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Utilization of Siderophore Producing Plant Growth Promoting Rhizobacteria to Improve Crucial Nourishment and Management of Phytopathogen in Cash Crops for Sustainable Development

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Abstract: *Sustainability in agricultural production is of great importance to meet the increasing demand for food and feed the growing world population. The use of plant growth-promoting rhizobacteria (PGPR) as an effective biofertilizer appears to be an ideal means of reducing global dependence on hazardous agrochemicals and improving food security. The microbial population that colonizes the rhizosphere includes bacteria, fungi, actinomycetes, protozoa, and algae. Free bacteria associated with the rhizosphere, beneficial for plant growth, generally include cyanobacteria of the genera All rhizobium, Azorhizobium, Bradyrhizobium, Mesorhizobium, Rhizobium and Sinorhizobium. Free nitrogen-fixing bacteria or associative nitrogen-fixing bacteria of the species Azospirillum, Enterobacter, Klebsiella, and Pseudomonas have been shown to adhere to the root and effectively colonize the root surface. In general, the promotion of plant growth and development can be facilitated in several ways: prevention of deleterious effects of phytopathogens by synthesis of biogenic chelating compounds such as siderophores, thereby increasing the production of plant hormones such as auxins, cytokinins, gibberellins, ethylene, antibiotics, volatile metabolites, enzymes, abscisic acid and solubilization of mineral phosphates and other nutrients have been reported for several bacterial genera PGPR. Therefore, this manuscript highlights the key mechanisms used by PGPR siderophore bacteria to facilitate plant growth by increasing the health and productivity of cultivated soils and the and Management of Phytopathogen in various cash Crops.*

Keywords: *Siderophore, PGPR, Management, Phytopathogen, Crop*

I. Introduction

The global need to increase agricultural productivity through dwindling land supplies has put a strain on the fragile agro-ecosystem. While the use of mineral fertilizers is considered the fastest and safest way to boost agricultural production, their cost and other restrictions discourage farmers from using them in recommended amounts. In recent years, concepts of Integrated Plant Nutrient Management (IPNM) and Integrated Plant Disease Management (IPDM) have been developed that aim to maintain and increase soil fertility by promoting plant growth and suppressing phytopathogens [1]. The rhizosphere is the most dynamic habitat on Earth and the main driver of ecosystem functioning and diversity. The dynamic interactions between rhizodeposits and microbial communities are important factors shaping the world of the rhizosphere. Root secretion plays a central role in determining the rhizosphere population. Root secretion includes a wide variety of chemical compounds secreted by the roots, ranging from the secretion of ions, free oxygen, water,

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enzymes, mucilages, primary and secondary carbon-containing metabolites, many aromatic compounds and actively metabolizing soil microbial communities. Plants exert beneficial, neutral, and harmful effects of intimacy with microbial partners. Rhizosphere microorganisms such as bacteria, fungi, nematodes, protozoa, algae, and micro-arthropods also play a critical role in the complex food web that takes advantage of a large amount of carbon captured by the plant and released into the rhizosphere. Root secretion plays a critical role in determining the symbiotic and protective associations between plant and soil microorganisms. The rhizosphere is also home to more than 8,000 species of fungi, which live in symbiosis or cause disease in plants have been described in the literature, for example, Agrobacterium tumefaciens, the causative agent of crown gall. Rhizoctonia solani is the most common pathogen and mainly causes soil fungal diseases in soybeans. The fungal soil pathogens mainly involved in crop loss in agriculture are Fusarium, Phytophthora, Pythium, and Rhizoctonia [2].

PGPR located near plant roots plays an important role in plant growth to increase crop/food yields to meet the ever-increasing food demand of a rapidly growing world population, which will reach nearly up to 9.7 billion by 2050. Therefore, the application of biological inputs and bio inoculants have been seen as sustainable approaches to increase soil organic matter, enzymes, and microbial populations, resulting in crop productivity. In this context, siderophore-producing microbes function as efficient PGPRs with multifunctional potential to promote plant growth [3-7] and suppress disease [2, 4]. Therefore, this paper emphasizes the main mechanisms involved by PGPR bacteria to facilitate plant growth to improve the health and productivity of cultivated soils and the management of phytopathogens in various crops.

