secondary pollutants–plant-assisted bioremediation which involves the combination of phytoremediation (remediation technique involving the use of vegetation) and bioaugmentation (addition of microorganisms to speed up the rate of contaminant degradation) (Karthikeyan and Kulakow, 2003).

Microorganisms are an essential part of soil which contribute greatly to the growth and development of plants. The microbial community associated with the roots of plants makes up the rhizosphere microbiome or rhizomicrobiome (Kotoky *et al*., 2018). Rhizosphere microbes (microorganisms in the soil influenced by roots of plants) such as Plant Growth Promoting Rhizobacteria (PGPR) play various significant roles in the promotion of plant growth by establishing mutualistic relationships with plants in which they synthesize varieties of phytohormones, supply nutrients such as potassium, nitrogen and phosphorus and act as biocontrol agents by producing antibiotics and bacteriocins against plant pathogens. These help to sustain the life of plants. The plants, in turn, produce root exudates or secretions which vary in composition depending on the genotype and level of plant progression (Ahemad *et al.,* 2011, van Dam and Bouwmeester, 2016). The impact of the rhizomicrobiome depends largely on the exudates, which also mediate interactions through signalling molecules produced and secreted by both plants and microorganisms (Venturi and Keel, 2016). The exudates cause positive chemotaxis towards the plant roots as they serve as nutrients to rhizosphere microorganisms which then colonize the root surface and are sustained by nutrition from the plant (Hussain *et al*., 2018). Organic compounds found in root exudates enhance plant–microbe interaction (Crowley and Kraemer, 2007).

Non-indigenous microorganisms capable of quick adaptation can also be inoculated into the soil to enhance the efficiency of biodegradation. These microorganisms produce enzymes which have the ability to break down organic pollutants. Plants and microorganisms, both indigenous and non-indigenous may be genetically engineered to improve their pollutant-degrading capabilities due to resulting complexity of metabolic pathways. The combined efforts of the pollutant degrading abilities of plants and microbes are considered as highly effective and environmentally acceptable (Singh, 2013). The aim of this paper was to review the interaction of microbes and plants in the attenuation of toxic wastes.

Plant-microbe interaction

Plants and their biotic/abiotic environment make up mixed habitats for microorganisms. The rhizosphere serves as a microhabitat around roots and usually extends 1–2 mm around them (Liu *et al*., 2014). However, some of these habitats may contain toxic mixtures of compounds or lack nutrients and water required to support microbial communities capable of remediation. Many plants interact with root-associated microorganisms to survive in toxic and nutrient-deficient environments (Paul, 2007). The growing plant secretes a wide range of chemicals in root exudates including phenolic compounds, amino acids and mucilages which aid root-microbe communication (Martin *et al.,* 2014). Moreover, plant roots can also secrete certain organic compounds including terpenes, flavonoids and phenols, which are structurally similar to some organic contaminants such as petroleum hydrocarbons which help to induce the expression of degrading genes and increase the abundance of the associated rhizospheric microbes (Xun *et al*., 2015).

Additionally, microorganisms utilize these organic compounds as carbon and energy sources while plant roots provide microaerophilic conditions, and exudates which increase the degradation of organic contaminants. Root exudates stimulate the degradability and bioavailability of organic xenobiotics to microbes by providing substrate for microbial metabolism and altering soil pH or contaminant solubility (Hussain *et al.*, 2018). Plant-microbe association enhance plant growth and development through different means: lowering ethylene concentration, production of plant growth regulator such as indole-3-acetic (IAA), 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase and suppress disease (Glick, 2010).

Besides, these associations also aid in nitrogen fixation, nutrient mobilization, siderophores and phosphate solubilization, plant growth and removal of toxic wastes such as heavy metals (Ahmad *et al.*, 2011; Verma *et al*., 2013). This synergistic relationship enhances the role of both plants and microbes (Macci *et al.,* 2013; Feng *et al.,* 2017) – microbes help their host plant to overcome stress caused by pollutants and improve plant growth, therefore enhancing shoot and root biomass, which in turn supports microbial populations and the degradation of organic pollutants (Compant *et al.,* 2010; Weyens *et al.*, 2013). The higher the microbial population the faster the degradation rate of contaminants in comparison to rates achieved by individual strains (Khan *et al.*, 2013).

