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Review Article

Plant Beneficial Mechanisms and Applications of Endophytic Bacteria

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Abstract

Endophytic bacteria and fungi reside inside the plant without causing any harmful effects to the host. They have ubiquitous distribution within the plant and can be isolated from different parts by surface sterilization followed by exposing the sterilized parts onto nutrient medium. They have significant impact on physiology and metabolism of the plants. This is due to the evolutionarily adapted multi-potent plant growth promoting and biocontrol mechanisms. Because of their plant beneficial features, they have the promises to develop into microbial inoculants for the field application as biofertilizers, plant strengtheners, phytostimulators or biopesticides. Their exploitation offer promising environment friendly support for emerging organic agricultural applications in worldwide. This review describes the mechanisms of plant beneficial features shown by endophytic bacteria to provide an insight in to their in planta role and applications.

Key Words: Endophytic Bacteria; Plant Growth Promoting properties; Biocontrol Agent; Biofertilizers

Introduction

Plants are naturally associated with microorganisms in various ways. Bacteria which enter the plant and establish mutualistic association without any harm are known as endophytic bacteria [1, 2, 3]. Here, the host provides unique protective niche for the endophytic organisms, and endophytes in turn synthesise diverse chemical scaffolds [4,5] which mediate increased plant growth, development, nutrient uptake and also protect plant from pathogen. Bacterial endophytes are considered to enter the host from the surrounding soil through wounds in the roots [6] or through root hairs [7] and subsequently it transverse the root cortex and reach various plant organs through vascular system or through the apoplastic routes. The nature and types of endophytes present in the plant is depend on its source, age, tissue type, time of sampling and environment [8,9]. The endophytic bacteria can produce an array of bioactive metabolites and hydrolytic enzymes as adaptive strategy for endophytic association. The endophytes can provide protection to plant from pathogen attack in addition to its plant beneficial properties such as production of indole acetic acid, phosphate solubilization, ammonia production, ACC deaminase activity, nitrogen fixation and siderophore production.

History of Endophytes and their Importance

The term endophyte was first coined by De Bary [10]. Hallmann et al [2] have defined the endophytic bacteria as all the bacteria that can be detected inside the surface sterilized plant tissues or extracted from inside plants and having no visibly harmful effect on the host plants. Endophytic bacteria have been isolated from diverse range of monocotyledonous and dicotyledonous plants such as oak [11], pear [12], sugar beets and maize [13,14,15,16,17]. The chemicogenomic interaction between plants and endophytes can expect to provide protection to plants from pathogens, insects and grazing animals [4,18].

Endophytic bacteria with plant growth promoting (PGP) and biocontrol properties have applications to enhance crop yield by maintaining ecological balance [19]. The advantage with use of endophyte as a biocontrol agent is their inherent adaptation to live inside the plants with promises to provide reliable disease suppression. They can protect their host from attack by fungi, insect, and mammals by producing secondary metabolites [20]. The endophytic communities mainly include the phyla, *Proteobacteria, Actinobacteria, Planctomycetes, Verrucomicrobia* and *Acidobacteria* [21]. Bacteria of the genera *Pseudomonas, Bacillus, Burkholderia, Stenotrophomonas, Micrococcus, Pantoea* and *Microbacterium* are some of the most commonly identified bacterial endophytes [2,22,23,5,21]. This can be highly complex as there are more than 300000 species of plants are present [24]. Each of these plants can be unique in their endophytic partners.

Endophytic Bacteria

Based on the types of microorganisms involved, the endophytes can be bacterial, fungal or those of actinomycetes. Bacterial endophytes are well characterized from many plants which include *Azorhizobium caulinodans* from rice [25], *Burkholderia pickettii* from maize [17], *Enterobacter sakazakii* from soybean [26], *Pseudomonas fluorescens*, *Pseudomonas putida* [27] and *Bacillus* spp from citrus plants [28].

