Journal of Natural Resource Conservation and Management
Vol. 2, No. 1, pp 32-42, 2021
doi: 10.51396/ANRCM.2.1.2021.32-42

Plant Growth Promoting Endophytic Bacteria for management of stresses in cereal crop productions

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Received : March 30, 2021
Revised : June 11, 2021
Accepted : June 20, 2021
Published : June 30, 2021

ABSTRACT

Agriculture of the future, which will be challenged by rising global food demand, a scarcity of arable lands and resources, as well as numerous environmental challenges, will need to be handled wisely using sustainable and eco-efficient methods. Cereals are the most essential crops for human nourishment, and they have a wide range of bacteria linked with them. The use of beneficial, plant-associated microbes to improve crop production in agriculture is a long-term strategy. Bacterial endophytes are endosymbiotic bacteria that live in plants, modulate phytohormone signaling, metabolic activity, and plant defense response pathways in their host plant. The application of agricultural techniques that preserve the natural variety of plant endophytic bacteria has emerged as a critical component of sustainable agriculture, ensuring plant production and agricultural quality, and plant response to abiotic and biotic stressors. Hence, using endophytic bacteria to increase cereal crop's performance under stressful circumstances such as cold, drought, salt, and heavy metal pollution, or to boost disease resistance, holds a lot of promise for long-term agricultural productivity.

Keywords: Abiotic, Biotic, Cereals, Endophytic bacteria, PGP, Stress tolerance.

INTRODUCTION

Global food demand is quickly rising, especially in emerging countries where agricultural lands and resources are insufficient to support the efficient crop production required to fulfill such a pressing need for food. Crops generally face an increasing number of abiotic and biotic stress combinations as a result of global warming and possible climatic anomalies, which adversely influence their growth and production (Narsai *et al.*, 2013; Suzuki *et al.*, 2014., Pandey *et al.*, 2015; Santoyo *et al.*, 2017). Cereals, for example, wheat, rice, maize, and sorghum are the most essential crops for the human diet. In a world where the population and need for food are growing, it is critical to assure high crop yields to meet current and near-future demands while also mitigating the effects of climate change. In recent decades, plant scientists and agronomists have boosted crop output through breeding programs and agronomic methods such as high-efficiency irrigation systems and ambient-controlled greenhouses. Advances in whole genome sequencing have enhanced breeding programs and allowed for the discovery of genomic variants in wild crop relatives, allowing for the identification of environmentally adapted and climate-resistant crops (Varshney *et al.*, 2011; Bansal *et al.*, 2013). This method, however, is limited to species that have a high-quality reference genome sequence and wild related populations that thrive in a variety of conditions (Henry, 2014), in addition to the technological challenges, which are labor-intensive, expensive, and unwelcomed by customers. Agro-biosystems that include the whole agroecosystem biochemical diversity and their ability to buffer the negative consequences of poor soil fertility, abiotic stress, pathogens, and pests are needed to increase agricultural productivity sustainably (Tilman *et al.*, 2011; Timmusk *et al.*, 2017). Soil is a composite system that includes an extensive range of conditions with varying physical, chemical, and biological characteristics. It is one of the biggest reservoirs of microbial biomass and variety, serving as a reservoir for microbe recruitment and enrichment of root endophytic populations (Bulgarelli *et al.*, 2012; Yeoh *et al.*, 2017). Agricultural microbial biotechnology, which incorporates positive plant-microbe and microbiome interactions, might be a viable long-term option for increasing agricultural productivity (Timmusk *et al.*, 2017).

Abiotic and Biotic stresses

Plants are constantly subjected to biotic stresses produced by pathogens as well as unfavorable environmental circumstances such as soil salinity, drought, high temperatures, nutritional shortages, and heavy metal exposure in nature (De Coninck *et al.*, 2015; Antoniou *et al.*, 2017; Hacquard *et al.*, 2017) that reduce crop growth, development, and production across the world (Gontia-Mishra *et al.*, 2014).

