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PLANT GROWTH-PROMOTING RHIZOBACTERIA – BIOTECHNOLOGICAL TOOLS TO IMPROVE CEREAL YIELDS

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Ensuring food security for the world's growing population is a significant challenge for scientists. Efforts are constantly being made to solve this problem, including the use of expensive molecular engineering techniques, which are not always successful. A cost-effective and environmentally friendly biotechnological alternative would be the use of plant growth-promoting rhizobacteria, demonstrated by numerous studies to play many beneficial roles in improving plant traits, e.g. enhanced yields.

Keywords: plant growth-promoting rhizobacteria (PGPR), yield, environmentally friendly, low-cost

1. Introduction

Cereals like bread wheat (*Triticum aestivum*), maize (*Zea mays*) and rice (*Oryza sativa*) are fundamental and essential grain crops for both human and animal consumption. According to the Statista statistics site, in 2020-2021, maize production exceeded 1.12 billion metric tons, wheat 775.8 million metric tons and rice about 505 million metric tons [1]. Since the world's population is constantly growing, the need to increase cereal production is continuous. However, the increasing occurrence of biotic and abiotic stress factors in the environment constitutes a severe global threat to improving cereal yields [2, 3]. To alleviate the detrimental effects of yield loss, expensive genetic engineering techniques for crop improvement have been developed. The use of plant growth-promoting rhizobacteria (PGPR) could represent a low-cost and environmentally friendly alternative biotechnological option. These kinds of soil bacteria, first described by Kloepper and Schroth in 1978 [4], were isolated from the immediate vicinity of plants, that is, from the rhizosphere. Later, several beneficial effects of PGPR in stimulating plant growth were described [5–7].

Nowadays, the PGPR biotechnology is more and more frequently used in the management of biotic and abiotic stress factors for a wide range of crop species in order to reduce their damaging effects, which ultimately can cause important yield losses [6,7]. Understanding the mechanisms at the basis of the PGPR technology in alleviating biotic and abiotic stress-induced damage in crops could be essential to reduce subsequent crop yield losses. Exploiting the positive effects of plant-microbe interactions might provide multiple multi-pronged solutions to the global food crisis, reduce the amount of irrigation provided by fresh water as well as solve environmental stress concerns and maintain soil health.

2. The most common effects of PGPRs on plants

Over the last decade, versatile positive properties of PGPRs have been intensely documented. Dozens of articles highlight the importance of these rhizobacteria in the process of alleviating damage brought about by abiotic stress. A large number of different PGPR species, e.g. *Pseudomonas alcaligenes, P. mendocina, Bacillus polymyxa, B. pumilus* and *Mycobacterium phlei*, have been described to play a positive role in stimulating growth in various plant species as well as in the process of improving their tolerance of high temperatures and the salinity of many crops [6, 7]. Shrivastava and Kumar (2015) indicated that certain PGPR species can produce antioxidants, therefore, can be useful for reducing oxidative stress-induced damage to plants [6]. In-

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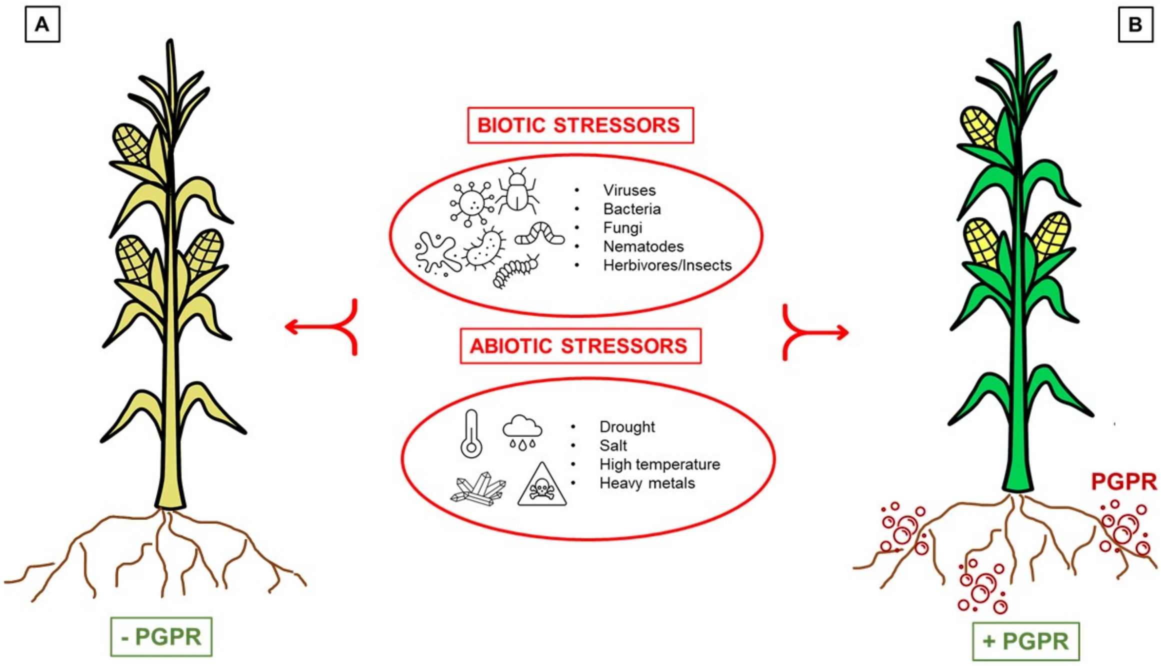

Figure 1: The impact of biotic and abiotic stress on crop resistance in the absence (panel A) and presence (panel B) of PGPR.

oculation with PGPRs improved seed germination and seedling growth, increased the concentrations of chlorophylls, antioxidant enzymes, proline, malondialdehyde and flavonoids as well as reduced the Na^+ content in different crops [8, 9]. Recently, a couple of authors documented a set of plant growth-promoting traits, namely the ability to solubilize phosphate as well as produce indole-3-acetic acid (IAA) and 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase of different PGPR species [7, 10, 11]. Furthermore, several physiological traits such as leaf chlorophyll content, stomatal conductance, leaf relative water content and membrane leakage adversely affected by cold stress were mitigated by PGPR [12].

