Microbiological Research 206 (2018) 131–140

Contents lists available at ScienceDirect

Microbiological Research

journal homepage: www.elsevier.com/locate/micres

Review

Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture

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ARTICLE INFO

Keywords:
Agriculture
Biofertilization
Nano-encapsulation
PGPR
Revitalization
Sustainable development

ABSTRACT

The progression of life in all forms is not only dependent on agricultural and food security but also on the soil characteristics. The dynamic nature of soil is a direct manifestation of soil microbes, bio-mineralization, and synergistic co-evolution with plants. With the increase in world's population the demand for agriculture yield has increased tremendously and thereby leading to large scale production of chemical fertilizers. Since the use of fertilizers and pesticides in the agricultural fields have caused degradation of soil quality and fertility, thus the expansion of agricultural land with fertile soil is near impossible, hence researchers and scientists have sifted their attention for a safer and productive means of agricultural practices. Plant growth promoting rhizobacteria (PGPR) has been functioning as a co-evolution between plants and microbes showing antagonistic and synergistic interactions with microorganisms and the soil. Microbial revitalization using plant growth promoters had been achieved through direct and indirect approaches like bio-fertilization, invigorating root growth, rhizoremediation, disease resistance etc. Although, there are a wide variety of PGPR and its allies, their role and usages for sustainable agriculture remains controversial and restricted. There is also variability in the performance of PGPR that may be due to various environmental factors that might affect their growth and proliferation in the plants. These gaps and limitations can be addressed through use of modern approaches and techniques such as nano-encapsulation and micro-encapsulation along with exploring multidisciplinary research that combines applications in biotechnology, nanotechnology, agro biotechnology, chemical engineering and material science and bringing together different ecological and functional biological approaches to provide new formulations and opportunities with immense potential.

1. Introduction

Agriculture has been the largest financial source since the dawn of civilization. About 7.41 billion people inhabit the earth, occupying 6.38 billion hectares of earth surface, of which 1.3 billion people are directly dependent on agriculture. For sustainable agriculture maintenance soil dynamic nature is of prime importance (Paustian et al., 2016; Tscharntke et al., 2012). Agriculture Organization of the United Nations (FAO) Food Balance Sheet 2004 shows that 99.7% of food for the earth's population comes from the terrestrial environment alone. As 79 million people are added to the world's population every year, there has been a continuous increase in the demand for food, and a simultaneous scarcity in supply (Alexandratos and Bruinsma, 2003). In India, 60.6% of land is used for agricultural purposes by half of its population to grow several forms of cereals, vegetables, and pulses. Agricultural productivity, water quality, and climate change are greatly influenced by the exchange of nutrients, energy, and carbon between soil organic matter, the soil environment, the aquatic ecosystem, and the atmosphere (Lehmann and Kleber, 2015). Soil content is regulated by a number of aspects, such as organic carbon content, moisture, nitrogen, phosphorous, and potassium content, and other biotic and abiotic factors. However, indiscriminate use of fertilizers, particularly nitrogen and phosphorus, has led to substantial pollution of soil by reducing pH and exchangeable bases; thus, making these nutrients unavailable to crops leading to loss of productivity (Gupta et al., 2015). According to the FAO, 38.47% of the world's land area is covered by agricultural

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http://dx.doi.org/10.1016/j.micres.2017.08.016
Received 18 April 2017; Received in revised form 20 July 2017; Accepted 5 August 2017
Available online 17 October 2017
0944-5013/

land, and although 28.43% of the land is arable, only 3.13% is permanently used for crop production. The situation is further detoriated as 20–25% of land worldwide is being degraded every year and another 5–10 Mha, will be degraded each year (Abhilash et al., 2016).

As expanding agricultural land is near impossible, the unprecedented demand places serious pressure on the terrestrial ecosystem for over-production. Hence, a more scientific and improved farming technique is necessary for fulfilling the increasing demands and also maintain the fertility of the soil. Some of the current techniques involved in sustainable agriculture are sustainable management practices (Ubertino et al., 2016), agricultural intensification (Shrestha, 2016), genetically engineered crops to form nitrogen-fixing symbioses, fixing nitrogen without microbial symbionts (Mus et al., 2016; Passari et al., 2016), use of microbes or genetically engineered microbes to promote plant growth (Perez et al., 2016; Kumar, 2016) and use of biofertilizers (Suhag, 2016; Kamkar, 2016). In addition, many other socio-economic and scientific techniques that contribute towards sustainable development of agriculture include disease resistance, salt tolerance, drought tolerance, heavy metal stress tolerance, and better nutritional value. Use of soil microorganisms, such as bacteria, fungi, and algae, is one possible way to fulfill these desired goals (Vejan et al., 2016).

