Research Article

Role of Endophytes in Agriculture

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Abstract

Pesticides have a sensitive role in food systems: they are applied in order to protect crops, but they have negative impacts on environment and human health. When health and environmental costs are factored in, pesticide application is much lower threshold than commonly practiced. Most healthy naturally propagated plants grown in field or potting soils are colonized by communities of endophytic bacteria. These bacteria form nonpathogenic relationships with their hosts: some beneficial, some neutral, and some detrimental. Such associations can increase plant growth and hasten development or improve resistance to environmental stress. Bacterial endophytes are endosymbiotic microorganisms prevalent among plants that colonize intracellular and intercellular spaces of all plant compartments and do not harm plant. The diverse endophytic microbial communities play integral and unique role in the functioning of agroecosystems. Bacterial endophytes have several beneficial effects on host plant *i.e*. growth promoting activity, modulation of plant metabolism and phytohormone signaling that leads to adaptation to various abiotic or biotic stress. This review summarizes the natural associations between bacterial endophytes and their hosts, and discusses how such relationships can be employed most productively in sustainable systems of agricultural crop production.

Keywords: ACC, biofertilizers, biological control, endophytes, PGPBEs, N_2 fixation

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Introduction

Presently, there are nearly seven billion people living in the world and this number is undeniably estimated to increase to about 8.2 billion around 2025. Due to increase in population, environmental damage is increasing as a result of fast growth in industrialization and urbanization [1]. The enormous use of chemical fertilizers in crops makes the country independent in providing large amount of food supply but on the other hand damages the environment to a great extent and causes harmful impacts on health of human and animals. Seeing all the consequences of continuous use of chemical fertilizers, organic farming has emerged as alternative area in terms of increasing demand of healthy food supply, long-term sustainability, and concerns regarding environmental pollution. “A biofertilizer is an inoculant which contains living microorganisms which when applied to seeds, plants, or soil, colonizes the rhizosphere or the interior of the plants and promotes plant growth by increasing the supply of nutrients to the host plant” [2]. Endophytic bacteria have an advantage over other rhizosphere inhabiting bacteria because they are residing inside plant cell so have an opportunity to readily exert direct beneficial effects to plants. Endophytes are extensively used to boost up microbial processes which increase the availability of nutrients that can be easily assimilated by the plants for their growth. These microbes improve soil fertility by fixing the atmospheric nitrogen, produce plant growth-promoting substances in the soil and solubilizing insoluble potassium and phosphates. These microbes have been encouraged to reap the naturally available biological system of nutrient mobilization which enormously increases soil fertility and crop yield [3]. Use of endophytic bacteria presents a special interest for development of agricultural applications that ensure improved crop performance under cold, draught or contaminated soil stress conditions or enhanced disease resistance.

Endophytes requirement is inescapable

Enormous use of chemical fertilizers to meet the increasing demand of food supply has unquestionably led to environmental pollution and ruthlessly damaged microbial habitats and beneficial insects. Hence, it is compulsorily required to reassess many of the present agricultural approaches which comprise of using chemical fertilizers, pesticides, herbicides, fungicides, and insecticides [4]. Keeping in mind the harmful effects of chemical fertilizers, biofertilizers are supposed to be a safe substitute to chemical involvement and minimizes ecological disturbance to a great extent. Biofertilizers are ecofriendly, low cost and their persistent use increases soil health and fertility [5].

Plants are described to harbor endophytes, but most likely, there is not a single plant species devoid of endophytes. The few examples of the false absence of internal populations may be because some microorganisms are not easily isolated or cultured. In overall endophytic bacteria occur at lower population densities than rhizospheric bacteria or bacterial pathogens [6]. The ability of diverse bacterial endophytes to promote plant growth occurs as a consequence of either direct or indirect mechanism. Direct promotion of plant growth occurs when a bacterium either facilitates the acquisition of essential nutrients or modulates the level of hormones within a plant. Nutrient acquisition facilitated by PGPB typically includes nitrogen, phosphorus and iron. Modulation of hormone levels may entail PGPB (Plant Growth-Promoting Bacteria) synthesizing one or more of the phytohormones auxin, cytokinin and gibberellin. In addition, some PGPB can lower levels of the phytohormone ethylene by synthesizing an enzyme, 1-aminocyclopropane-1-carboxylate (ACC) deaminase that cleaves the compound ACC, the immediate precursor of ethylene in all higher plants. Indirect promotion of plant growth occurs when a PGPB decreases the damage to plants following infection with a phytopathogen including some soil fungi and bacteria. This usually occurs by the inhibition of the pathogen by the PGPB [7].