Principles and mechanisms of plant-microbe interaction

The attenuation of toxic wastes using plant-microbe interactions is aimed at the reduction of the toxicity of these wastes and/or complete decontamination of sites affected by them, hence reduction of pollution caused by these wastes. The elimination of these pollutants is important in order to ensure the sustenance of the environment and the health of man, animals and plants. The interactions between plants and microorganisms are often invisible to the naked eye and usually occur in various ways at various levels.

Plant development is dependent on the continuous relationship between shoots and roots in the soil and microorganisms found in the rhizosphere; this relationship could be neutral, beneficial or pathogenic. Regardless of the kind of interaction, microbes are indicated to use the same mechanisms but for different functions.

Chemotactic response towards plant root exudates

The progressive motion of a cell or organism in response to chemical stimuli is known as chemotaxis. Chemotaxis signalling offers motile soil bacteria the ability to sense and respond to the various ranges of chemical substances produced by plant roots known as root exudates. It is a process that permits bacterial locomotion towards plant roots and is therefore crucial for competitive root colonization. Certain factors such as the kind of exudate produced, temperature, pH and the water potential of the environment affect the chemotactic ability of microorganisms (Scharf *et al*., 2016).

Chemotactic response is imperative for microorganisms to look for nourishment around them. Basically, chemotaxis is classified into two, positive chemotaxis and negative chemotaxis. In positive chemotaxis, microorganisms progress towards a released substance which is valuable such as a required nutrient or supplement while negative chemotaxis involves the development of microbes away from released substances which may be lethal such as toxins (Bernard, 2012).

Chemotaxis and colonization go hand in hand as the two most important components in a plant-microbe association. It has been propounded that chemotaxis towards root exudates is the initial phase of bacterial colonization; in addition, formation of biofilms on plant roots is a proposed execution of on-going colonization. It is therefore expected for the most part that the root exudates assume a necessary part in the rhizosphere exchange between plants and microorganisms. Root exudates do not only serve as a Carbon source for microorganisms in the soil; they, in addition, serve as signals to attract or repel microbes. Organic acids such as malic acid, citric acid, acetic acid, lactic acid and so on are vital components of root exudates (Sushma, 2003).

Knowing the kind of chemicals deposited into the soil by the roots of plants is fundamental and critical in the interaction between plants and microorganisms to magnify the significant roles of useful rhizosphere microbial strains. The production of root exudates relies solely upon the plant, that is, its species, physiology, phase of advancement and situation of the root system and this reliance is said to have an impact on microbial networks in rhizospheric soil. It may attract organisms that will make advantageous associations with the plant or it may attract pathogens to the plant. For example, Isoflavin, a compound known to be secreted by the roots of Soya bean plants attracts a pathogen (*Pytoptherasojae)* and a mutualistic organism (*Bradyrhizobium japoicum*) (Sandro *et al*., 2003; Choi *et al*., 2004).

Plant root surface colonization

The multiplication of microbes around, in or on plant roots is known as root colonization. It involves the scattering of microorganisms from the point of introduction or inoculation to actively growing roots, and proliferation and development in the rhizosphere. It is a general assumption that the colonization of plant roots is a prerequisite step for the formation of favourable relationships. The numerous traits and genes involved in root colonization which are still poorly understood have led to failed attempts to regulate and control these advantageous effects of microflora in the rhizosphere (Parke, 1991).

The colonization process is initiated by a dispersal phase and is succeeded by a growth phase. The dispersal phase could arise as an effect of growth or chemotaxis of the microorganisms towards root cap cells which have been diminished by continued friction by soil particles, mucilage and useful root exudates such as sugars, enzymes and fatty acids. The growth phase is the stage in which the microorganisms develop and reproduce. Bacterial colonies become infused in the mucilage around the roots and on the exterior of epidermal cells. Mycorrhizal fungi colonize the root cortex, producing hyphae and vesicles or forming sheaths on short roots (Bennett and Lynch, 1981; Foster, 1986; Parke, 1991).