Plant Growth Promoting Rhizobacteria (PGPR)

The term yield-enhancing bacteria (YIB) or PGPR has been used since 1974 in a broad sense and includes rhizobacteria that promote plant growth by releasing phytohormones directly, fixing nitrogen in the rhizosphere, dissolving insoluble forms of nutrients such as phosphate, promoting mycorrhizal function, and regulating ethylene production in plant roots. Furthermore, some rhizobacteria could suppress major plant pathogens [8-9]. The most indicated rhizobacteria as PGPR are those that have an important function in promoting plant growth [10]. The PGPR fraction involved in controlling phytopathogenic infestations in income crops is mentioned in table 1. Apart from Azotobacter sp. and Azospirillum sp., several other bacteria including various species of Pseudomonas, Acetobacter, Alcaligenes, Klebsiella, Enterobacter, Xanthomonas, and Bacillus sp. have been considered as PGPR [11].

Iron Nutrition Improves PGPR in Crops

Iron performs a crucial position in microorganisms, flowers, and animals [12]. It exists in states and, therefore, it's far appropriate as an electron transporter. It is part of molecular, and its deficiency can reason boom inhibition, lower in RNA and DNA synthesis, inhibition of sporulation, and adjustments withinside the molecular morphology. It regulates the biosynthesis of porphyrins, toxins, vitamins, antibiotics, cytochromes, pigments, siderophores, and fragrant compounds. It is needed as a cofactor through one-of-a-kind enzymes and proteins which include peroxidase, superoxide dismutase, nitrogenase, hydrogenase, glutamate synthase, ribonucleotide diphosphate reductase, aconitase, DAHP synthetase, cytochromes, ferredoxin, and flavoproteins. Iron garage proteins like ferritin in animals and bacterioferritin in microorganisms have additionally been discovered. The aggressive cap potential of microbes to sequester iron via their siderophores and its assistance in the development of flowers seems like one of the most feasible processes to accurate this deficiency to improve quality yield [13].

Microbial Siderophore Production

There is spare proof related to iron uptake by plants through microorganism siderophores, that converts the insoluble sort of iron into a soluble form. Siderophore manufacturing microorganism strains possess iron-regulated outer membrane proteins (IROMPs) on their cell surface that transport ferrous iron complicated to the individual cognate membrane; iron so becomes available for metabolic processes. IROMPs of the varied siderophore-producing bacterium are characterized [14].

Table 1: Siderophore producing PGPR for controlling diseases in cash crops

Siderophore BCAs	**Target pathogen/disease**	**Crops**
Pseudomonas putida	Fusarium wilt	Radish, Cucumber
	Fusarium solani	Beans
	Erwinia carotovora	Potato
Pseudomonas cepacia	Fusarium oxysporum	Onion
Pseudomonas aureofaciens	G. graminisvar tritici	Wheat
Pseudomonas fluorescence	Erwinia carotovora	Potato
	G. graminis/Take all	Wheat
	Fusarium glycinia	Wheat
	Sarocladium oryzae	Soybean, Paddy
Bacillus pumilus	Gaeumannomyces graminis var. tritici	Wheat
Bacillus subtilis	Rhizoctonia solani	Wheat
Enterobacter cloacae	S. homeocarpa	Turfgrass
Enterobacter aerogenes	Enterobacter	Apple
Bradyrhizobium sp.	Fusarium solani	Sunflower
	Rhizoctonia solani	Mungbean
Rhizobium meliloti	Macrophomina phaseolina	Groundnut

Production of Siderophores

Siderophores (Sid = iron, Phores = bearers) are low molecular weight (<10,000 Da), iron-containing ligands that are produced by microbes as catchers to combat low iron stress [15] to overcome the insolubility of the available iron, but also to regulate and control its absorption, since it becomes toxic in high concentrations [16]. All facultative aerobic and anaerobic microbes (except lactobacilli) are known to produce siderophores that act as iron chelates [17]. A huge sort of siderophores is produced with the aid of using microorganisms and fungi and their variety is growing as new siderophores are being identified. Siderophores had been categorized primarily based totally on their fundamental chelating groups. Generally, they may be classified [18] (1) hydroxamate, e.g., ferribactin, aerobactin, francobactin, ferrioxamine, and Schizokinen and (2) catecholate or carboxylate [19], e.g., enterochelin, aerobactin and parabactin [13, 20]. Recently, Winkelmann and Dreschel [21] have brought 3 greater lessons of bacterial siderophores namely (3) peptide, (4) mycobactin, and (5) citrate hydroxamate. Fungal siderophores have been categorized into 5 lessons (1) ferrochrome, (2) coprogens, (3) rhodotorulic acid, (4) fusarinines (fusigens), and (5) rhinophores [13]. The know-how of siderophore and their cognate membrane device is essential for knowing the fundamentals of growth, metabolic activity, host invasion, and virulence in microbes. In all instances, iron is a prerequisite [21]. *P. fluorescens* inoculation greater seed germination, root period, and shoot period of wheat (*Triticum aestivum*) beneath neath pot subculture conditions.