Endophytes

An endophyte is an endosymbiont, often a bacterium or fungus, which lives within a plant for at least some part of its life cycle without causing apparent disease. Endophytes are ubiquitous and have been found in all species of plants studied to date; however, most of the endophyte/plant relationships are not well understood. Endophytes are also known to occur within lichens and algae [8]. Many economically important kinds of grass (e.g., *Festuca* spp. and *Lolium* spp.) carry fungal endophytes in genus *Epichloë*, some of which may enhance host growth, nutrient acquisition and may improve the plant's ability to tolerate abiotic stresses, such as drought, and enhance resistance to insects, plant pathogens and mammalian herbivores. Endophytes may benefit host plants by preventing pathogenic or parasitic organisms from colonizing them. Extensive colonization of the plant tissue by endophytes creates a "barrier effect", where the local endophytes outcompete and prevent pathogenic organisms from taking hold. Endophytes may also produce chemicals which inhibit the growth of competitors, including pathogenic organisms [9].

Fungal endophytes

Since the first description of symbiosis as ‘the living together of dissimilar organisms’ [10], an array of symbiotic lifestyles have been defined based on fitness benefits or impacts to macroscopic hosts and microscopic symbionts [11]. Fungi are plant-like organisms that lack chlorophyll. An endophytic fungus is a fungal microorganism primarily ascomycetous, which spends the whole or part of its life cycle colonizing inter and intra-cellularly inside the healthy tissues of the host plants, causing no apparent symptoms of diseases. These are fungal microorganisms which asymptomatically inhabit plant tissues and have been isolated from many species of woody plants and grasses [12]. Endophytic fungi are found in all kinds of plants, *i.e*. trees, grasses, algae and herbaceous plants. These fungal symbionts can have profound effects on plant ecology, fitness, and evolution [13], shaping plant communities [14] and manifesting strong effects on the community structure and diversity of associated organisms (*e.g*. bacteria, nematodes and insects [15]. Mycorrhizal fungi that colonize plant roots and grow into the rhizosphere, endophytes reside entirely within plant tissues and may grow within roots, stems and/or leaves, emerging to sporulate at plant or host-tissue senescence [16]. The symbiosis between plant and endophyte was established, which produces bioactive (plant growth regulatory, antibacterial, antifungal, insecticidal, *etc*.) substances to improve the growth and efficacy of the host in nature.

Bacterial endophytes

Endophytic populations, like rhizospheric populations, are conditioned by biotic and abiotic factors [17], but endophytic bacteria could be better saved from harsh environmental conditions. Endophytic bacteria in a single plant host are not restricted to a single species, they comprise of several genera and species. Endophytic bacteria have been recognized [18] and they were isolated from surface-disinfected tissues and also microscopically visualized by tagging with fluorescently labeled tags. Use of the term putative endophytes has been recommended for those not validated microscopically. True endophytes may also be recognized by their capacity to reinfect disinfected seedlings.

Endophytic existence: from rhizosphere to internal plant tissue

Endophytic bacteria reside in plant interior and remain always in contact with plants and benefit them in many ways.

This microecosystem has been widely known as one of the primary sources for endophytic colonization [19]. [20] reported that bacterial endophytes are special than rhzospheric bacteria because they can interact with plant in very efficient way. Thus, endophytes have different routes to make entry into the plant tissues, specially in roots. [21] reported that in spite of already established seed endophytes, most commonly endophytic bacteria enter in to plants through tissue wound formed due to plant growth and primary and lateral root cracks. Root wounds result in the release of exudates *i.e.* plant metabolites, they become the sites for bacterial attachment. Other ways through which bacterial endophytes enter plants include stomata which are present on leaves, young stems and lenticels which are usually present in the periderm of stem [22]; and germinating radicles [23]. Bacteria can also enter via the emergence of lateral roots or root hair cells. [19] Showed that in the case of cotton plants, endophytic bacterium *Enterobacter asburiae* JM22 entry in the plant was abetted by the ability to hydrolyze plant cell wall-bound cellulose.

