ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.12 pp 416-421, 2016

Influence of Rhizobacteria on Induction of Plant Resistance to Stresses

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Abstract : Biotic and abiotic are the most serious stresses affecting plant growth and productivity. Plants responding to stresses produce several protective compounds and proteins such as pathogenesis related (PR) proteins, directly disease related proteins and other proteins. Plant growth-promoting bacteria (PGPB) are bacteria that can enhance plant growth and protect plants from disease and abiotic stresses through a wide variety of mechanisms; those that establish close associations with plants, such as the endophytes, could be more successful in plant growth promotion. Rhizobacteria are microorganisms that reside within plants. Among them are species that contribute to plant's vigour and ability to cope with pests and harsh environments. Several important bacterial characteristics, such as biological nitrogen fixation, phosphate solubilization, ACC deaminase activity, and production of siderophores and phytohormones, can be assessed as plant growth promotion (PGP) traits. This review presents an overview of the importance of soil-plant-microbe interactions to be developed for the improvement of tolerance to biotic and abiotic stresses.
Key Words: Rhizobacteria, Plant resistance, biotic and Abiotic stresses.

Introduction

Stress

Stress factors are divided into biotic (living) and abiotic (non-living) stresses. Biotic stress includes a variety of pathogenic microorganisms, insects and higher animals including interference from humans. On the other hand, abiotic stress include factors such as water logging, drought, heat, cold, wind, intense light, soil salinity and inadequate or excess of mineral nutrients[1]. Abiotic and biotic stresses originating from the environment that cause tissue damage to plants practically all result in the rapid accumulation of reactive oxygen species (ROS) leading to an oxidative microenvironment in cells. Drought is expected to cause serious plant growth problems for more than 50% of the arable lands by 2050[2]. Global warming will increase the severity and frequency of drought in the future leading to a possible decrease in global food production. The protection of cells from damage caused by the different reactive oxygen compounds (e.g. superoxide, hydroxyl radical, hydrogen peroxide, singlet oxygen) is the important task of antioxidant systems in plants. ROS produced in plant cells – that play important roles in signal transduction processes under stress-free conditions – can be detoxified through several ways: either by electron donors such as glutathione, ascorbate, carotenoids and tocopherol, or via chemical reactions catalysed by enzymes like superoxide dismutase, peroxidases, glutathione S-transferase and the enzymes of the ascorbate−glutathione cycle.

Salt stress is another abiotic stress of anthropogenic origin that poses problems increasing parallel with the growth of areas affected by aridity. High salt concentrations in soil and irrigation water are a major threat to agricultural production in arid and semiarid regions.

Management of Stresses

Several strategies could be employed to manage the deleterious effects of both abiotic and biotic stress factors on plants. For decades the most adopted strategy relied heavily on conventional plant breeding for genetics improvement aiming for resistant/tolerant varieties[3]. However, conventional plant breeding techniques have practical limitations. For instance, plant breeding is a relatively slow process often dependent on costly programs and highly influenced by seed companies[4]. On the other hand, genetic improvement could be also achieved by utilizing biotechnology aiming to engineer resistant/tolerant varieties carrying modified genes[4]. Microbial communities are able to develop a range of activities that are very important in maintaining biological balance and sustainability in soil particularly under stress conditions[5]. Under stress conditions, plants are more dependent on microorganisms that are able to enhance their metabolic activity to combat stress[5]. Rhizobacteria that exert beneficial effects on plant growth and development are referred to as plant growth promoting rhizobacteria (PGPR). PGPR are beneficial native soil bacteria that colonize the rhizosphere or plant roots and result in increased plant growth and yield . PGPR are adapted to adverse conditions and may protect plants from the deleterious effects of drought stress, thus increasingcrop productivity in arid or semiarid areas[5]. Several PGPR are reported to induce drought stress tolerance in some plants such as wheat, maize, sunflower, sugarcane and green gram[6]. The presence of excess ions in the rhizosphere causes injury to plant roots, followed by their gradual accumulation in the aerial parts with heavy damage to plant metabolism, which leads to stunted growth and reduced yield. Plants have developed complex mechanisms to avoid NaCl toxicity and low water potential in soil caused by salinity as well as drought. Furthermore, mutualistic symbiosis with mycorrhizal and endophytic fungi can confer salt tolerance to plants and decrease yield losses in cultivated crops grown in saline soils.