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Entry of Endophytic Bacteria in Plants

Endophytic colonization and mobility within host plants are mediated by several factors such as lipopolysaccharides, flagella, pili, and twitching motility [29,30,31]. The endophytic bacteria from the soil get enter into host plant through cracks formed in lateral root junctions followed by quick spread with in the intercellular spaces of the root [32]. Root cracks are recognized as the hot spot for bacterial colonization [33]. Some of the endophytic bacteria can also have the ability to colonize flowers, fruits and seeds but their presence was limited under natural conditions [34].

Isolation of Endophytic Bacteria

There are various methods that have been used for the isolation of endophytic bacteria. Bell et al. [35] have suggested the isolation of endophytic bacteria from grapevine by vaccum or pressure extraction technique. Endophytic bacteria could be easily isolated by the surface sterilization method using 2% sodium hypochlorite followed by wash with sterilized distilled water [36,37]. This simplest procedure of surface sterilization can be followed by exposing the surface sterilized piece of the sample material onto specific media for outgrowth of endophytes [38,39,40]. For the identification of the isolated endophytic bacteria both conventional biochemical tests [41] and rapid method involving 16S rDNA sequence analysis can be used. 16S rDNA based method makes it possible to identify the organism up to genus and possibly to species level by comparing the sequence deposition in available databases [42]. Some of the most common genera of endophytic bacteria characterized from different parts of the plants include *Acinetobavter, Acetobacter, Alkaligenes, Arthrobacter, Azospirillum, Azotobacter, Bacillus, Beijerinckia, Burkholderia, Enterobacter, Pseudomonas, Ralstonia* and *Serratia* [43].

Mechanisms of Plant Growth Promotion

Several studies have been conducted to investigate the mechanisms involved in the plant growth enhancement by endophytic bacteria [44]. These involve direct and indirect mechanisms [45]. The direct mechanisms include (i) those which facilitates the acquisition of nutrients like nitrogen, solubilization of phosphorous and the sequesteration of iron (ii) which modulates plant growth through the production of auxin, cytokinin and ACC deaminase which reduce the level of ethylene. Indirect plant growth support is provided by the production of antibiotics, cell wall degrading enzymes, induced systemic resistance and the production of exopolysaccharides [46,47]. These mechanisms may subject to variation in its expression based on rhizospheric or endophytic life style of organisms.

Direct Mechanisms

Nitrogen Fixation: Nitrogen (N) is the most vital nutrient for plant growth and productivity. The atmospheric N_2 is converted into plant-utilizable forms by the process called biological N_2 fixation (BNF). Here nitrogen is converted to ammonia by nitrogen fixing microorganisms with the help of the enzyme system nitrogenase [48]. BNF occurs generally at mild temperature by nitrogen fixing microorganisms, which are widely distributed in nature [49].

Phosphate solubilization: Phosphate solubilization is one of the major mechanisms for plant growth promotion by the plant associated bacteria. Phosphorous is the second most important nutrient required for plants after nitrogen for their growth and development but it exist in soil as mineral salts or incorporated into organic compounds. Plants can only absorb it in two soluble forms, the monobasic ($H_2PO_4^-$) and the diabasic (HPO_4^{2-}) ions. To overcome this P deficiency in soils, phosphatic fertilizers are frequently applied in soils. The challenges like high cost and hazardous effect to the environment demand the need for economically and environment friendly methods for improving crop production even in the low phosphorus soils. In this context, exploring the role of bacteria to release immobilized phosphorous have tremendous applications [50]. They could convert insoluble phosphate compounds such as tri calcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate into available forms for plants via the process of chelation, exchange reaction and by the secretion of organic acids [51,52]. The bacterial genera *Azospirillum, Azotobacter, Bacillus, Beijerinckia, Burkholderia, Enterobacter, Erwinia, Flavobacterium, Microbacterium, Pseudomonas, Rhizobium* and *Serratia* have been reported to have tremendous phosphate solubilizing efficiency [53,54].

IAA Production: Indole-3-acetic acid (IAA) is a phytohormone which is known to be involved in root initiation, plant cell division, extension, and differentiation. IAA also affects plant growth and development by stimulating seed and tuber germination, increasing the rate of xylem and root development; controlling processes of vegetative growth, initiating lateral and adventitious root formation, mediating responses to light, gravity and fluorescence, affecting photosynthesis, pigment formation, biosynthesis of various metabolites, and providing resistance to stressful conditions. Production of IAA by endophytic bacteria indicates its role in modulating diverse process in plant physiology. Moreover, IAA producing bacteria promote shoot and root elongation which provide greater access to host plant for nutrient absorption from soil [55].