Siderophore Based PGPR for Plant Growth Promotion

Siderophores seem to work to deliver and store iron in the cell. The possibility of using siderophores from other microbes (heterologous siderophores) is of great selective advantage in the case of nutrient competition in the soil. It can also be a means of saving metabolic effort within the microbes [22]. The most important biotechnological exploitation of siderophores in the rhizosphere area of the plant, where they provide the plant with iron nourishment, serves as the first defense against invading root parasites and helps to eliminate toxic metals from contaminated soils. There is sufficient evidence of the uptake of iron by plants by microbial siderophores, which convert the insoluble form of iron to a soluble form. Iron is an essential element for the growth, metabolism, and survival of most cell types on earth [12]. Although it is the fourth most abundant and abundant element in soil, it rarely occurs in free form. they secrete high-affinity iron chelators (siderophores) to secure iron traces from the environment into the cell and to transport this precious metal true to the original to the siderophore-producing cell [23]. Sayyed et al. [24] reported that A. feacalis produced siderophores under iron-deficient conditions in succinic acid medium and that the siderophores broth of A. feacalis promoted the growth and germination of seeds *in Chlorophytum borivillianum* and *Withania somnifer*a, both in the plate test and in the open potted environment. Test under natural conditions in the soil. A 75% increase in the germination rate was observed in seeds of *W. somnifera* and bulbs of *C. borivillianum* bacterized with *A. feacalis sideroforegénica*. In W. somnifera: 41.15% increase in root length, 26.55% increase in shoot length. and a 48.66% increase in chlorophyll content has been reported. While in *C. borivillianum* 21.17% root length, 41.15% shoot length, 26.05% chlorophyll content, 12.39% tuber increase, 9.2% tuber length and 29.26% tuber weight increase. Sayyed et al. [25-26] reported the ability to promote plant growth of A. feacalis and P. at the field level. The co-inoculation of A. facials with P. fluorescens showed a stronger promotion of plant growth in A. hypogea than the individual inoculation with one of these two rhizobacteria. After 90 days of sowing, this led to an increase in the shoot length of 21.39%, an increase in root length of 16.30%, an increase in chlorophyll content of 43.05%, an increase in the number of pods by 22.51%, and an increase in the number of branches by 31.25%.

Siderophore Producing PGPR for Management Phytopathogen

Siderophores that produce PGPRs have been implicated in the biological control of several plant diseases, such as cotton wetting, wheat root rot, potato seed rot, vascular wilt, and root rot. peanut stalk [27]. Various researchers have reported the antagonistic action of Rhizobium, Azotobacter, and Azospirillum on phytopathogens. Saikia and Bezbaruah [28] reported that the hydroxamate type of A. chrococcum which produces the siderophore was able to inhibit F. oxysporum, F. udum, F. solani, F. moniliforme, Ustulina zonata, and Fomes lamnensis. The siderophores that produce PGPRs function like BCAs by depriving the pathogen of iron nutrition, which leads to increased crop yields [29]. Freitas and Pizzinato [30] reported that inhibition of Colletotrichum gossypi by rhizobacteria producing siderophores led to the promotion of the growth of cotton plants. Sindhu et al. [27] examined the role of PGPR in inhibiting plant pathogens (Table 2). Sindhu [27] and Johri et al. [14, 31] reported the role of siderophores producing fluorescent strains of Pseudomonas RBT 13, which showed antagonistic action against various phytopathogenic bacteria and fungi. Microorganisms that could produce potent siderophores become ecologically competent BCAs provided they exhibit strong root colonization [13]. Siderophore produces the growth of plants promoting rhizobacteria (PGPR) against common phytopathogens. PGPR has proven to be a better biological control compared to chemical fungicides used alone.

Table 2. Functional role of siderophore producing PGPR as biocontrol agent

BCA utilized	Target disease	Target pathogen	Crop
Pseudomonas putida	Wilt	Fusarium sp	Radish
	Wilt	Fusarium sp	Cucumber
	Wilt	F. solani	Beans
	Potato decay	Erwinia carotovora	Potato
Pseudomonas fluorescens	Potato decay	Erwinia carotovora	Potato
	Take-all	Gaeumannomyces graminis	Wheat
		F. glycinia	Wheat
	Fusarium wilt	Sarocladium oryzae	Soybean, Rice
Pseudomonas cepacia	Wilt	F. oxysporum	Onion
Bacillus subtilis	Wilt	F. roseum	Corn
Bacillus sp.	Root rot	Rhizoctonia	Wheat
	Take-all	Pythium	Wheat
Rhizobium sp.		Macrophomina phaseolina	Soybean
Bradyrhizobium sp.	Wilt	F. solani	Sunflower
		R. solani	Mungbean

Mechanism of Phytopathogen Suppression

Considering the mechanism of motion is essential as it offers a whole lot of concepts in figuring out the maintenance, enhancement, and implementation of BCA. BCAs engage with phytopathogens immediately or in a roundabout way through the following mechanism.