The rhizosphere refers to a unique zone formed by soil under the influence of a plant root system[7]. Root's rhizosphere is characterized by a great microbial diversity as well as complex interactions between microorganisms and the roots[8]. Application of PGPR to induce abiotic stress tolerance in plants is extensively investigated as an attractive strategy to control plant stress[6].

Agricultural production currently depends on the large-scale use of chemical fertilizers[9]. These fertilizers have become essential components of modern agriculture because they provide essential plant nutrients such as nitrogen, phosphorus and potassium. However, the overuse of fertilizers can cause unanticipated environmental impacts[10]. To achieve maximum benefits in terms of fertilizer savings and better growth, the PGPB-based inoculation technology should be utilized along with appropriate levels of fertilization. Moreover, the use of efficient inoculants can be considered an important strategy for sustainable management and for reducing environmental problems by decreasing the use of chemical fertilizers[11,12].

PGPR have been employed to control several plant pathogens, including *Fusarium* spp.[13]. Biological control could be achieved either by using the ability of several PGPR strains to antagonise the disease causing agents or inducing plant resistance[14]. For instance, Shi et al[15] reported that *B. amyloliquefaciens* antagonized *F. Graminearum* growth which in turn significantly inhibited DON production in wheat seeds. Several PGPR are also capable of mycotoxin detoxification as shown by Cheng et al[16] that reported the ability of two *Bacillus* isolates to detoxify DON in wheat and maize. The detoxification was achieved by transforming DON to a less toxic product deep oxyvomitoxin (DOM). Productions of toxic and microbial growth inhibiting metabolites are widely considered the most powerful mechanism employed by rhizobacteria against plant pathogens[17]. It is estimated that some *Bacillus* and *Paenibacillus* species devote from 4% to 8% of their genomes for genes encoding proteins involved in synthesizing bioactive compounds[17].

Stress-induced bacterial genes are also associated with plant-bacterial interactions. The bacterial enzymes superoxide dismutase and glutathione reductase were crucial for the endophytic colonization of rice roots by *G. diazotrophicus* PAL5[18]. *Bacillus amyloliquefaciens* FZB42 genes involved in chemotaxis and motility were induced through exudates from P-deficient maize plants, whereas the exudates from N-deficient plants triggered a general bacterial stress response[18]. The influence of bacteria in the rhizosphere of plants is largely due to the production of auxinphytohormones[19]. Several bacterial species can produce indolic compounds (ICs) such as the auxinphytohormone indole-3-acetic acid (IAA), which present great physiological relevance for bacteria-plant interactions, varying from pathogenesis to phytostimulation[19]. Costa *et al.*[20]. Simultaneously analyzed the PGPB datasets from seven independent studies that employed similar methodologies for bioprospection and observed that 64% of all isolates and 100% of all bacterial genera presented siderophore-producing strains. A number of mechanisms have been investigated aiming to reduce the levels of ethylene in plants. One of these mechanisms involves the activity of the bacterial enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase[21]. ACC deaminase regulates the production of plant ethylene by metabolizing ACC (the immediate precursor of ethylene biosynthesis in higher plants) into α-ketobutyric acid and ammonia[22]. A significant amount of plant ACC might be excreted from the plant roots and subsequently taken up by soil microorganisms and hydrolyzed by the enzyme ACC deaminase, thus decreasing the amount of ACC in the environment. When associated with plant roots, soil microbial communities with ACC deaminase activity might have a better growth than other free microorganisms, as these organisms use ACC as a source of nitrogen[23]. Bacterial ACC deaminase activity can be conceptually divided into two groups, based on high or low enzymatic activity[23]. High ACC deaminase-expressing microorganisms nonspecifically bind to a variety of plant surfaces, and these microbes include rhizosphere and phyllosphere microorganisms and endophytes. However, low ACC deaminase-expressing microorganisms only bind to specific plants or are only present in certain tissues, and although these microbes do not lower the overall level of ethylene produced by the plant, they might prevent a localized increase in ethylene levels. Low ACC deaminase-expressing microorganisms include most, if not all, rhizobia species[23].

Several studies have reported the isolation of phosphate-solubilizing bacteria from soils or rhizospheres. Confirming that endophytes are important for phosphate solubilization, Chen *et al.*[16] observed that the endophyte *Pantoea dispersa*, isolated from the roots of cassava (*Manihot esculenta* C.), effectively dissolved Ca3(PO4)2, FePO4, and AlPO4, producing salicylate, benzene-acetic and other organic acids. Moreover, the inoculation of *P. dispersa* in soil enhanced the concentration of soluble P in a microbial population, increasing the soil microbial diversity, which suggests that an endophyte could adapt to the soil environment and promote the release of P.