Occurrence and Biodiversity of bacterial endophytes in agricultural crops

Recent estimations suggest that the globe encompasses about 300,000 species of plants, the majority of which are colonized by microbial endophytes [24]. Endophyte distribution within plants depends on a combination of ability to colonize and the allocation of plant resources. Root endophytes often colonize and penetrate the epidermis at sites of lateral root emergence, below the root hair zone, and in root cracks. These colonizers are capable of establishing populations both inter- and intracellularly [25]. After initial colonization, some endophytes can move to other areas of the plant by entering the vascular tissues and spreading systemically [26].

Table 1 Endophytic bacteria isolated from common agricultural crop plants [19]

Plant species and organ	**Bacterial endophyte taxa**	**References**
Alfalfa (*Medicago sativa* L.) roots	γ-proteobacteria: *Erwinia sp., Pseudomonas sp.* firmicutes: *Bacillus megaterium, B. chosinensis* actinobacteria: *M. trichothecenolyticum*	[27]
Black pepper (*Pipernigrum* L.) roots	γ -proteobacteria: *Pseudomonas sp., Serratia sp.* firmicutes: *Bacillus sp.* actinobacteria: *Arthrobacter sp., Micrococcus sp., Curtobacterium sp.*	[28]
Carrot (*Daucus carota* L. var. *sativus)*	α-proteobacteria: *Agrobacterium radiobater* γ-proteobacteria: *Klebsiella terrigena, P. putida, P. fluorescens, P. chlororaphis* firmicutes: *Bacillus megaterium*	[29]
Maize (*Zea mays* L.) stems, roots	α-proteobacteria: *Rhizobium etli* β-proteobacteria: *Bukholderia pickettii, B. cepacia, Achromobacter, Herbaspirillum seropedicae* γ-proteobacteria: *Erwinia sp., Enterobacter sp., E. cloacae, Stenotrophomonas sp., Klebsiella sp., K. terrigena, K. pneumoniae, K. variicola, Pseudomonas sp., P. aeruginosa, P. fluorescens* *firmicutes: Bacillus sp., B. mojavensis, B. thuringiensis, B. megaterium, B. subtilis, B. pumilus, Lysinibacillus, Paenibacillus* actinobacteria: *Corynebacterium sp., Arthrobacter globiformis, Microbacterium testaceum*	[30]; [31]; [32]; [33]; [34]
Red clover (*Trifolium Pratense* L.), leaves, stems, roots and fresh nodules	α-proteobacteria: *Agrobacterium rhizogenes, A. tumefaciens, Methylobacterium sp., Phyllobacterium sp., Rhizobium sp., Sphingomonas sp.* β-proteobacteria: *Acidovorax sp., Bordetella sp., Comamonas sp.,Variovorax sp.* γ-proteobacteria: *Enterobacter sp., Aerobacter cloaceae, Escherichia sp.,Klebsiella sp., Pantoea agglomerans, Xanthomonas compestris, X. oryzae, Pseudomonas cichorii, P. corrugata, P. fulva, P. syringae, P. tolaasii, Serratia sp., Pasteurella sp., Psychrobacter sp., P. immobilis* firmicutes: *Bacillus brevis, B. megaterium* actinobacteria: *Arthobacter ilicis, Cellulomonas sp.,Curtobacterium citreum, C. luteum, Micrococcus varians*	[35]

Role of bacterial endophytes in overcoming salinity and temperature stress

Abiotic stress in plants such as drought, water logging, extreme temperatures, salinity and oxidative stress are the main reason of crop loss worldwide. Plants are adapted to high stress conditions probably include a combination of phenotypic plasticity and genetic changes, and are believed to involve processes special to the plant genome [36]. [37] reported that few species are able to inhabit high stress environments which typically have less levels of plant abundance compared to neighboring low stress habitats. Though, almost all plants in natural ecosystems are believed to be symbiotic with endophytes and these endophytes can have reflective effects on plants including increased root and shoot biomass, increased yield, tolerance to stresses such as drought, salt, and, heat and to biotic stresses such as pathogens and herbivores [38]. However, [39] studied *Pseudomonas* strains improving *Asparagus* seedling growth and seed germination under water-stress conditions. Likewise, *Pseudomonas fluorescens* MSP-393 acted as a PGPR for many crops grown in the saline soils of coastal ecosystems [40] and *Pseudomonas putida* Rs-198 supported cotton seedling grown under salt stress, increasing germination rates and protecting against salinity stress by increasing the absorption of Mg^{2+}, K^{+} and Ca^{2+}, decreasing Na^{+} uptake, and improving the production of endogenous indole acetic acid [41].