In addition, certain PGPR species are important factors in relieving not only abiotic but also biotic stress-induced damage. Plants are commonly attacked by aphids and fungi, which cause substantial yield losses in crops and especially affect the production of cereal grains globally [3, 13, 14]. Naeem et al. (2018) showed the positive effect of *Bacillus* spp. and *Pseudomonas* spp. in terms of enhancing the productivity of wheat attacked by aphid populations [3]. Fungi represented by the genus *Fusarium* infest cereals worldwide, moreover, *F. graminearum* is responsible for cereal head blight and maize ear rot in North and South America, Europe as well as Asia [14, 15]. To reduce the considerable amount of destruction caused by *F. graminearum*, several authors propose the use of an effective, economical and environmentally friendly biotechnological tool. They demonstrate that different PGPR species have antagonistic effects on *F. graminearum* and possess the ability to promote wheat growth under adverse biotic and abiotic stress conditions as well [16, 17]. Fig. 1 illustrates the impact of biotic and abiotic stress on crop resistance in the absence and presence of PGPR.

Finally, PGPR species can also function as important components of biofertilizers and biopesticides since they can improve the nutrient content and quality of soil through the mechanisms of nitrogen fixation and phosph ate solubilization. As biopesticides, these rhizobacteria protect the plants as a result of their ability to synthesize antibiotics [18, 19]. Efforts to implement such environmentally friendly technologies are increasing annually and could be part of the solution to the ever-increasing demand for food to feed the growing global population .

3. PGPR mediates increases in cereal-crop yields

Biotic and abiotic stress factors usually cause a series of negative effects on crop yield, quantity and quality. Under adverse environmental conditions and exposed to multifarious pathogen attacks from viruses, bacteria, fungi, insects, etc., plants respond defensively, implying changes in several physiological and nutritional parameters, hormonal imbalances and important yield losses [7, 10, 18]. Globally, wheat, maize and rice are essential staple foods for billions of people. Annually, these cereals are grown on hundreds of millions of hectares of land and are consumed by several billion people in hundreds of countries. As a result of population growth, production must continuously be enhanced. Predictions state that by the year 2050, consumers will need 60% more wheat compared to the present production rate [20]. This must be

Table 1: Beneficial effects of some PGPR species on wheat, maize and rice yields

PGPR species	Effect on yield	Cereal species	Reference
Azospirillum sp. *Bacillus* sp. *Bacillus megaterium* *Paenibacillus polymyxa* *Raoultella terrigena*	Enhanced grain yield; Enhanced straw yield; Increased uptake of macro nutrients (N, P, K, Ca, Mg and S); Increased uptake of micro nutrients (Fe, Mn, Zn and Cu).	wheat	[12]
Bacillus sp. *Pseudomonas* spp.	Enhanced grain yield; Enhanced straw yield; Enhanced number of grains per spike; Enhanced number of productive tillers.	wheat	[3]
Alcaligenes faecalis *Bacillus aryabhattai* *Pseudomonas corrugat a* *Pseudomonas arsenicoxydans* *Pseudomonas brassicacearum* *Pseudomonas azotoformans*	Enhanced grain yield; Enhanced plant growth-promoting traits (shoot and root lengths, fresh and dry weights).	wheat	[21]
Bacillus pumilus *Bacillus safensis* *Lysinibacillus sphaericus* *Paenibacillus alvei*	Enhanced grain yield; Phosphate solubilization (except for *L. sphaericus*); Nitrogen fixation.	maize	[22]
Cupriavidus necator *Pseudomonas fluorescens*	Enhanced aerial biomass; Increase in N and P use efficienc ies.	maize	[23]
Azospirillum brasilense *Azotobacter chroococcum* *Pseudomonas aeruginosa* *Pseudomonas fluorescens* *Pseudomonas putida*	Enhanced grain yield; Enhanced IAA production; Enhanced phosphate solubilization.	rice	[24]
Bacillus sp. *Bacillus thuringiensis* *Pseudomonas mosselii*	Enhanced grain yield; Enhanced root and shoot biomasses; Enhanced production of IAA , siderophores and ACC deaminase as well as the ability to solubilize phosphate .	rice	[26]

achieved without expanding the area of arable land and by using eco-friendly and low-cost biotechnological strategies. One of these strategies is the use of PGPR to enhance crop productivity. Table 1 presents the impact and efficacy of different PGPR species in enhancing wheat, maize and rice yields [3, 12, 21–25].

4. Conclusions

The use of plant growth-promoting rhizobacteria to improve cereal yields represents a prosperous, environmentally friendly and economical strategy. PGPR are useful tools to reduce the effects of biotic and abiotic stress on plants, therefore, could contribute towards optimal plant growth and development as well as enhance their yields. Finally, PGPR could represent a resource to ease the emerging global food crisis.

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