Salinity

Salinity is a major hazard to agriculture, affecting about 10% and 25-30% of total arable and irrigated areas, respectively (Aquastat, 2016; Shahid *et al.*, 2018). It has an impact on not just crop yield but also soil stability and characteristics. Salinity is predicted to affect approximately 27% of the world's arable land, or one-third of all arable land (Al Omron *et al.*, 2012). Salt stress is harmful to plant growth because it causes osmotic and ionic stress in plants, which results in decreased water absorption, transpiration, photosynthesis, and ionic homeostasis disruption (Kaushal, 2020). Furthermore, high levels of reactive oxygen species (ROS) lead to oxidative stress, which damages DNA, proteins, and membranes (Liu *et al.*, 2017). Saline soil hinders crops from growing normally, resulting in low crop yields or even crop failure (Sagar *et al.*, 2020; Yadav *et al.*, 2019). Plants' growth and development are influenced by the quality of the soil, its nutritional content, and its physicochemical qualities (Majeed *et al.*, 2018). The usual techniques of amelioration of soil salinity *i.e.*, the cultivation of salt-tolerant crops (Nia *et al.*, 2012), plant breeding, soil scraping, and chemical leaching of excess salts by adding gypsum, calcium chloride, and other chemicals have had some success, but these have detrimental consequences for soil health (Egamberdieva *et al.*, 2019) and developing countries are unable to implement these strategies (Cantrell and Linderman 2001).

Drought

Climate change-induced water scarcity poses a serious agricultural hazard, limiting crop growth and production, and hence food security. Droughts and high heat have lowered worldwide cereal output by 9-10% in recent decades, with this phenomenon linked to a decrease in both harvested area and yields (Lesk *et al.* 2016). During droughts that occurred in the last few decades, the harvested area decreased by more than 5% (Lesk *et al.* 2016), highlighting the present continuous depletion of agricultural soil. Drought stress changes rhizosphere physicochemical and biological characteristics that influence soil microbial activity and agricultural yield (Vurukonda *et al.*, 2016). Drought stress also lowers chlorophyll concentration due to pigment photo-oxidation generated by an oxidative burst caused by an excess of ROS (Farooq *et al.*, 2009), which impacts protein and lipid peroxidation, compromising membrane integrity and stability (Mittler, 2002; Moran *et al.*, 1994). The stomatal closure, which increases incoming radiation relative to available intracellular CO_2, causes a ROS burst driven by water shortage, interrupting the rate of electron generation (Murata *et al.*, 2008). As a result, as drought-induced stomata shut, photosynthesis, gas exchange, and water usage are all affected, resulting in a reduction in leaf expansion and, plant growth and yield.

Heavy Metal Pollution

The anthropogenic heavy metal build-up, such as that caused by industrialization or contemporary farming methods, produces a wide range of human health, environmental, and agricultural issues (Emamverdian *et al.*, 2015). The concentration of heavy metals in soil is determined by the composition and character of the bedrock; but, in agricultural soils, the concentration of these elements may be raised by adding various types of substances that contain them in varying proportions.As a result, heavy metal might be extracted by plants, posing a severe threat to agricultural yield and quality

(Keunen *et al.*, 2011). To deal with heavy metal toxicity, plants have evolved a variety of physiologic, metabolic, and genetic defensive mechanisms. These methods are largely aimed at preventing heavy metal absorption into plant roots by limiting metal uptake from the soil (Patra *et al.*, 2004; Dalvi and Bhalerao, 2013). Low-molecular-weight organic acids from root exudates, for example, may function as chelating agents to prevent plants from absorbing heavy metals (Montiel-Rozas *et al.*, 2016). Furthermore, if heavy metals can penetrate plant tissues, detoxification and antioxidant defense mechanisms are triggered (Manara, 2012). Despite these defense systems, most plant species experience poor growth and production when exposed to high levels of heavy metals. This issue can be solved with the help of microbes (Burd *et al.*, 2000; Ma *et al.*, 2011).

