

PLANT GROWTH PROMOTION ACTIVITY OF BACTERIAL ENDOPHYTES

Abstract

Endophytes are bacterial and fungal members which can be detected inside the tissues of a healthy plant without producing any types of symptoms. Bacterial endophytes include a group of microbes which can be found inside a plant that help improve plant growth and derive better nutrients. This Plant Growth Promoting Bacterial group is less explored than the rhizospheric bacteria which are found in the soil near the plant root. A mechanism underlying direct and indirect plant growth promotion contributes to the great potential of endophytic bacteria in a wide range of real-world applications. A better understanding of morphological and genomic level details is needed to reveal unexplored qualities which would definitely add to the future prospects.

Keywords: Endophytes, Plant Growth Promoting Bacteria, Siderophore, ACC deaminase, Ethylene, Rhizosphere

Authors

Sreelakshmi Rajesh

Cell Culture Lab, Department of Botany,
Union Christian College
Aluva, Ernakulam, Kerala, India.
Pin-683 102

M. Anilkumar

Cell Culture Lab, Department of Botany,
Union Christian College
Aluva, Ernakulam, Kerala, India.
Pin-683 102
E mail: drmaumar@gmail.com

I. INTRODUCTION

Endophytes are endosymbiotic microorganisms colonizing the internal tissues of healthy host plants [1] and possess the ability to improve the quality and growth rate of their respective hosts [2]. Their colonization does not produce any disease symptoms or morphological changes like gall formation of plant tissues [3]. Most of the plants on earth are host to one or more types of endophytes [4]. These endophytes can be either bacteria or fungi [5,6]. Their population density in a host plant can vary from hundreds to more than 9×10^9 bacteria per gram of plant tissue [7,8, 9]. They can be either obligate or a facultative and the obligate types cannot be cultured due to their specificity of growth conditions. On the other hand, facultative endophytes can be cultured outside the plant tissue using artificial nutrient media [10, 11]. Endophytes form an important part of the micro-ecosystem inside plant tissues [12]. The most explored endophytes are non-pathogenic fungi that provide a number of useful characteristics to their host plant. However, bacterial endophytes remain an unexplored group [13]. Any bacteria which could be isolated from a surface-sterilized plant or extracted from its tissues can be called an endophyte if it does not affect the plant negatively. Bacteria can positively promote plant growth whereas studies show that plants are able to select these beneficial bacterial members in their microbiome including those inside the plant tissues [14, 15, 16]. There is no shred of evidence suggesting that these bacteria take advantage in this relationship [17], but certainly, they get protection from pathogens in adverse times. They could also communicate much better than the rhizospheric bacteria at times of stress [18,19].

Plant growth promoting bacteria include diverse group of genera like *Acetobacter*, *Achromobacter*, *Anabaena*, *Arthobacter*, *Azoarcos*, *Azospirillum*, *Azotobacter*, *Bacillus*, *Bukholderia*, *Clostridium*, *Enterohacter*, *Flavobacterium*, *Frankia*, *Hydrogenophaga*, *Kluyvera*, *Microcoleus*, *Phyllobacterium*, *Pseudomonas*, *Serratia*, *Staphylococcus*, *Streptomyces*, *Vibrio*, *Rhizobium* etc [20]. The presence of different endophytic bacterial species depends upon the host plant, bacteria, and biotic and abiotic factors [21, 22]. *Bacillus* and *Pseudomonas* are two bacterial genera frequently reported from agricultural crops [23]. Endophytes generally belong to α -, β -, and γ - proterobacteria out of which γ - proterobacteria is the most prevailing and common subgroup [21]. Endophytic bacteria may be culture-dependent and or independent. Normally culture-dependent endophytic bacteria belong to Proterobacteria [5]. These bacteria can colonize almost every part of a plant including underground and aboveground parts [24] and are isolated from leaves, stems, flowers, fruits, seeds, roots and tubers [22]. Most of them have a phase in their life cycle that alternates between plant and soil. In order to get a clear picture of the endophytic diversity of a plant, metagenomics approaches are the most accepted and novel method. This can unravel the actual amount of culturable and non- culturable endophytic composition without compromise. Amplification of bacteria specific genomic regions and application of bioinformatic tools are combined to enumerate the bacterial composition inside plant organs [25, 26].