El-Akhal et al [42] described that strain of *Mycobacterium phlei Bacillus polymyxa Alcaligenes sp., Paenibacillus sp.,* produced calcisol and enhanced maize growth and nutrient uptake under high temperature conditions as well as under salinity. PGPR strains also ensure the availability of nutrients, enhance the nutrient use efficiency besides promoting plant growth and also mitigate biotic and abiotic stresses [43]. However, the degree of efficiency of the PGPR may differ with crops, varieties or species, cultural conditions and inoculant strains.

Role of endophytes in plant growth promotion

Endophytic bacteria can influence plant growth differ among species and strains, so usually not by single mechanism but there are many ways through which plant growth is promoted. Researches have been directed regarding the abilities of various bacteria to promote plant growth. Conceptually, plant growth promoting bacterial endophytes may affect plant growth either directly or indirectly. Direct promotion of plant growth occurs when either (i) the plant growth promoting bacteria enable the attaining of resources from the environment including potassium, nitrogen, phosphorous, and iron; (ii) modify plant growth by providing or regulating various plant hormones including cytokinin, auxin or ethylene. Indirect promotion of plant growth by endophytic bacteria through production of metabolites, HCN and antibiotics against pathogenic bacteria and fungi.

Direct mechanisms

Biological nitrogen fixation

All organisms require nitrogen (N) to synthesize bio-molecules such as proteins and nucleic acids. Nitrogen is provided to agricultural lands by the application of urea and ammonium nitrate as chemical fertilizers. Microorganisms having the ability of biological nitrogen fixation (BNF) are responsible for the reduction of N_2 to ammonia (NH_3) [44]. *Rhizobium* is the best example of nitrogen fixer which fixes nitrogen in a sustainable manner. These microorganisms were traditionally considered to be responsible for legume infection process, though rhizobia can also behave as endophytes in nodules and frequent isolation of rhizobial strain from nodule often promotes growth of plant. Endophytic rhizobia isolated from *vicia* nodules after sequencing of different genes were classified into genera *Ensifer* and *Shinella* as well as in the species *Rhizobium tropici* [45].

The unavailability of good quality seed and absence of effective rhizobial inoculation were reported for low yields. Apart from the rhizobial endophytes there are some promising nonrhizobial endophytic biofertilizers that include the members of *Azoarcus, Achromobacter, Burkholderia, Gluconoacetobacter, Herbaspirillum, Klebsiella and Serratia* [46]. The efficient N supply by endophytic diazotrophic bacteria in sugarcane and kallar grass suggests the possible avenues of biological nitrogen fixation in interior niches of plants. It is evident from the reports that the *Gluconoacetobacter diazotrophicus* (*Acetobacter diazotrophicus*) is the main contributor of endophytic biological nitrogen fixation in sugarcane, and it has the ability to fix the N approximately 150 Kg N ha^{-1} $year^{-1}$ [47].

Azoarcus is recognized as another potential N_2 fixing obligate endophytic diazotroph. It dwells in the roots of kallar grass, and increased the hay yield upto 20–40 t ha^{-1} $year^{-1}$ without the addition of any N fertilizer in saline sodic, alkaline soils [48]. These investigations suggest that endophytic diazotrophs have a considerable potential to increase the productivity of non-legumes including important cash crop plants.