Soil Healthy

The importance of soils has been memorialized by the United Nations Food and Agriculture Organization after they recognized 2015 as the Year of the Soil. Most of the Egyptian soils particularly those in Delta region are now suffering from many chemical and biological stress that significantly diminish their production. To combat these stresses, they should first be monitored and their action clarified. The term soil health is recently used to describe its status in terms of ability to sustain agricultural production and conserve biodiversity. Now, soil health has partly if not for the most part replaced the expression soil quality that was in existence since early 1990s. The prime dissimilarity between the two expressions is that soil quality was alerting distinctive peculiarity inside an operative group. The expression health shifted the insight to be integrative, holistic and systematic as well, however both expressions are still noticeably overlapping.The meaning of soil health varies between the users who might place differing priorities upon the multiple functions of a soil ecosystem. Therefore, the term soil health could only be understood within the context of the user of the term, and their aspirations of a soil. Generally, soil health status is resilient to its natural composition and how environmental stresses affect their sustainable use. There are several biological properties of a given soil ecosystem that could be followed as indicators of soil health, alone or in combination with other chemical or physical properties.Many types of chemical and biological contaminants always invade into the different soil ecosystems causing serious adverse impacts to all its components both living and non-living. Certainly the soil resistance to contaminants is linked with their content of collides, i.e. clay minerals, minute organic particulates and microorganisms. When soil ecosystems are characterized with high adsorption capacity, they retain most of the contaminants. At the same time grown and natural plants could absorb contaminants removing them away from the ecosystem. Using the human health analogy, a healthy soil could be categorized being in a state of composite well-being in terms of biological, chemical and physical characters; not degraded, functioning in its full potential and providing a full range of functions in such a way that it maintains this capacity into the future.

The advantages of using plants as biological detectors for contaminants are extensive. The techniques employed are relatively simple and could be performed with agility, plants grow at low costs, assays could be carried out under a wide range of environmental conditions, assays could be done for single or mixtures of contaminants, plants could be used as *in situ* monitoring for several years.

It is now commonly recognized that soil microbialbiomass is huge reaching millions per gram. Most environmental microbiologists now believe that not less than 80% of soil nutrient functions in a soil ecosystem are essentially controlled by micro-organisms. Microbial cells could be used as biomarkers together with their molecular and biochemical activities. Furthermore, several fungi were used as biological detectors for contaminants.

On the other hand, soil enzymes which are closely linked with element cycles and are well indicator for soil ecosystem health could be used as biological indicators. They are proper parameters to distinguish, quantify and monitor the status of microbial and physico-chemical properties in soil ecosystem and good detectors for changes in proportion of changes in soil ecosystem. The enzyme activities were successfully used as markers for biogeochemical cycles, degradation of organic matter, and soil remediation processes. Enzymes are also utilized as biological detectors, because they provide quick information about changes in the quality of a given soil ecosystem.

Soil stability results from a combination of biotic and abiotic characteristics, and the microbial communities could provide a quantitative measure of soil health, as these bacteria determine ecosystem functioning according to biogeochemical processes[24]. Soil health defines the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health[25]. The factors controlling broad-range soil health comprise chemical, physical, and biological features, such as soil type, climate, cropping patterns, use of pesticides and fertilizers, availability of C substrates and nutrients, toxic material concentrations, and the presence or absence of specific assemblages and types of organisms[26-29]. needs, productivity in extreme environments, PGPRs are surely a major target to be developed f or the improvement of tolerance to ab iotic stresses, including gextremes in water availability, temperature, and soil contamination by salts and heavy metals. PGPR are bioresources having novel and potential tool for providing substantial benefits to the agriculture exposed to stresses. Application of PGPRs is gaining worldwide importance and acceptance and appears to be the trend for the future. Thus, to meet human needs, productivity in extreme environments, PGPRs are surely a major target to be developed f or the improvement of tolerance to abiotic stresses, including extremes in water availability, temperature, and soil contamination by salts and heavy metals. PGPR are bioresources having novel and potential tool for providing substantial benefits to the agriculture exposed to stresses. Application of PGPRs is gaining worldwide importance and acceptance and appears to be the trend for the future

The challenge for plant scientists in the 21st century will be to develop stable multiple stress tolerance traits in agronomically important crop plants, thus improving yields particularly in areas with adverse environmental conditions, and contributing to global food security.

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