II. PLANT GROWTH PROMOTING BACTERIA

Plant growth-promoting bacteria (PGPB) are not always seen as associated with plants but can be seen in bulk soil. They wait until appropriate colonization mechanisms evolve in the host plant. Gram-negative PGPB (non-spore-forming bacteria) in the absence of

their host form cysts and flocs that are large and visible aggregates that help them to withstand desiccation and reduce cell metabolism majority of PGPB store large amounts of polyhydroxybutyrate which is then used up in terms of nutrient scarcity [20]. They produce a large amount of secondary metabolites and hydrolytic enzymes [27]. An increase in the production of plant growth hormones and increasing availability of plant nutrients like nitrogen and phosphorus are some of the mechanisms that underlie plant growth-promoting activity of endophytes [28].

Plant growth-promoting bacteria (PGPB) comprise two types of soil bacteria-rhizospheric and endophytic bacteria. Rhizospheric bacteria are the ones found around the root of plants and endophytic species are found colonized inside a host plant [29]. Both these types have similar mechanisms of plant growth promotion. However, the significant difference is that the endophytic bacteria once stabilized inside a host plant are resistant towards variations in soil pH, water content or temperature. These are the major limiting factors in the case of rhizospheric bacteria [28] isolation and characterization.

III. ENDOPHYTIC BACTERIAL COLONIZATION INSIDE A PLANT

After bacterial cell inoculation, they colonize the rhizosphere of the host plant [30] and slowly attach to the root surface by forming a string of cells in a pattern [31]. They gradually colonize the entire root surface and some rhizodermal cells through the creation of microcolonies and biofilms of bacteria [32]. In order to attain successful endophytic colonization, the endophytic bacterial species must competently colonize the rhizosphere and rhizoplane of the plant [33] along with other rhizospheric members [34]. Adaptation of bacteria with the nutrients available in root exudates of target plants is inevitable [35].

Bacterial adhesion to cell surface structures is controlled by polysaccharides, pili and bacterial adhesins [36]. Every endophytic bacterium has its own colonization pattern, site preference and specialized mechanism for penetration [37]. Bacterial attachment to plants can happen by chemotaxis where bacteria migrate towards the root within hours of attachment. This occurs by hydrophobic interaction and lectin recognition with the bacteria and plant cells [20]. Bacterial penetration can occur through active and passive modes [16]. In the passive mode, bacteria enter into plants either through the emerging points of lateral roots or wounds [38]. remain “invisible” to the plant's immune system since they enter through the plant's natural cracks. The lateral root emergence point includes the epidermis, cortex, endodermis, casparian strip and pericycle which serve as the highway for endophytic microbe entry [39]. Active penetration by a proficient endophyte is through dedicated machinery of attachment and proliferation involving lipopolysaccharides, flagella, pili, twitching motility and quorum sensing [38, 39, 40, 41].

Bacteria move from cell to cell through the release of cell wall degrading enzymes, pectinases and cellulases [42] and then spread to above-ground tissues [39]. This movement inside the host is with the help of bacterial flagella and plant transpiration stream [42,43]. The final endophytic bacterial sink from the plant roots is the leaf tissues. They can also gain entry into this destination from the phyllosphere through leaf stomata [44]. The number and diversity of endophytic bacteria in the root will be higher and only a few reach shoots and reproductive organs [45, 39]. It might be the vascular tissues which pave the way for endophytic bacteria to the reproductive structures [46].