Microbial production of IAA has been reported to take place by both tryptophan dependent or independent mechanisms. In the presence of tryptophan, microbes release greater quantities of IAA and related compounds [56,57]. Microbial synthesis of IAA occurs through pathways like indole-3-acetonitrile (IAN) pathway, indole-3-acetamide (IAM) pathway, tryptamine pathway, indole-3-acetaldoxime pathway and the indole-3-pyruvate (IPyA) pathway [58,59]. The indole-3-pyruvic acid pathway (IPyA pathway) was found to be the main route for IAA production in the presence of exogenous tryptophan. The first step in this pathway is the conversion of tryptophan into IPyA by an aminotransferase enzyme. Then it undergoes decarboxylation reaction to form indole-3-acetaldehyde (IAAld) by the enzyme indole-3-pyruvate decarboxylase (IPDC) and this IAAld is then oxidized to produce IAA. Biological significance of microbial IAA production has been evidenced by the presence of multiple biosynthetic routes for the same. Even more pathways for the same is also expected due to presence of multiple biosynthetic pathways in some organisms.

Several studies have demonstrated the ability of endophytic fungi also to synthesise IAA with significant role in the development of plants. The inoculation of IAA producing endophytic *Paecilomyces formosus* on japonica rice has shown to result in increased plant growth with significant differences in plant height and biomass compared with the control [60,61]. The detection and quantification of IAA produced by endophytic bacteria or endophyte fungi has shown to be carried out by using HPLC with same experimental procedure [60,57].

1-Aminocyclopropane-1-Carboxylate (ACC) Deaminase Activity: Ethylene is an important metabolite endogenously produced by all plants for the normal growth and development. Apart from ethylene being a plant growth regulator, it has also been known as a stress hormone because of its role in stress conditions like salinity, drought, water logging, heavy metals and pathogenicity. The biosynthesis of ethylene from methionine takes place in three steps. First, ATP and water binds to methionine which results in the formation of S-adenosyl methionine (SAM) with the release of three phosphates. It is further converted into ACC with the help of an enzyme 1-amino-cyclopropane-1-carboxylic acid synthase (ACC-synthase). Subsequently, ACC is enzymatically converted to ethylene. However presence of increased level of ethylene negatively affects the overall plant growth and development resulting in reduced crop yield [62].

ACC deaminase is a multimeric enzyme with a molecular mass of 35-42kDa [63, 64]. It is a sulfhydryl enzyme that utilizes pyridoxal 5-phosphate as an essential co- factor and several aminoacids such as D- serine and D- cysteine as substrates. It is a sulfhydryl enzyme that utilizes pyridoxal 5-phosphate as an essential co-factor and several amino acids such as D-serine and D-cysteine as substrates. Mechanisms involved in the cleavage of ACC by ACC deaminase includes fragmentation of cyclopropane ring and deamination to form α-ketobutyrate and ammonia [65].

ACC deaminase produced by endophytic bacteria can have the potential to use ACC from plant root and convert it into α-ketobutyrate and ammonia. The decreased ACC level lowers ethylene production and minimise plant stress. Hence inoculation of plants with ACC deaminase producing bacteria can have the promises to protect plants from stress conditions. Bacterial strains exhibiting ACC deaminase activity have been identified for the genera like *Acinetobacter*, *Achromobacter*, *Agrobacterium*, *Alcaligenes*, *Azospirillum*, *Bacillus*, *Burkholderia*, *Enterobacter*, *Pseudomonas*, *Ralstonia*, *Serratia* and *Rhizobium* [66].

Different types of endophytic bacteria isolated from various parts of the plant have been reported to have diverse mechanisms for plant growth enhancement (Table 1).