Temperature

Global climate change affects the present and future mean temperatures, as well as the possibility of severe weather events such as periods of intense heat and frost. Heat and cold shocks are physical shocks that impact plant growth and production by directly altering molecular (DNA and proteins) and supramolecular (membranes and chromosomes) structures (Ruelland, and Zachowski, 2010; Knight, and Knight, 2012). Excessive production of ROS, which primes to oxidative stress (Hasanuzzaman *et al.*, 2013; Ritonga and Chen, 2020), causes damage to membranes, pigments, proteins, and nucleic acids, and therefore impairs plant growth and improvement(Xu *et al.*, 2006; Adam and Murthy, 2014), is one of the main effects of heat and cold stress. Heat and cold stress, like other forms of abiotic stress, change chlorophyll production and photosynthesis because both stressors have a major effect on chloroplast metabolism and structure. For example, heat stress disrupts the structural structure of thylakoids and promotes grana stacking loss and swelling (Ashraf and Hafeez, 2004; Rodríguez *et al.*, 2005). Whereas, low temperatures cause changes in the photosynthetic apparatus' structure, resulting in a reduction in the number of functional PS II reaction centers, the loss of light-harvesting Chl, and the development of a large thylakoid protein complex implicated in LHC II, PS II, and PS I (Savitch *et al.*, 2002; Ensminger *et al.*, 2006). Even brief periods of both forms of stress can significantly diminish crop output (Nievola *et al.*, 2017). Heat and cold responses in plants include alterations at the molecular, physiological, and cellular levels. Plants create suitable solutes, antioxidants, and osmoprotectants chemicals, among other things, to organize and protect proteins and cellular structures, as well as to maintain cell turgor by osmotic adjustment (Ritonga and Chen, 2020; Janska *et al.*, 2010; Julca *et al.*, 2012; Zhu *et al.*, 2016). Furthermore, cold and heat stress can cause plants to absorb less water owing to a reduction in their water potential, which can lead to dehydration (Nievola *et al.*, 2017; Levitt, 1980).

Biotic stress

Several pathogenic diseases instigated by fungi, bacteria, viruses, and nematodes are important biotic restraints that result in reduced crop development and yield outputs (Majeed *et al.*, 2018). Plant diseases are a persistent and serious danger to the world food supply, with estimates of 20 to 30 percent global crop losses, mostly in food-insecure countries (Savary *et al.*, 2019). Pesticide usage, resistance gene breeding, and genetic modification of plant immune components have all aided in reducing the threat (Vannier *et al.*, 2019). However, high pesticide intake raises economic, environmental, and safety problems. Therefore, antibiotic microorganisms are a feasible alternative that is becoming more acceptable. Microbial products and inoculants for plant protection have lately received interest in this area, owing to significant efforts to systematically extract, identify, and describe plant-associated microorganisms that interact closely with healthy plants (Finkel *et al.*, 2017).

Sustainable methods, such as the use of plant beneficial microbes, are becoming more essential because of these disadvantages. Plant growth-promoting bacteria (PGPB) may be effectively managed in the agro-farming system as alternative techniques to minimize most of the biotic and abiotic stresses that crop experience and to enhance their yields, resulting in the usage of synthetic fertilizers being reduced to a minimum (Majeed *et al.*, 2018).

Plant Growth Promoting Endophytic Bacteria

Plant-beneficial bacteria are a type of bacteria that assist their host plants to cope with a variety of biotic and abiotic stressors that might inhibit their growth (Miliute *et al.*, 2015) (Table 1).

In their host plant, these bacteria may survive both outwardly and inside. Bacteria that reside

Table 1. List of reported endophytic bacterial strains isolated from cereal crops to alleviate various abiotic stresses.