Microbes and leguminous plants in holobiant relationships through bio-mineralization and synergistic co-evolution have great potential for improving soil quality and fertility (Paredes and Lebeis, 2016; Rosenberg and Rosenberg, 2016; Agler et al., 2016). Co-evolution of soil microbes with plants is vital to respond to extreme abiotic environments, resulting in improved economic viability, soil fecundity, and environmental sustainability (Khan et al., 2016; Compant et al., 2016). Association of plants with microbes can be best explained by plant growth promoting rhizobacteria (PGPR), which show antagonistic and synergistic interactions resulting enrichment of plant growth (Rout and Callaway, 2012; Bhardwaj et al., 2014). PGPR greatly affect soil characteristics and play a vital role converting barren, poor quality land into cultivable land. Revitalization of soil quality and plants growth by PGPR had been an area actively exploited for enhanced agriculture productivity in many parts of the world (Gabriela et al., 2015). This is generally achieved through direct or indirect approaches. The direct approach involves providing the plant directly with compounds that promote plant growth. This approach is achieved through techniques such as bio-fertilization, rhizo-remediation, and plant stress control (Goswami et al., 2016). Absorption of water and nutrients from the soil is the most common environmental factor constraining growth of terrestrial plant species. PGPR as bio-fertilization improves plant growth by increasing the accessibility or uptake of nutrients from a limited soil nutrient pool. Neutralizing plant stress is another important effect of PGPR and applies to both biotic and abiotic stress. Biotic stress is a biological threat (insects, disease), whereas abiotic stress is in the form of physical (light, temperature, etc.) or chemical stress that the environment inflicts on a plant (Gabriela et al., 2015). PGPR are also indirectly involved in promoting plant growth by lessening or preventing the deleterious effects of one or more phyto-pathogenic organisms. In this case, plant growth is promoted by antibiosis, induction of systemic resistance (ISR), and competitive exclusion (Tripathi et al., 2012).

Although reports on enhancement of plants growth through PGPR are widely available, there had been paucity of information between the potential uses of PGPR for sustainable development and their present applications. Use of PGPR's area also seriously limited due to variability and inconsistency of result observed under laboratory, green house and field trails. These gaps can be filled using modern nano-biotechnological approaches and use of techniques such as nano-encapsulation and micro-encapsulation. This review highlights some of the approaches that can be adapted to implement PGPR as a tool to combat plant diseases and enhance agricultural productivity.

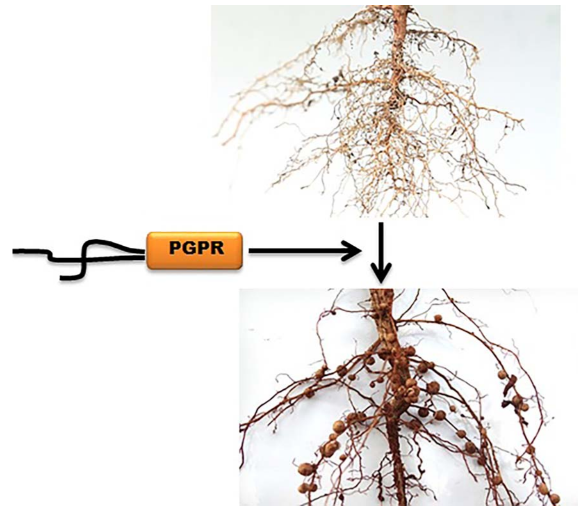

Fig. 1. Location of the plant growth promoting rhizobacteria in plant roots.

2. Plant growth promoting rhizobacteria

Plants have always been in a symbiotic relationship with soil microbes (bacteria and fungus) during their growth and development. The symbiotic free-living soil microorganisms inhabiting the rhizosphere of many plant species and have diverse beneficial effects on the host plant (Raza et al., 2016a,b) through different mechanisms such as nitrogen fixation and nodulation are generally referred to as Plant Growth Promoting Rhizobacteria (PGPR) (Fig. 1). They tend to defend the health of plants in an eco-friendly manner (Akhtar et al., 2012). PGPR and their interactions with plants are exploited commercially and have scientific applications for sustainable agriculture (Gonzalez et al., 2015). Applications of these associations have been investigated in oat, canola, soy, potato, maize, peas, tomato, lentil, barley, wheat, radicchio, and cucumber (Gray and Smith, 2005).

PGPR are involved in various biotic activities of the soil ecosystem to make it dynamic for turnover and sustainable for crop production (Gupta et al., 2015). They competitively colonize plant roots system and enhance plant growth by different mechanisms, including phosphate solubilization (Ahemad and Khan, 2012) nitrogen fixation (Glick, 2012), production of indole-3-acetic acid (IAA), siderophores (Jahanian et al., 2012), 1-amino-cyclopropane-1-carboxylate (ACC) deaminase, and hydrogen cyanate (Liu et al., 2016); degradation of environmental pollutants, and production of hormones and antibiotics or lytic enzymes (Xie et al., 2016). In addition, some PGPR may also infer more specific plant growth-promoting traits, such as heavy metal detoxifying activities, salinity tolerance, and biological control of phytopathogens and insects (Egamberdieva and Lugtenberg, 2014).

2.1. Rhizosphere

Rhizosphere also known as the microbe storehouse is the soil zone surrounding the plant roots where the biological and chemical features of the soil are influenced by the roots. Bacteria in the rhizosphere may be symbiotic or non-symbiotic, which is determined by whether their mode of action is directly beneficial to the plant or not (Kundan et al., 2015). The root system, which serves as anchorage and for uptake of water and nutrients, is a chemical factory where phenolic compounds are synthesized and released to simultaneously arbitrate numerous underground interactions. The compounds released by plant roots act as chemical attractants for a huge number of heterogeneous microbial communities. The composition of these compounds depends upon the physiological status and species of plants and microorganisms (Kang et al., 2010).

Three different components make up the rhizosphere: the