Indirect Mechanisms

Indirect mechanisms generally involve biocontrol properties. Plant growth promoting bacteria (PGPB) can also promote plant growth by protecting the plant from the deleterious pathogens. Mechanisms used by biocontrol organisms to control pathogens have potential applications to reduce the use of chemical pesticides in a cost effective and eco-friendly manner.

Production of Antibiotics and Lytic Enzymes

Plant growth promoting bacteria produce a wide range of antibiotics and enzymes which protect the plant from phytopathogens. Antibiotics are low-molecular weight, chemically distinct group of organic compounds mostly produced by microorganisms which are deleterious to the growth and metabolic activities of other microorganisms even at very low concentrations [91,92]. There are many reports on the biocontrol properties and applications of *Pseudomonas* spp. due to its abundance in the plant. Recently, more bacterial biocontrol agents other than *Pseudomonas* spp. have also been reported. Antibiotics produced by bacterial biocontrol agents include phenazines (Phz), pyrrolnitrin (PRN) and other lipopeptides [93,94,95,96].

Phenazines: Phenazines are a group of nitrogen containing heterocyclic compounds produced by a variety of bacteria. Both Gram negative and Gram positive species reported to have the ability to synthesise phenazine which include *Nocardia, Sorangium, Brevibacterium, Burkholderia, Erwinia, Pantoea agglomerans, Vibrio* and *Pelagiobacter* [97,98]. Among various bacteria, *Pseudomonads* have been extensively studied for phenazine compounds. In most of the cases, the phenazine production has been identified to be mediated by the core biosynthetic genes which are flanked by one or more genes resulting in the production of additional phenazine derivatives. In our previous study also, endophytic *Pseudomonas aeruginosa* with phenazine-1- carboxylic acid mediated antifungal activity has been reported from ginger rhizome [94].

Pyrrolnitrin: Pyrrolnitrin [3-chloro-4-(2-nitro-3- chlorophenyl) pyrrole] is a dichlorinated phenylpyrrole antibiotic. This was primarily used as clinical antifungal agent for the treatment of skin infections caused by the fungus *Trichophyton*. Further, it was used as effective agricultural fungicide [99]. Pyrrolnitrin has previously reported as antifungal basis of *Burkholderia*, *Enterobacter*, *Myxococcus, Pseudomonas* as well as by some *Serratia* sp. [100,101,102]. Endophytic *Serratia* sp. G3 from wheat was also reported to have antifungal activity due to the production of pyrrolnitrin, chitinase, and siderophore [103].

2,4-Diacetylphloroglucinol (DAPG): 2,4-diacetylphloroglucinol (DAPG) are major group of secondary metabolites which belong to the group of compounds phloroglucinol. These compounds are generally synthesized by species of *Pseudomonads* [104]. Several studies also reported *Serratia* sp. and *Pseudomonas* sp. to have the potential to biosynthesize DAPG and its role in the biocontrol of many phytopathogens [105,106]. DAPG is basically a polyketide which is synthesized by the condensation reaction of acetyl CoA with malonyl CoA. The genes which are included in the biosynthesis are *phlA, phlC, phlB, phlD* and *phlE* [107]. DAPG is reported to have broad range of biological activities including antifungal, anti-helmenthic and herbicidal properties [104].

Ecomycin: Ecomycins are novel lipopeptide compounds produced by plant associated fluorescent bacteria called *Pseudomonas viridiflava.* This bacterium is known to exist on or within the tissues of leaves of *Lactuca sativa* and many grass species [108].

Table.1 Details of selected endophytic bacteria and their plant beneficial features