Table 1: Plant Growth-Promoting Endophytic Bacteria Isolated From Various Plants

Bacterial Species	Source Plant	Role	References
<i>Acetobacter diazotrophicus</i>	<i>Saccharum officinarum</i> L. <i>Ananas comosus</i> (L.) Merr.	Nitrogen fixation	[47, 20]
<i>Pseudomonas fluorescense</i>	<i>Dianthus caryophyllus</i> L. <i>Solanum melongena</i> L. <i>Solanum lycopersicum</i> L.	Disease resistance Biocontrol ACC deaminase activity	[48,49,15]
<i>Bacillus polymyxa</i>	<i>Triticum aestivum</i> L.	Metabolizing sorbitol	[50]
<i>Azospirillum</i>	Cactus	Enhance seedling establishment and survival in eroded desert areas	[20]
<i>Streptomyces virginiae</i> Y30 and E36	<i>Solanum lycopersicum</i> L.	Biocontrol	[51]
Enterobacter	<i>Gossypium hirsutum</i> L.	Protects 70% from Verticillium wilt	[52]
<i>Streptomyces</i> sp.	Clover Rice and chickpea Mung bean Soyabean	Helps in nutrient absorption Nutrient absorption and plant growth Improves plant growth Nutrient absorption and increased plant growth	[53,54,55,56,57]
<i>Streptomyces lydicus</i>	Pea	Nodulation	[58]
<i>Streptomyces aurantiogriseus</i>	Rice	IAA production	[59,60]
<i>Microbacterium takaoensis</i> strain P1P4	<i>Solanum lycopersicum</i> L.	ACC deaminase activity	[15]
<i>Bacillus psychrosaccharolyticus</i>	<i>Solanum lycopersicum</i> L.	ACC deaminase activity	[15]
<i>Pseudomonas</i> sp.	<i>Olea purpurea</i> L.	Biocontrol	[61]
<i>Azoarcus</i> sp. BH72	Kallar grass	Iron assimilation	[62]
<i>Variovorax paradoxus</i> S110	Potato	ACC deaminase activity, Iron assimilation	[63]
<i>Azospirillum</i> sp. B510	Rice	ACC deaminase activity, IAA and siderophore production	[64]
<i>Stenotrophomonas maltophilia</i> R551- 3	Poplar	Antibiotic production	[65]
<i>Serratia</i>	Poplar	Volatile production	[65]

<i>proteamaculans</i> 568			
<i>Herbaspirillum seropedicae</i> SmR1	Sorghum	ACC deaminase activity	[66]
<i>Enterobacter</i> sp. 638	Poplar	Iron assimilation, antimicrobial production, IAA and siderophore production	[67]
<i>Pseudomonas putida</i>	Poplar	IAA production	[65]
<i>Gluconacetobacter diatrophicus</i> Pal5	Onion	IAA production, Phosphate and zinc solubilization	[68]
<i>Bacillus subtilis</i> BSn5	Konjac	Invitro antibiosis	[69]
<i>Burkholderia phytofirmans</i> PsJN	Onion	ACC deaminase activity, IAA and siderophore production	[70]

IV. MECHANISM OF GROWTH PROMOTION

Mechanisms hired by plant growth promoting bacterial endophytes are analogous to that of rhizospheric bacteria [33]. This plant growth strategy can happen in different ways, either through direct or indirect mechanisms. Indirect mechanism involves providing increased disease resistance by inhibiting phytopathogens [71, 72, 73, 74]. Nitrogen fixation, siderophore production, and phytohormone synthesis are some of the direct mechanisms of growth promotion [75]. They increase the plant's stress tolerance level against high salinity, pesticide load, droughts and metal toxicity [20]. Endophytic bacteria are also reported to promote plant growth by changing stomatal responses, modification of nitrogen accumulation and metabolism and osmotic pressure regulation thereby altering plant physiology [76,77]. Some actinobacterial species improve soil fertility by producing siderophores, solubilizing phosphate, or by the producing amylase, chitinase, cellulase, invertase, lipase, keratinase, peroxidase, pectinase, protease, phytase and xylanase that improve the availability of natural fertilizers [78]. *Rhizobacteria* found as endophytes in plant roots continue to induce a stimulating activity in the colonized areas [79, 80]. This stimulation of plant growth occurs by increased plant health or by influencing its physiology. This can be attributed to the extra protection rendered by endophytes from pathogens directly or indirectly or by making them less vulnerable to phytophagous insects [81]. For example, *Streptomyces*, an agriculturally important endophytic soil bacterium produces a metabolite which upsurges host plant defence and reduces disease symptoms in adverse conditions [82]. They have got a number of antibacterial and antifungal metabolites and plant growth promoting (PGP) traits [83]. Results have shown that more than 60% of the antimicrobial and plant growth- promoting compounds originate from this genus [84]. The antibiotic production is often species specific and helps plant protection against pathogens whereas; *Streptomyces* receive plant exudates that promote its growth and development [85]. Bacterium *Pseudomonas putida* GR 12-2 is a documented and explored plant growth promoting rhizobacteria [86]. Later it was found that it contains an enzyme 1- aminocyclopropane- 1- carboxylate (ACC) deaminase that stimulate plant growth, specifically root elongation by sequestering and hydrolyzing ACC from germinating seeds and thereby ethylene [87,74].