Cereal crops	Endophytic Bacteria	Stress Management	References
Barley (*Hordeum vulgare L.*)	*Hartmannibacter diazotrophicus*	Salinity	Suarez *et al.* (2015)
Maize (*Zea mays L.*)	*Azospirillum lipoferum* *Alcaligenes faecalis* *Azospirillum brasilense* *Herbaspirillum seropedicae* *Bacillus phytofirmans* *Enterobacter* sp.	Drought	Cohen *et al.* (2009) Naseem and Bano (2014) Cura *et al.* (2017) Naveed *et al.* (2014)
	Rhizobium, *Pseudomonas*, *Bacillus* sp., *Arthrobacter pascens*	Salinity	Bano and Fatima (2009) Ullah and Bano (2015)
Rice (*Oryza sativa L.*)	*Bacillus amyloliquefaciens,* *Pseudomonas alcaligenes,* *Pseudomonas pseudoalcaligenes* *Pseudomonas pseudoalcaligenes* *Bacillus pumilus*	Salinity	Chauhan *et al.* (2019) Nautiyal *et al.* (2013) Rangarajan *et al.* (2002) Jha and Subramanian (2014)
Sorghum (*Sorghum bicolor*)	*Pseudomonas brassicacearum*	Salinity	Gamalero *et al.* (2020)
Wheat (*Triticum aestivum L.*)	*Pseudomonas pseudoalcaligenes,* *Bacillus amyloliquefaciens,* *Azotobacter vinellandii,* *Bacillus pumilus, Burkholderia* sp. *Curtobacterium albidum,* *Sphingomonas pokkalii* sp. *Serratia* sp. *Klebsiella* sp.	Salinity	Jha and Subramanian (2014) Nautiyal *et al.* (2013) Sahoo *et al.* (2014) Khan *et al.* (2016) Sarkar *et al.* (2018) Vimal *et al.* (2019) Palaniyandi *et al.* (2014) Ansari *et al.* (2019) Singh and Jha (2016) Singh *et al.* (2015)
	Azospirillum brasilense, *Bacillus amyloliquefaciens* *Piriformospora indica* *Pseudomonas putida* *Pantoea theicola*	Drought	Kasim *et al.* (2013) Yaghoubian *et al.* (2014) Ali *et al.* (2011) Chen *et al.* (2017)

outside of their host plants are categorized as either epiphytic (living on the plant's leaf surfaces) or rhizospheric (living in the soil's plant roots) (Compant *et al.*, 2010). Whereas, endophytic bacteria are bacteria that live and grow inside their host plant (Hardoim *et al.*, 2008). All of these bacteria have several features that aid in the development of the host plant (Compant *et al.*, 2010). Endophytic bacteria are bacteria isolated from surface-sterilized plant tissues that do not damage their host plants (Santoyo *et al.*, 2016). Endophytic bacteria can not only assist the host plant to develop but also help it to tolerate stress and create allelopathic effects on competing plant species (Cipollini *et al.*, 2012; Mei and Flinn, 2010; Rosenblueth and Martönez-Romero, 2006). As a result, they help their host survive biotic and abiotic threats, as well as competition from other organisms. Endophytic bacteria have been found to enhance the development of plants such as wheat, rice, canola, potato, tomato, and many others, according to several studies (Mei and Flinn, 2010; Sturz and Nowak, 2000). Bacterial endophytes may have an advantage over bacteria in the rhizosphere because residing within a plant's tissues allows them to remain in constant touch with the plant's cells. Bacteria in the rhizosphere, on the other hand, may be able to penetrate and colonize plant roots (Santoyo *et al.*, 2016). According to recent estimates, the world has over 300,000 plant species, the great majority of which include endophytes (Smith *et al.*, 2008). Microbial endophytes have been discovered in all of the plant species studied. An endophyte-free plant is a rare exception to what is normally seen in nature, according to Partida-Martinez and Heil (2011).

Host plant growth promotion mechanisms

The impact of endophytic bacteria on plant health and growth has received a lot of attention (Compant *et al.* 2019). Endophytic bacteria have been proven to have many positive impacts on their plant hosts, both directly and indirectly (Figure 1). They can help plants grow better under normal and stressed conditions by assisting them in getting nutrients (by biological N_2 fixation) and solubilizing minerals (*e.g.* P, K, and Fe). They can also help plants grow better by modulating growth-related hormones (*i.e.* producing indole acetic acid, gibberellin, cytokinins, and 1-aminocyclopropane-1-carboxylate deaminase). Endophytic bacteria indirectly improve plant growth by discouraging phytopathogens through mechanisms such as antibiotic and lytic enzyme production, nutrient unavailability for pathogens, and priming plant defense mechanisms, thereby protecting the plants from future pathogen attacks and increasing plant tolerance to abiotic stresses (Miliute *et al.*, 2015; Etalo *et al.*, 2018).