Endophytic bacteria	**Source**	**Mechanisms of plant growth promotion**	**References**
Paenibacillus sp.	*Curcuma longa*	Indole-3- acetic acid production	[67, 68]
Klebsiella sp.	*Piper nigrum, Curcuma longa*	ACC deaminase, phosphate solubilization, siderophore and IAA production.	[69, 70, 71, 72]
Pseudomonas sp.	*Zingiber officinale,* *Elettaria cardamomum*	IAA production, ACC deaminase and siderophore production, antifungal activity	[73, 74, 75, 76, 77, 78]
Ralstonia sp.	*Musa accuminata* cv. Grand Naine	Phosphate solubilization, ammonia production, IAA synthesis, Nitrogen fixation, siderophore production and HCN production	[79, 80]
Bacillus sp.	*Capsicum annuum, Eletteria cardamomum, Curcuma longa* L	IAA production, ACC deaminase production, phosphate solubilization and siderophore, production, antifungal activity	[75, 81, 82, 83]
Pantoea sp.	*Eletteria cardamomum*	ACC deaminase production	[75]
Stenotrophomonas sp.	*Datura metel*	IAA Production, phosphate solubilization	[84]
Agrobacterium sp.	*Solanum lycopersicum*	IAA production, ACC deaminase, phosphate solubilization, siderophore production	[76]
Rhizobium sp.	*Solanum lycopersicum*	IAA production, ACC deaminase, phosphate solubilization, siderophore production	[76]
Burkholderia sp. *Burkholderia australis*	*Vitis vinifera* L., *Saccharum officinarum* x *spontaneum* L.	Phosphate solubilization, IAA production, siderophore production, nitrogen fixation	[85,86]
Novosphingobium sediminicola, Ochrobactrum intermedium, Gluconacetobacter diazotrophicus, Herbaspirillum seropedicae, H. rubrisub albicans and Burkholderia sp.	*Saccharum officinarum* L.	Nitrogen fixation	[87,88]
Azospirillum *Amazonense*, *Rhodopseudomonas palustris*, *Pantoea ananas*, *Klebsiella oxytoca*, *Cytophagales* sp., *Flavobacterium gleum*	*0ryza sativa*, *0ryza Alta* and *0ryza. ridleyi*	Nitrogen fixation, IAA production	[89]
Sphingomonas paucimobilis, Bacillus megaterium, Pantoea sp., *Enterobacter ludwigii*	*Pennisetum purpureum* Schumach	IAA production, ACC deaminase Activity, nitrogen fixation, ammonia production, siderophore production inorganic phosphate solubilization.	[90]

There are mainly three types of ecomycin lipopeptide compounds have been identified and partially purified. These include ecomycin A, B and C. Among them, ecomycin A is structurally similar to the already known antibiotic syringotoxin [109,110]. Ecomycin B and C are novel because of their unique aminoacid composition [108,111,112,113]. This compound was also reported to have broad antifungal properties against human pathogens *Cryptococcus neoformans* and *Candida albicans.*

Pseudomycin: The pseudomycins are another group of antifungal peptides identified from plant associated bacterium *Pseudomonas syringae. P. syringae* is a member of the *Pseudomonadaceae* family and belong to the Phylum Proteobacteria. The pseudomycins are lipopeptides which contain non-traditional aminoacids such as L-chlorothreonine, L-hydroxy aspartic acid and diaminobutyric acid and are active against human pathogenic fungi such as *Candida albicans* and *Cryptococcus neoformans* as well as phytopathogens including *Ceratocystis ulmi* and *Mycosphaerella fijiensis*. The pseudomycins are also being used for the agricultural purpose to manage black sigatoka disease in bananas [4].

Munumbicins and Kakadumycins: Munumbicins and kakadumycins are peptide antibiotics produced by endophytic *Streptomyces* sp. NRRL 30562 and 30566 respectively. These compounds are active against broad range of bacteria such as *Bacillus anthracis, Streptococcus pneumoniae, Enterococcus faecalis*, *Staphylococcus aureus* and also active against multiple-drug-resistant (MDR) *Mycobacterium tuberculosis*. Munumbicins E-4 and E-5 and kakadumycin A were also found to have activity against *Plasmodium falciparum* and it was found to have more antimalarial activity than the reported chloroquine [114,115].