Microbes involved in root colonization could be indigenous or introduced. Colonization of plant roots by indigenous microorganisms comes about when a root comes in contact with fungi and/or bacteria that are affiliated with decomposing organic materials and gelatinous material dispersed in the soil; as opposed to colonization by microorganisms that are introduced on seeds or other plant propagules which must scatter on the developing root from one inoculum origin, and compete with other established autochthonous microorganisms for colonization (Foster, 1986).

Synthesis of compounds by microorganisms

Some microorganisms associated with plant roots have beneficial properties which could be direct or indirect and can function simultaneously or independently. Such properties include warding off pathogenic organisms, production of hormones that improve plant growth and fixing unavailable or deficient nutrients which therefore preserve the existence of plants. Plant Growth Promoting Rhizobacteria (PGPR) are bacteria that colonize the plant root surface (rhizoplane) and/or the soil around the root (rhizosphere) and have the ability to enhance plant growth and development by either supplying plants with substances produced by the bacterium or promoting the absorption of certain nutrients from the surrounding environment (Glick, 1995; Beneduzi *et al.,* 2012).

Most PGPR are known to serve as microbial antagonists, indirectly promoting development of plants by serving as biocontrol agents by producing compounds that inhibit the survival of pathogenic organisms or by strengthening a plant's resistance to pathogens. PGPR could produce hydrolytic enzymes (lipases, proteases and chitinases) that are capable of breaking down fungal cells capable of causing disease. They also produce siderophores (which facilitate the nutritional requirements of iron by chelation) and antibiotics, which inhibit or decrease the growth and metabolic activities of phytopathogens. In addition, they produce bacteriocins (which are toxic to bacteria that are closely affiliated with the producing bacterial strain) and hydrogen cyanide which works to great effect in synergy with the above-mentioned compounds (Ramette *et al*., 2006).

Through the synthesis of growth hormones, PGPR are also capable of enhancing plant growth. Some of these hormones include gibberellins (for the stimulation of growth and major growth processes) auxins (promote development of roots and cell elongation), cytokinins (manage differentiation of cells in the meristem of plants (Zaidi *et al*., 2015; De Rybel *et al*., 2016). They also promote plant growth by synthesizing amino-cyclopropane carboxylic acid (ACC) deaminase to reduce ethylene production (Divya and Kumar, 2011). A very important mechanism of PGPR in plant growth enhancement is Nitrogen fixation which is the process of transforming atmospheric nitrogen to Ammonia. Plant Growth Promoting Bacteria also function by competing with pathogens for nutrients or binding sites on the plant surface (Beneduzi *et al.,* 2012).

Plant-microbe interaction in toxic waste attenuation has some advantages over conventional methods; it is cost effective, less complex and requires less energy. Besides, it is eco-friendly and sustainable. Additionally, it can be tailored to the requirements of the polluted site for efficient attenuation, does not destroy the soil structure and allows for continuous use of site after decontamination (Abatenh *et al*., 2017). This technique however has some disadvantages. Introduction of genetically modified plants and microbes can have adverse effects on the natural occurrence, structural and functional composition of microbial communities (Abatenh *et al*., 2017), and is restricted to root zone and areas of soil the roots spread or gain access to, as such, pollutants not in this range may not be attenuated. Also, the process of degradation may be time consuming depending on the concentration of the pollutant and the bioavailability of pollutant-degrading microorganisms, and requires highly skilled manpower. Limited bioavailability of microorganisms capable of contaminant degradation and stress induced by contaminants which leads to slow germination of seeds, and development of plants and low rates of biomass production restrict the implementation of these technologies in a large scale (Divya and Kumar, 2011).

CONCLUSION

The interaction of plants and microbes is pivotal in the attenuation of toxic wastes, hence, there has been a recent rise in the development of technologies to support it. The combination of the application of phytoremediation and bioremediation simultaneously could solve some of the issues encountered in individual application. Rhizoremediation, phytoremediation and their accompanying mechanisms are current technologies being successfully applied not only to the removal of pollutants but also to the reduction of toxicity through diminishing of pollutant concentrations in the rhizosphere.

Despite new efforts, more research is needed to attain advancement in developing technologies such as suitable combinations of genetically modified plants and microorganisms and improvement in the efficiency of their degradation; and more work is still undone in carrying out field-based studies on experiments that have been carried out in the laboratory for the commercialization of conceivable approaches.

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