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Review

Does plant—Microbe interaction confer stress tolerance in plants: A review?

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A B S T R A C T

The biotic and abiotic stresses are major constraints for crop yield, food quality and global food security. A number of parameters such as physiological, biochemical, molecular of plants are affected under stress condition. Since the use of inorganic fertilizers and pesticides in agriculture practices cause degradation of soil fertility and environmental pollutions. Hence it is necessary to develop safer and sustainable means for agriculture production. The application of plant growth promoting microbes (PGPM) and mycorrhizal fungi enhance plant growth, under such conditions. It offers an economically fascinating and ecologically sound ways for protecting plants against stress condition. PGPM may promote plant growth by regulating plant hormones, improve nutrition acquisition, siderophore production and enhance the antioxidant system. While acquired systemic resistance (ASR) and induced systemic resistance (ISR) effectively deal with biotic stress. Arbuscular mycorrhiza (AM) enhance the supply of nutrients and water during stress condition and increase tolerance to stress. This plant-microbe interaction is vital for sustainable agriculture and industrial purpose, because it depends on biological processes and replaces conventional agriculture practices. Therefore, microbes may play a key role as an ecological engineer to solve environmental stress problems. So, it is a feasible and potential technology in future to feed global population at available resources with reduced impact on environmental quality. In this review, we have attempted to explore about abiotic and biotic stress tolerant beneficial microorganisms and their modes of action to enhance the sustainable agricultural production.

1. Introduction

The 21st century has been marked by global climate change. Many research studies have reported that environmental stresses are a major global threat to future of food security (Battisti and Naylor, 2009), while the world population is projected to reach from a current estimated 7 billion approximately to 8.9 billion by 2050 (Singh et al., 2011). Due to increasing climate variation, population and reduction in soil health for crop cultivation are threats for agricultural sustainability. It can become more prevalent in coming future due to these climate change and extensive agricultural practices (Wassmann et al., 2009). Since our traditional agriculture system which is unsustainable while population is increasing (Masciarelli et al., 2014), it is becoming very difficult for farmers and policy makers to produce such large amounts of food to fulfil the needs of growing population. On another hand, the indiscriminate use of chemical fertilizers, pesticides, weedicides etc. in agriculture causes extreme loss of beneficial microbial diversity from the soil.

Our agro-ecosystem is continuously affected by abiotic and biotic stress which directly change the crop productivity and, soil health and fertility. Various stress factors negatively affects the growth and productivity of crop plants. The stresses are simply classified as abiotic and biotic stress. Abiotic and biotic stress contributes 50% and 30% respectively to losses in agricultural productivity worldwide. The abiotic and biotic stress can either be natural or human induced. The major abiotic stresses are temperature, drought, salinity, and heavy metal stress. Stress condition has a wide range of effects on the plant morphology, physiology, biochemistry and even on gene regulation. Temperature, water deficiency, salinity and heavy metal pollutant are major stress factors in relation to climate change. The abiotic stress factors also influence the biotic stress and reduce crop productivity. The major effect of these stresses result loss of soil microbial diversity, soil fertility and competition for nutrient resources (Chodak et al., 2015).

Only the possible alternatives is plant associated microbial community, such as mycorrhizal fungi and plant growth promoting bacteria (PGPB), which helps the plants growth and development under different types of abiotic and biotic stresses. The application of efficient microorganisms like plant growth promoting rhizobacteria (PGPR) and mycorrhizal fungi are helpful in enhancing and improving sustainable agriculture and environmental stability. Microbes associated with plants, on the basis their effects on plants are classified into three groups: beneficial, deleterious and neuter. Various genera of

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Pseudomonas, *Enterobacter*, *Bacillus*, *Variovorax, Klebsiella*, *Burkholderia*, *Azospirillum*, *Serratia,* and *Azotobacter* are termed as PGPR which promote plant growth and development under both normal and stress condition. However, most of plant growth promoting microbes (PGPM) and arbuscular mycorrhizae (AM) are unable to tolerate drought, salinity, and heavy metal stress. So, it is a very challenging task for the farmers as well as the scientists to develop biofertilizers which are applicable in such prevailing condition. The PGPM and mycorrhizae, maintains plant fitness and health under abiotic and biotic stress environment (Vimal et al., 2017). The future challenge lies how to develop such a biofertilizers which are applicable in all these stress conditions. However, some of them have the potential to tolerate these stresses and promote plant growth and development. These stress tolerant microbes have a different mechanism to overcome the harsh conditions and also consolidate plants. However, a novel approaches are needed in order to explore plant-microbe interaction to control plant growth and disease resistance under sustainable agriculture (Finkel et al., 2017). Overall, the plant associated beneficial microbes enhance the efficiency of their growth and development under abiotic and biotic stress condition. In this review, we have attempted to explore the beneficial effect of stress tolerant microbes and their modes of action to enhance the sustainable agricultural production.