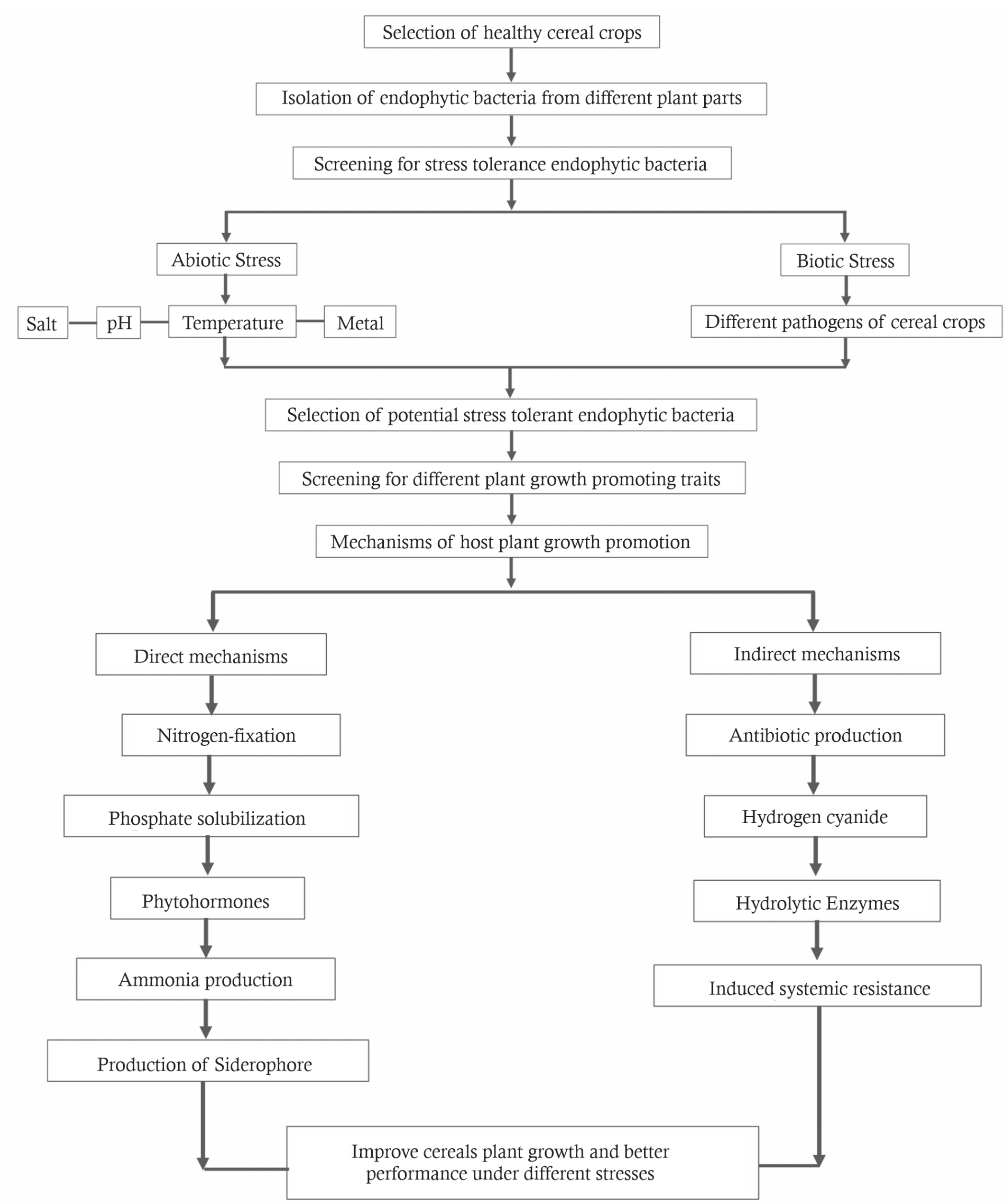

Fig. 1. Mechanism of plant growth-promoting endophytic bacteria to improve cereal crops growth under abiotic and biotic stresses