Phosphorus solubilisation

Phosphorus is an essential macronutrient for growth and development of plants involved in important metabolic pathways like photosynthesis, biological oxidation, nutrient uptake and cell division [49]. Worldwide soils are supplemented with inorganic P as chemical fertilizers to support crop production but repeated use of fertilizers deteriorates soil quality [50]. Therefore, the present scenario is shifting towards a more sustainable agriculture. [51] Revealed that phosphorous is mainly absorbed by plants in two forms which are soluble forms: the monobasic (H_2PO_4) and the dibasic (HPO_4). Though, a large amount of phosphorous is present in insoluble forms and is readily not accessible for plant growth. [52] Reported that soluble components such as aluminum in acid soils (pH <5) and calcium in alkaline solis (pH > 7) showed the high reactivity with phosphorous and that results in low level of P in soil. Organic (incorporated into biomass or soil organic matter) and inorganic compounds, primarily in the form of insoluble mineral complexes, are major sources of available P in the soil [53]. Phosphate-solubilizing bacteria and fungi constitute approximately 1-50% and 0.1-0.5%, respectively, of the total population of cultivable microorganisms in the soil [54]; [55]. Phosphate-solubilizing bacteria solubilize inorganic soil phosphates, such as $FePO_4$, $Ca_3(PO_4)^2$, and $AlPO_4$, through the production of siderophores, organic acids, and hydroxyl PGPB in agricultural soils. Endophytic bacteria possess the capacity to solubilize phosphates, and it was suggested by the authors that the endophytic bacteria from soybean may also participate in phosphate assimilation [56]. Application of phosphate-solubilizing bacteria increases soil fertility due to their ability to convert insoluble P to soluble P by releasing organic acids, chelation and ion exchange [57]. The positive effect of P solubilizers has been reported on food and fodder crops [58].

Potassium solubilisation

Potassium (K) is the third vital nutrient required for plant growth and endophytic bacteria are able to solubilize insoluble form of potassium. Potassium solubilizing microorganisms present could provide an alternative technology to make potassium available for uptake by plants [59]; [60]. A wide range of bacteria namely *Pseudomonas*, *Burkholderia*, *Acidothiobacillus ferrooxidans*, *Bacillus mucilaginosus*, *Bacillus edaphicus*, *B. circulans* and *Paenibacillus* sp. have been reported to release potassium in accessible form from potassium-bearing minerals in soils [61]. These potassium solubilizing bacteria (KSB) were found to dissolve potassium, silicon and aluminium from insoluble K-bearing minerals such as micas, illite and orthoclases, by excreting organic acids which either directly dissolved rock K or chelated silicon ions to bring K into the solution [62]. Thus, application of K solubilizing bacteria as biofertilizer for agriculture improvement can reduce the use of agrochemicals and support ecofriendly crop production [63].

Siderophore production

In plant growth promoting bacteria, iron in Fe^{3+}-siderophore complex on bacterial membrane is reduced to Fe^{2+} which is further released into the cell from the siderophore via a gating mechanism [64]. Binding of the siderophore to a metal increases the soluble metal concentration [65]. On the alleviation of high level of heavy metal contamination bacterial sideophores are released and plants assimilate iron from bacterial siderophores by means of different mechanisms, for instance, chelate and release of iron, the direct uptake of siderophore-Fe complexes, or by a ligand exchange reaction [66]. Numerous studies of the plant growth promotion vis-a`-vis siderophore-mediated iron-uptake as a result of siderophore producing rhizobacterial inoculations have been reported [67]. [68] evaluated the role of the siderophore-producing *Pseudomonas* strain GRP3 on *Vigna radiate* for iron nutrition. After 45 days, the plants showed a decline in chlorotic symptoms and iron, chlorophyll a and chlorophyll b content increased in strain GRP3 inoculated plants compared to control.

Production of indolic compounds

Microbial synthesis of the phytohormone auxin has been well-known for a long time. [69] Reported that 80% of microbes isolated from the rhizosphere of various crops possess the ability to synthesize and release auxins as secondary metabolites. Indole acetic acid (IAA) affects division of plant cells, extension, and differentiation; stimulates tuber and seed germination; increases the rate of root and xylem development; initiates lateral; controls processes of vegetative growth and adventitious root formation; pigment formation, biosynthesis of various metabolites, mediates responses to light, gravity and florescence; affects photosynthesis, and resistance to stressful conditions. IAA produced by plant growth promoting bacteria possibly; delay the above physiological processes of plants by changing the plant auxin pool. Additionally, bacterial IAA increases root surface area and length, and thereby provides the plant greater access to soil nutrients. Similarly, the production of IAA in bacteria relaxes the cell walls and increases the release of exudates and also provides extra nutrients to support the growth of other helping bacteria of rhizosphere. Thus, endophytic bacterial IAA is identified as an effector molecule in plant– microbe interactions, both in pathogenesis and phytostimulation [70].