V. DIRECT PLANT GROWTH PROMOTION

1. Production of Phytostimulators

Bacterial endophytes promote plant growth by increasing the production of phytohormones like ethylene, abscisic acid, cytokinins, gibberellins and auxins [88, 89, 90, 91, 92].

Several bacterial endophytes nearly 80% have been reported to produce auxin [93, 89] and most of them use tryptophan as a precursor [91]. Auxins are important plant growth hormones helping in lateral root formation and plant growth promotion at times of stress. Many rhizospheric bacteria are reported to produce and secrete gibberellins in the rhizosphere. Gibberellins are important in cell elongation, cell division and seed germination [89].

Bacterial endophytes produce an enzyme 1- aminocyclopropane- 1- carboxylate (ACC) deaminase which helps to reduce plant hormone ethylene in plants by breaking down ACC to α - ketobutyrate and ammonia [94, 95, 12, 96, 74, 97]. Ethylene is a major plant hormone which plays a significant role in times of seed germination, root initiation, fruit ripening, flower wilting, leaf abscission and in times of stress [98]. This hormone is normally synthesized in small amounts in plants except at the time of fruit ripening. During stress conditions like salinity, wounding, extremes of temperature, pathogen attack, flooding, drought, nutritional stress, heavy metal pollution, organic pollutants etc [99, 100, 101] plants undergo tremendous ethylene biosynthesis and is termed as “stress ethylene”[98,99]. Significant amount of damage that happens to the plant is due to the concentration of stress ethylene and not from the direct consequence of stress [99, 102] that can help to reduce levels of ethylene and promote plant growth can be used in times of stress to the plants. However, treatment with certain chemicals can cause negative effects to the plant and environment [98, 18]. Bacterial endophytes having capability to produce ACC deaminase enzyme can be successfully used to reduce ethylene content and increase plant growth activity in times of stress [30]. Bacterial endophyte, *Achromobacter xylosoxidans* AUM54, is reported to produce ACC deaminase thereby reducing ethylene levels in *Catharanthus roseus* grown in saline soil [103].

There are endophytes like *Azocarus sp.* that are known for fixing nitrogen [93, 104, 5, 62]. They are able to bind with atmospheric nitrogen and convert it into ammonia that can be used up by the plant.

Phosphorus is an important mineral needed for plant growth which plants cannot directly absorb. Rhizospheric bacteria are known to produce enzymes that act on phosphorus from organic and inorganic molecules to make them available to plants [90, 105, 106]. Most of the endophytes too have the property of performing this function. Phosphorus mobilization can be actively done by endophytes when they are still in their rhizoplane or rhizosphere soil i.e., when they have not entered the root interior. Nine out of eighteen endophytes isolated from ginseng stem could solubilize mineral phosphate [93].

Iron is a mineral which is largely inaccessible as it is poorly soluble in water [107]. But, these mineral ions are needed by all organisms. Bacteria secrete some low- molecular

weight molecules called siderophores that have a greater affinity towards ferric ions [108]. Siderophores have been important since they are found to have a significant role in plant disease suppression [109,110,111]. Endophytic bacteria are reported to produce siderophores in vitro [112] and may produce these metabolites inside root to cope with the highly iron depleted micro environments [5].