A plant without endophytes would be less able to cope with infections and more vulnerable to environmental stress conditions, according to findings of rhizospheric PGPB distribution in nature (Timmusk *et al.*, 2011). Plant-endophyte interactions are thought to be over 400 million years old, and they have proven to be so successful that plants still interact with and even require endophytes to thrive in harsh environments (Rodriguez and Redman 2008). Vertical seeding or horizontal transfer of endophytic microorganisms from the soil to the plants are two ways endophytic bacteria can enter and colonize plants. Plant-microbe interactions continue to provide mutualistic advantages in either case (Verma and White, 2018; Huang *et al.*, 2016). Endophytic microorganisms can provide the following benefits to their plant host as a result of this extremely advantageous mutualistic interaction: They boost the nutrients accessible to the plant host, function as protective defenders against diseases and destructive pests, improve the plant's capacity to endure or tolerate environmental stressors, aid in the modulation of their plant host's development, and can also help with weed growth (Irizarry and White, 2018; Verma *et al.*, 2018; 2017). In reality, plants have the potential to "choose" as endophytes those bacteria that offer them some advantage from their plant-associated microbial communities, whether aboveground or belowground.

Plants are connected with bacteria that promote stress resistance systems under stressful situations, according to research (Marasco *et al.*, 2012; Santoyo *et al.*, 2016). Endophytes have been presented as a potential alternative to the indiscriminate use of agrochemicals because of these positive interactions between microorganisms and plants. Pests are not eliminated even with the use of agrochemicals, and yearly worldwide pest-induced agricultural losses continue to be up to 25% of overall production, in addition to causing disease resistance and environmental pollution (Lugtenberg, 2015). In comparison to the soil or the rhizosphere, the endophytic habitat provides a protected environment, giving bacteria capable of colonizing it an ecological advantage (Downie 2010; Berendsen et al. 2012). Bacteria within the host have access to a lot of resources, have little competition, and are protected from external stress, and in certain circumstances, this lifestyle allows their spread by passive transfer (Compant et al. 2020; Badri et al. 2009). Similarly, living in plant tissues allows these bacteria to interact directly with their hosts, thereby altering plant phenotypic (Downie 2010).

The positive effects of the endophytic microbiome have long been used for human benefit through the use of bacteria on crops to increase yields (Compant *et al.* 2019). Wounds and natural breaks, such as the zones of the emergence of the lateral roots and the root cap, are used to get access to the plant tissues (Knief *et al.* 2011; Spaepen 2015). Instead, active mechanisms involving endoglucanase and pectinolytic enzymes that macerate plant cell wall polymers locally have been reported (Reinhold-Hurek et al. 2006; Compant et al. 2005). Endophytic bacteria are thought to generate lower amounts of these enzymes than phytopathogens, preventing plant defenses from being triggered (Elbeltagy et al. 2000; Afzal et al. 2019). Endophytic bacteria can colonize the plant systemically by being carried by xylem channels, or they can colonize a particular tissue by colonizing the intercellular gaps (Reinhold-Hurek and Hurek 1998; Spaepen 2015). PGPB may be successfully managed in the agro-farming system as alternative methods to regulate most of the abiotic stressors that crop experience and to enhance their yields, resulting in the usage of synthetic fertilizers being reduced to a minimum (Majeed *et al.*, 2018).

CONCLUSION

Endophytic bacteria found in plants have a lot of potential as biofertilizers and biopesticides. We demonstrated that there are several examples of promising outcomes in the literature, suggesting that endophytes can play an important role in limiting the damage induced by abiotic and biotic stressors. Although many of these bacteria have been found and can have a wide range of hosts, they rarely produce consistent results in the field. One cause for this is because we don't fully understand the intricate dynamics that govern plant-endophyte interactions. At the molecular level, we need to find out the intricacies that regulate the plant-endophyte interaction. More work has to be done to increase the efficacy of endophytic bacteria by developing effective formulations, administration procedures, and integrated approaches in cereal crops.

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