1-Aminocyclopropane-1-carboxylate (ACC) utilization

Generally, ethylene is an essential metabolite for the normal growth and development of plants [71]. This plant growth hormone is produced endogenously by approximately all plants and is also produced by different biotic and abiotic processes in soils and is important in inducing multifarious physiological changes in plants. The stress conditions such as water logging, drought, salinity, heavy metals and pathogenicity results in increase in endogenous level of ethylene which negatively regulates the overall growth of plant and this leads to the defoliation and alteration in other cellular processes that greatly affects the crop performance [72]. Currently, bacterial strains exhibiting ACC deaminase activity have been identified in a wide range of genera such as *Acinetobacter*, *Achromobacter, Agrobacterium, Alcaligenes, Azospirillum, Bacillus, Burkholderia, Enterobacter, Pseudomonas, Ralstonia, Serratia* and *Rhizobium* etc. [73]. Such bacterial endophytes trap the ethylene precursor ACC and convert it into 2-oxobutanoate and ammonia [74]. [75] showed that some forms of stress are dismissed by enzyme ACC deaminase producers, such as effects of phytopathogenic microorganisms (viruses, bacteria, and fungi *etc*.), and heavy metals, radiation, wounding, insect predation, high salt concentration, draft, extremes of temperature, high light intensity, and flooding resistance to stress from polyaromatic hydrocarbons.

Ammonia excretion:

Ammonia can be produced by several processes such as nitrite ammonification, degradation and decarboxylation, deamination, the urease-mediated hydrolytic degradation of urea and this ammonia produced by bacteria is taken up plants as a source of nitrogen for their growth [76]. Generally, all free-living rhizospheric microbes and some symbiotically association with plant fixes nitrogen which can be used by plant for growth, for example, *Gluconacetobacter*, *Herbaspirillum*, *Azospirillum*, *Bacillus*, *Enterobacter*, *Klebsiella*, *Pseudomonas*, and *Burkholderia*. These bacteria are appreciated for their significance in agricultural fertility. [77] screened 50 isolates for NH_3 production and out of which only seven bacterial isolates were able to produce ammonia while one *S. maltophilia* KC010525 was unable to produce ammonia.

Indirect mechanisms

Production of metabolites

Microorganisms are used to control various diseases, which is known as biological and also an environment friendly approach [78] and these microbes are known as biocontrol agents. In biological controls chief activities employed by PGPR and competition for niche exclusion, nutrients, induced systemic resistance and antifungal metabolites. [79] Reported that many rhizobacteria have been reported to produce antifungal metabolites like pyrrolnitrin, phenazines, 2, 4-diacetylphloroglucinol, pyoluteorin, HCN, viscosinamide and tensin. Few species of bacteria produces and excrete hydrogen cyanide (HCN) which is a powerful inhibitor of cytochrome C oxidase and many other metalloenzymes. HCN is a metabolite and it has no role in primary metabolism. Proteobacteria have HCN synthase which is a membrane bound flavoenzyme that oxidizes glycine, producing HCN and CO_2. The GacS/GacA (global control) is a two-component system which controls the expression of HCN gene cascade. This regulation of secondary metabolism, expresses itself during the transition from exponential to stationary growth phase. [80] Revealed that cyanide produced by *P. fluorescens* strain CHA0, accounts for part of the biocontrol capacity which suppresses fungal diseases on plant roots.

Some bacterial endophytes synthesize antibiotic substances that inhibit the growth of some plants pathogens. *Serratia mercescens* and *Bradyrhizobium sp*., both play an important role in plant growth promotion and biocontrol by producing siderophores, IAA, HCN and P solubilisation [81].

Field efficacy of endophytes

The effect of plant growth promoting rhizobacteria in crop productivity differs under greenhouse, field trials and laboratory because of unstable atmosphere and projected result is occasionally tedious to attain. Climatic disparities also have a huge impact on the success of plant growth promoting rhizobacteria but sometimes unfavorable growth conditions in the field are to be expected as normal functioning of agriculture. Plant growth promoting (PGP) traits do not work independently of each other but additively such as IAA, phosphate solubilization, N_2 fixation, siderophore biosynthesis, ACC deaminase and antifungal activity, *etc*. are responsible for the plant growth promotion and increased yield. Under both natural agroecological places and controlled soil environment result in significant increase in yields of different crop. Due to the prevailing hesitancy worldwide to encirclement foods produced by genetically modified plants, PGPR as bioinoculant may be advantageous for promoting plant growth. The wide scale application of PGPR may decline the worldwide dependence on agricultural chemicals. Likewise, it is a technology which is cheerfully practicable to farmers in both developed and developing countries.