VI. INDIRECT PLANT GROWTH PROMOTION

1. Disease Resistance

Endophytic bacteria have evolved various mechanisms to suppress disease occurrence in host plants like rhizosphere bacteria [107, 113, 114,115, 116, 117, 118, 119, 120, 121, 122]. Many of such mechanisms were found in in vitro studies. For example, many of the isolated endophytic bacteria were able to produce antibiotics against some fungal pathogens in vitro. *Pseudomonas*, *Streptomyces* and *Bacillus* were found to be the endophytic bacterial antagonists in potato [123].

Bacterial endophytes are reported to use a mechanism known as Induced Systemic Resistance (ISR) [16, 89, 124, 125, 126, 127] through bacterial surface molecules, metabolites and volatiles [88, 89, 119] that is different from that of Systemic Acquired Resistance (SAR) [128]. Bacteria like *Bacillus amyloliquifasciens*, *Bacillus pumilus*, *Bacillus subtilis*, *Pseudomonas fluorescens*, *Pseudomonas syringae* and *Serratia marcescens* are some of the ISR inducing endophytes [129].

2. Adaptation Against Biotic and Abiotic Stress

Role in phytohormone production and regulating plant metabolism makes bacterial endophytes a part of plant abiotic and biotic stress managing systems. They might be providing plants with some important crop adaptation strategy as endophytic bacteria have themselves got mechanisms to overcome high salt, drought or water-logged conditions of soil [130]. Bacterial endophyte *Burkholderia phytofirmans* PsJN in Grapevine plants are reported to increase cold stress managing mechanism by varying use of carbohydrates and photosynthetic activity [131, 132]. In rice plants stress tolerance was increased due to endophytic bacteria *Pseudomonas pseudoalcaligenes* by secreting higher concentrations of glycine betain-like compounds [133].

Abscisic acid (ABA) is a plant derived hormone playing a great role in plant water balance and osmotic stress tolerance. Its values are found to be high when the plant is under stress condition. Endophytic bacterium *Azospirillum* sp. was reported to increase abscisic acid level in maize plants at times of water stress [134].

3. Biocontrol Activity of Bacterial Endophytes

Advancement in strategies and incorporation of genomic level approaches in endophytic research has helped in better understanding the biocontrol potential of bacterial endophytes [135]. *Bacillus amyloliquefaciens* isolated from peanuts produce antimicrobial compounds that lead to decrease in the incidence of peanut bacterial wilt caused by *Ralstonia solanacearum* [136]. The same bacterial endophyte, but a different strain Bg- C31 isolated from mangrove produces antimicrobial proteins against *Ralstonia solanacearum* causing

capsicum bacterial wilt [137]. *Pseudomonas fluorescens* PICF7 from *Olea europea* act against *Verticillium* wilt caused by *Verticillium dahlia* by enhancing plant growth and induced systemic resistance [138,139]. *Serratia marcescens* UPM39B3 promoted growth in banana plants by deferring the onset of symptoms for 7- 10days against *Fusarium* wilt caused by *Fusarium oxysporum* [140].

4. Rhizoremediation

The Removal of environmental pollutants using rhizospheric microbes is termed as rhizoremediation (Kuiper et al., 2004). It is referred to as phytoremediation [141] when degradation is carried out by plants and the role of microbes are unnoticed. Endophyte *Burkholderia cepacia* in *Lupinus luteus* L. (yellow pine) is genetically modified to improve organic pollutants remediation [142]

VII. PLANT GROWTH PROMOTION BY INOCULATION OF PGPB

There are many bacteria that are used to exploit their plant growth promotion activity on a commercial scale. *Azospirillum* is one among the best-known symbiotic Plant growth promoting bacteria (PGPB). Experiments have shown that this bacterium can increase crop yield by 5- 30%, however inoculum establishment is very difficult. This may be due to some reasons:

- I. If the bacteria are not successfully attached to the root epidermal layer, growth substances produced by the bacteria will diffuse to the soil and will be used up by the microbes present in the soil.
- II. If the attachment is unsuccessful bacteria may get washed out from the rhizosphere soil of its host plant which reduces their chance of survival.
- III. Some other non-beneficial root microbes may have already colonized potential association sites of PGPB [143,144, 145].