1.1. Plant–microbe interactions: PGPM assisting stress tolerance

Plant growth and survival under adverse conditions may enhance by the application of stress tolerant PGPM and AM fungi (Nadeem et al., 2014). Indirect and direct mechanisms were used by microbes to promote plant growth and development during stress conditions. Different biochemical and molecular mechanisms are used by microbes to promote growth and development. For example, inoculation with PGPM, promote plant growth by regulating hormonal and nutritional balance, producing plant growth regulator and inducing resistance against phytopathogens (Spence and Bais, 2015). PGPM produce certain metabolites which reduced pathogen population around plant surrounding. For example, Siderophore produced by these microbes in rhizosphere reduced iron availability to certain pathogens and resulted in reduced their growth (Złoch et al., 2016). Further they also facilitate plant growth by fixing atmospheric nitrogen, solubilize phosphate and producing plant hormones (Ahmad et al., 2011). Some other mechanisms include nutrient mobilization, production of exopolysaccharide, rhizobitoxine, etc. (Vardharajula et al., 2011) that help the plant to cope up the unfavourable environment. Rhizobitoxine promote plant growth and development under stress condition by inhibiting ethylene production (Kumar et al., 2009). Besides these, microbes may have the ability to enhance plant growth and development by key enzymes such as ACC-deaminase, chitinase, and glucanase under stress condition (Farooq et al., 2009). In addition, some bacteria have sigma factors to change gene expression under adverse condition to overcome negative effect (Gupta et al., 2013). In addition to PGPM, the interaction of fungi with the root of the higher plant is also another important aspect of growth and development. Most commonly presence of mycorrhizae in agricultural field is AM. These fungi play an important role in nutrient cycling, absorption and translocation of nutrients. These mechanisms of microbes help the plant to maintain its actual growth under stress environment by mitigating the negative impact of stress on plant growth and development. So, the PGPM were found to be a potential substitute for inorganic fertilizers and pesticides. Therefore, the plant-microbe interaction may be important for sustainable agriculture and future food security concern. The plant growth promoting bacteria *Bacillus* and *Paenibacillus* promote plant growth and health in three different ways such as promotion of host plant nutrition and growth, antagonism against pathogens and stimulate defence mechanism and promote sustainable agriculture (Govindasamy et al., 2010). The sustainable agriculture practice with application of stress tolerant PGPM may be enhance the yields and nutritional quality of food grains under changing climate as well as saving of 20–25% cast of chemical fertilizers and pesticides. Using of these practices by the farmers can be enhanced the financial income with production of organic foods and vegetables.

2. Abiotic stress

2.1. Drought and its impact on crop productivity

Drought is recognized as serious environmental stress that attracted the attention of environmentalists and agricultural scientists. It is a major agriculture problem worldwide, limiting plant growth and productivity. Almost all of major agriculture land world are affected by drought stress. It produces wide variety of implication in human society, including economy (Disante et al., 2011; Mishra and Singh 2010). Drought stress affects various growth parameters and stress responsive gene during stress condition. Limited water content reduces cell size, membrane integrity, produce reactive oxygen species and promote leaf senescence that lead to decreased crop productivity (Tiwari et al., 2015). Despite it, during water deficient condition plants undergo a series of physiological and molecular change, such as increase ethylene production, change in chlorophyll content, damage photosynthesis apparatus and inhibit photosynthesis (Lata and Prasad, 2011). In addition, drought stress results in accumulation of free radicals that induce change in membrane function, protein conformation, lipid peroxidation and finally cell death (Tiwari et al., 2016). The frequency and intensity of drought is supposed to increase in coming future due to impact of climate change.

2.1.1. Mechanism of drought stress tolerance

Drought stress tolerant microbes have ability to enhance plant growth and development under water deficient condition. Microbes have evolved, adapt and/or develop a tolerance mechanism to survive under low water potential (Table 1). They may form thick wall or enter dormant stage, can accumulate osmolytes, produce exopolysaccharides (EPS). These plant associated microbes have various mechanisms to cope up negative impact of drought on plant as well as on soil. Irrespective of water content, they provide nutrient and better environment condition for the continuous growth of plants. The beneficial microbes colonized around rhizosphere, promote plant growth and development through various direct and indirect mechanisms. The potential mechanism includes (1) production of phytohormones such as indole-3-acetic acid (IAA), cytokinins and abscisic acid (ABA) (2) Bacterial exopolysaccharides (3) ACC deaminase (4) induced systemic tolerance. Phytohormones produced by plant play crucial role in growth and development (Farooq et al., 2009; Porcel et al., 2014). In addition, PGPR have ability to synthesize plant hormones that stimulate plant growth and division under stress condition. IAA, a most active auxin that regulates the vascular tissue differentiation, adventitious and lateral root differentiation, cell division and shoot growth during drought stress (Goswami et al., 2015). The ABA is an important growth regulator during drought stress. When seed or plant is inoculated with PGPR, the concentration of ABA increases and regulates physiology of plants to tolerate drought stress. ABA amelorates drought stress via regulating transcription of drought related gene and root hydraulic conductivity (Jiang et al., 2013). For example, *Azospirillum brasilense* ameliorates the response of *Arabidopsis thaliana* to drought mainly via enhancement of ABA levels (Cohen et al., 2015) (Table 1). The 1-Aminocyclopropane-1-carboxylate (ACC) is immediate precursor of ethylene during stresses. Bacterial ACC deaminase hydrolyzes ACC into ammonia and alpha-ketobutyrate (Bal et al., 2013). Drought stress tolerant and PGPR increase biomass, water potential, decreasing water loss in maize plant under stress condition. These inoculants decrease antioxidant activity and also enhance production of proline, free amino acid, and sugar in plants (Vardharajula et al., 2011). Under water deficient condition the chlorophyll content decreases and reduces photosynthesis in soybean

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