Other lipopeptides: Lipopeptides are major antimicrobial compounds secreted by *Bacillus* spp. The antifungal lipopeptides are grouped under iturins and fengycins. Antibiotics that belong to the family iturin are basically cyclic lipopeptides such as iturin A, mycosubtilin, bacillomycin etc. and are one of the most commonly studied compounds produced from *Bacillus* spp. with promising for their promising antifungal activities [116,117,96]. These are small molecular weight compounds with a mass of 1.1 kDa and consists of a cyclic peptide with 7 amino acid residues and 11-12 carbons atoms at their hydrophobic tail. Due to this structure, the compound exhibits strong amphiphilic nature and thus have high probability to act on target cellular membranes [118]. Biosynthesis of iturins was mostly studied in *Bacillus* sp. where it consists of an operon with four open reading frames *ItuA*, *ItuB*, *ItuC*, and *ItuD* [119]. Iturin A specifically shows a strong and broad spectrum antibiotic activity and have the potential to reduce the use of chemical pesticides in agriculture [120]. The fengycin family comprises fengycin A and fengycin B, which differ in a single amino acid in the sixth position (d-alanine and d-valine respectively). Their production was reported from the endophytic bacterium *B. amyloliquefaciens* ES-2 [121] and *B. subtilis* B-FS01 [122]. Evaluation of the antifungal activity of the isolated lipopeptides obtained from endophytic *Bacillus subtilis* showed fengycins to have promising activity [123].

Growth enhancement through the production of cell wall degrading enzymes is another mechanism used by plant growth promoting bacteria to control soil borne pathogens [124]. Certain enzymes produced by the PGPB like β-1, 3-glucanase, chitinase, cellulase, and protease inhibit the growth of fungal pathogens by the degradation of the cell wall. PGPB with one or more of these enzymes have been found to have biocontrol activity against a range of pathogenic fungi including *Botrytis cinerea, Sclerotium rolfsii, Fusarium oxysporum, Phytophthora* spp., *Rhizoctonia solani*, and *Pythium ultimum*. The studies on the biocontrol property of *S. marcescens* B2 against the soilborne pathogens *R. solani* and *F. oxysporum* have been reported as due to the production of the chitinolytic enzyme [125].

Sequestering of Iron: Iron (Fe) is the most abundant element on earth which cannot be readily assimilated by either bacteria or plants because of its nature of existence as ferric ion (Fe^{+3}). Both microorganisms and plants require a higher level of iron which makes the plant, bacteria and fungi to compete for iron [126]. This limitation has been overcome by some bacteria by synthesizing low-molecular weight compounds (400–1500 Da) called siderophores. These siderophores binds with ferric ion and make siderophore-ferric ion complex which subsequently binds with membrane receptors at the bacterial cell surface and facilitates the uptake of iron by microorganisms. Plant growth enhancement with the help of bacterial siderophores have been studied extensively and it showed effect of siderophore producing microorganisms on increased iron inside plant tissues leading to improved plant growth. And there are over 500 known types of siderophores with different chemical structures and can be mainly classified into 3 main groups like catecholates (phenolates), hydroxamates and carboxylates.

Induced Systemic Resistance: Induced systemic resistance is the physiological state of enhanced defensive capacity elicited by the plant in response to specific environmental stimuli or by the subsequent biotic stresses. Priming of plants with potential organisms can enhance innate defenses against a broad range of plant pathogens. Many bacterial components can affect induced systemic resistance such as lipopolysaccharides (LPS), flagella, siderophores, cyclic lipopeptides, 2, 4-diacetylphloroglucinol, homoserine lactones, and volatiles like, acetoin and 2, 3-butanediol etc.

Exo polysaccharide Production: Certain PGPB can have the ability to synthesize exopolysaccharides (EPS). These provide plant growth and development by facilitating the circulation of nutrients and also protecting the plant from pathogen attack. Other functions performed by EPS producing microbes constitute shielding from desiccation, protection against drought, attachment to surfaces, plant invasion defense response in plant-microbe interactions.