Antibiosis Production

Rhizobacteria are known to produce a wide variety of antibiotics, including pyrrole nitrine, pyoluteorin, tropolone, pyocyanin, and 2,4-diacetylfloroglucinol [32] that have been reported to be involved in the suppression of various pathogens by causing fungistasis, inhibition of spore germination, lysis of fungal mycelia or exerting a fungicidal effect [27]. Phenazine, a powerful antibiotic produced by *P. fluorescens*, has been used to control wheat disease caused by Gaeumannomyces graminis, a first commercially used biological control agent (BCA) for the control of crown gall in dicotyledons, which specifically inhibits *A. tumifaciens* [27].

Predation and Parasitism

BCA is also a predator or a parasite of the pathogen. Mycoparasites, adore *Coniothyrium minitans* and *Sporidesmium sclerotivorum*, are tested as BCA, and a few of them are economical in dominant diseases caused by fungus sp. and alternative sclerotia forming fungi [33].

Commercial Aspects of Using Siderophore-Based PGPR as BCAs

Ample work has been carried out in the recent past on the biological control of plant diseases, which has also led to the development of commercial organic products. Some of the decisions that will determine whether an organic control product is marketed are use decisions that are not based on science. Before a company approaches commercial production, it must evaluate several factors including product demand, potential market size, and existing competing products (formulation). To be an ideal biological control product it must satisfactorily meet important criteria such as: (a) The biocontrol product should have a comparatively wide spectrum of activity, with high, consistent, associated reliable efficacy. (b) Bioproducts conjointly must have an acceptable period while not special storage necessities and meet the appropriate standards for environmental and toxicological safety. (c) Thorough understanding of the mechanism(s) of action and ecological ability of the bioproducts must be created to assure an efficacious product. (d) the appliance of the biocontrol products ought to be easy, potential with existing plant protection equipment. (e) Bioproducts also must be extremely compatible with chemical agents.

Benefits of Using Siderophore Utilization

Applications of PGPR as bioinoculant to crops would scale back the utilization of chemical fertilizers and chemicals thereby would prohibit the event of pesticide resistance in pathogens. Target organisms rarely develop resistance towards BCA as happens with the use of chemicals. PGPR is safe for crops, eco-friendly, and farmer friendly as they originate from nature. PGPR-based BCAs are safer than the chemical pesticides currently in use. they are doing not imposing the matter of biomagnification. Their self-replication circumvents recurrent application [13, 34]. Bioinoculants are often used as seed coatings. After sowing, bio-vaccines must be able to settle in the rhizosphere at sufficient population density to be beneficial. Bioinoculants must therefore survive in the rhizosphere, use nutrients excreted by plant roots, multiply, the whole Can effectively colonize the plant's root system and compete with the native microflora. successful application of bio-vaccines [35]. For certain PGPBs, efficient root colonization is related to their ability to secrete a site-specific recombinase [36]. The transfer of the site-specific recombinase gene from rhizosphere-competent P. fluorescens to rhizosphere-incompetent Pseudomonas strains increased its ability to colonize root tips [37-38].

II. Conclusion

The use of siderophore producing PGPR is an ecological alternative to chemical fertilizers and pesticides, the use of many studies has been committed research has been devoted to the genus Pseudomonas because of its functional potential as PGPR and BCA, and much remains to be learned of non-symbiotic endophytic bacteria that have more pronounced plant growth-promoting effects. Biotechnology may be carried out to similarly enhance lines that have favored qualities, i.e., formula ease, stability, and ready root colonization, via way of means of developing transgenic lines that integrate a couple of mechanisms of action. Research into the mechanisms of plant boom advertising via way of means of rhizosphere microorganism in the mechanisms for Promoting Plant Growth not only provided a relatively reliable method for improving food quality and soil health but also suggested bioremediation potential through the detoxification of pollutants such as agrochemicals and heavy metal pesticides. The industrial use of PGPR as a vital thing of agricultural exercise is getting used efficiently in diverse growing countries. This is very important in balancing the right PGPR with the plant and the right environmental conditions for the best results in plant growth. In addition, greater efforts should be made to develop good vaccine delivery systems that facilitate the persistence of PGPR in the environment.

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