Some research has shown that endophytes could significantly increase the yields in different crops after their inoculation. To reveal the effects of endophytes, various inoculation experiments have been performed. [82] Reported that out of 14 endophytes three improved soybean nodulation and plant weight when coinoculated with *Bradyrhizobium japonicum.* [83] Reported the impact of endophytes on soybean plant growth and development, two isolates had positive effects on root weights. Maximum shoot dry weight was given by I-73 (213 mg per plant) of *Glycine max* followed by I-109 (203 mg per plant) of *Glycine soja*. Both of these isolates enhanced the total plant biomass by more than 80% in comparison to uninoculated control. [84] reported in his study that endophytic bacterial inoculation had significant effect on seed germination, root and hypocotyl growth of *Solanum nigrum* seedling; 37 out of 77 isolates increased seedling vigor. Of these 37 isolates, 22 considerably improved seed germination up to 100% compared with uninoculated controls. [85] Assessed the effects of non-rhizobial endophytes from the surface sterilized root nodules of *Medicago sativa* L. on alfalfa growth. Coinoculation of all endophytic strains with *Sinorhizobium meliloti* significantly increased nodule number of alfalfa, but no significant effect on growth parameters with respect to inoculation with individual *Sinorhizobium meliloti*. Under pot house conditions inoculation of *Pseudomonas* sp. PS1 in Greengram greatly enhanced plant dry weight, leghaemoglobin, root N, shoot N, root P, shoot P, nodule number, total chlorophyll content, seed yield and seed protein [86]. Likewise, [87] described that nonrhizobial nodule-associated bacterial (NAB) isolates M2N2c and B1N2b (*Exiguobacterium sp*.) showed maximum positive PGP traits. Under pot house conditions, NAB isolates when coinoculated with rhizobial strain - *S. meliloti*, showed plant growth promotion with respect to increase in plant's root and shoot length, chlorophyll content, nodulation efficiency, and nodule dry weigh.Under field conditions, *P. putida* strain R-168, *P. fluorescens* strain R-93, *P. fluorescens* DSM 50090, *P. putida* DSM291, *A. lipoferum* DSM 1691, *A. brasilense* DSM 1690 inoculation in Maize crop exhibited increase in plant height, seed weight, number of seed per ear, leaf area and shoot dry weight significantly [89]. Similarly, [88] reported that *Pseudomonas fluorescens* PGPR1, PGPR2, PGPR4 in Peanut (*Arachis hypogaea* L.) under both Pot and field environment significantly enhanced pod yield and nodule dry weight over the control.

Bradyrhizobium sp. 750, *Pseudomonas* sp., *Ochrobactrum cytisi* inoculation in *Lupinus luteus* under field conditions increased both biomass, nitrogen content, accumulation of metals (improved phytostabilisation potential) [90]. [91] also stated that *Pseudomonas* sp. in wheat field and soybean, enhanced soil enzyme activities, total productivity and nutrient uptake.

Conclusion

The bacterial endophytes have engrossed huge consideration for their ability to promote plant growth through by acting as biocontrol agents (indirect mechanism) or direct mechanisms. Even though the mechanisms of plant growth promotion between endophyte and rhizospheric bacteria can be very alike because most of the studies have been done in rhizospheric bacteria, assuming that mechanism is same in endophytic bacteria. Though, the rhizospheric environment is somewhat dissimilar from that of internal plant tissues. For example, the variations in abiotic factors such as light emission, soil type, temperature, pH, the availability of oxygen as well as the struggle for nutrients, and the interaction with other organisms in the rhizosphere, can be key factors in the development of different strategies for interaction, lifestyle and survival inside the plant. These endophytic bacteria by various actions make available necessary nutrients which also reduces the application of chemical fertilizers. With a further understanding of the functioning of bacterial endophytes in the future scientists may be able to engineer bacterial endophytes to facilitate their potential to improve plant growth and development. The importance of assessing the ecological and evolutionary relevance of these processes should be stressed. The enhancement of bacterial colonization spurred by specific carbonaceous exudates by plant roots and the capacity of certain bacteria to modulate plant metabolism are key issues for further study, because these could provide insight into possibly mutualistic plant endophyte relationships. Particular endophytes could often have important, if not essential, roles for plant growth and development.

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