In addition to these bacteria, endophytic fungi have also been reported to have several beneficial effects on the plant growth and disease protection which include protection from phytopathogens and enhancement of plant yield through the production of phytohormones like auxins and gibberrillins to increase metabolic activity of the plant [127]. *Aureobasidium* sp. BSS6 and *Preussia* sp. BSL10 isolated from *Boswellia sacra* showed higher potential for indole acetic acid production both by tryptophan-dependent and independent pathways. *In vivo* evaluation of plant growth enhancement effect of *Preussia sp.* BSL10 on *B. sacra* tree showed significant improvement in plant growth parameters and the deposition of photosynthetic pigments [128]. Some endophytic fungi would able to produce different bioactive compounds such as alkaloids, diterpenes, flavonoids, and isoflavonoids to protect plant from biotic and abiotic stresses [129,130]. Plant growth-promoting ability of endophytic fungi isolated from *Rosa rugosa*, *Camellia japonica*, *Delonix regia*, *Dianthus caryophyllus* and *Rosa hybrid* collected from Yunnan, Southwest China showed its ability to improve the host plants growth more efficiently [131].

Applications of Endophytic Bacteria

The production of natural products by endophytic bacteria make it an important source in the development of products for various plant diseases. Molecules derived from natural products, particularly those produced by plant and microbes have a great potential for the development of new pharmaceutical products also. This can be achieved by the discovery of plethora of endophytes (both fungi and bacteria) with broad spectrum activities. So studies on endophytic microorganisms from diverse plants is important. Endophytic microorganisms also have great contribution in production of anti-diabetic [132], anti-cancerous [4], antiviral [133] and even immunosuppressive compounds [134]. Endophytic bacteria include a wide range of antimicrobial producing strains, which make it as a potential source of antimicrobial substances [135]. Endophytic bacteria can also be used for biocontrol purpose because of their well known capability to produce bioactive compounds like surfactin, fengycin, iturin, pyroluetrin etc. [136]. They have the promises for field application as biofertilizers, phytostimulators or as biopescticides. Screening for plant growth promoting and antagonistic properties of bacterial endophytes isolated from potato (*Solanum tuberosum* L.) have shown their ability to enhance biomass yield of *Phaseolus vulgaris* L and was found to have protective effect against potato pathogens *Pectobacterium atrosepticum*, *Fusarium sambucinum* and *Clavibacter michiganensis* subsp. *epedonicus* [137]. The endophytic *Pseudomonas fluorescens* ALEB7B isolated from *A. lancea* have been reported to have the ability to produce nitrogenous volatiles like formamide and N,N-dimethyl-formamide with significant growth promotion on *A. lancea*. Moreover, the main bacterial volatile benzaldehyde significantly promoted volatile oil accumulation in *A. lancea* by activating plant defense responses and thereby enhancing the plant growth and development [138]. Several commercially available microbial products from diverse sources as explained in Table. 2, indicate promises of endophytes also for such applications.

Conclusion and Perspectives

From the emerging understanding on endophytic bacteria, they can consider to have immense promises in the new generation agricultural practices. From the available information on plant beneficial mechanisms of these organisms they can consider to have a heavy deposition of yet to known mechanisms with determining effect for plant growth and development. This also involves mechanisms with promises in their biocontrol application. Hence a detailed insight into plant endophytic interactions can have promising applications.

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Table.2 Representatives of microbial inoculants introduced as agricultural products

Organism	Product name	Company
Pseudomonas	Abtech Pseudo, abtech Pseudochitinase, PSEUDO-GUN, Salavida, Proradix	ABTECH, Maharashtra Bio Fertilizers, India PVT.LTD, Sourcon Padena
Bacillus spp.	Abtech Bacillus, YiedShield	ABTECH, Bayer Crop Science
Azospirillum	Abtech Azospirillum, AZOSPIRILLUM, AZOGREEN, Biopromoter	ABTECH, Maharashtra Bio Fertilizers, India PVT.LTD, Omega Ecotech Products India Private Limited, Manidharma Biotech
Rhizobium	Abtech Rhizobium, RHIZOBIUM	ABTECH, Maharashtra Bio Fertilizers, India PVT.LTD
Phosphobacteria	Abtech Phosphobacteria	ABTECH
Azotobacter	AZOTOBACTER	Maharashtra Bio Fertilizers, India PVT.LTD
Acetobacter	ACETOBACTER	Maharashtra Bio Fertilizers, India PVT.LTD
Trichoderma viridae	Green Light	Green life Biotech Laboratory
Serratia plymuthcia HRO-C48	RhizoStar	Prophyta Biologischer Pflanzenschutz

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