VIII. CONCLUSION

It is evident that bacteria play an important role in balancing the link between plant physiology and different ecosystems. Apart from rhizospheric bacteria, bacterial endophytes are better adapted with their hosts and can be used positively in plant growth promotion activities. However, endophytic bacterial species were less explored when compared to rhizospheric bacteria. Now, these plant growth promoters are of growing interest. Endophytes could be used as bio inoculants to promote plant growth and fitness in agricultural crops. They could also be used in industrial and medical applications like antibiotic production. However, like some rhizosphere bacteria, endophytes are found to be potential human-pathogenic bacteria which may cause some serious health issues. It is important to screen all the endophytes at initial stages of research itself.

CONFLICT OF INTEREST

The authors report no conflict of interest.

ACKNOWLEDGEMENTS

This research is supported by Junior Research Fellowship (JRF) funded by Council of Scientific & Industrial Research (CSIR) and University Grants Commission (UGC).

REFERENCES

- [1] Smith KP, Goodman RM. 1999. Host variation for interaction with beneficial plant-associated microbes. *Annual review of Phytopathology*. 37: 473- 491. DOI: <https://doi.org/10.1146/annurev.phyto.37.1.473>
- [2] Eevers N, Gielen M, Sanchez- Lopez A, Jaspers S, White JC, Vangronsveld J, Weyens N. 2015. Optimization of isolation and cultivation of bacterial endophytes through addition of plant extract to nutrient media. *Microbial Biotechnology*. 4: 0- 15. DOI: <https://doi.org/10.1111/1751-7915.12291>
- [3] Compant S, Mitter B, Colli- Mull JG, Gangl H, Sessitsch A. 2011. Endophytes of grapevine flowers, berries, and seeds: identification of cultivatable bacteria, comparison with other plant parts, and visualization of niches of colonization. *Microbial Ecology*. 62: 188- 197. DOI: <https://doi.org/10.1007/s00248-011-9883-y>
- [4] Ryan RP, Germaine K, Franks A, Ryan DJ, Dowling DN. 2008. Bacterial endophytes: recent developments and applications. *FEMS Microbiology*. 278: 1–9. DOI: <https://doi.org/10.1111/j.1574-6968.2007.00918.x>
- [5] Reinhold-Hurek B, Hurek T. 2011. Living inside plants: bacterial endophytes. *Current opinion in Plant Biology*. 14: 435–443. DOI: <https://doi.org/10.1016/j.pbi.2011.04.004>
- [6] Singh LP, Gill SS, Tuteja N. 2011. Unraveling the role of fungal symbionts in plant abiotic stress tolerance. *Plant Signaling & Behavior*. 6: 175–191. DOI: <https://doi.org/10.4161/psb.6.2.14146>
- [7] Jacobs MJ, Bugbee WM, Gabrielson DA. 1985. Enumeration, location, and characterization of endophytic bacteria within sugar beet roots. *Canadian Journal of Botany*. 63: 1262- 1265. DOI: <https://doi.org/10.1139/b85-174>
- [8] Misaghi IJ, Donndelinger CR. 1990. Endophytic bacteria in symptom- free cotton plants. *Phytopathology Journal*. 80: 808- 811.
- [9] Chi F, Shen SH, Cheng HP, Jing YX, Yanni YG, Dazzo FB. 2005. Ascending migration of endophytic rhizobia, from roots to leaves, inside rice plants and assessment of benefits to rice growth physiology. *Applied and environmental Microbiology*. 71: 7271- 7278. DOI: <https://doi.org/10.1134/S0003683815030059>
- [10] Waheeda K, Shyam KV. 2017. Formulation of novel surface sterilization method and culture media for the isolation of endophytic actinomycetes from medicinal plants and its antibacterial activity. *Journal of plant pathology & microbiology*. 8: 339- 345.
- [11] Christina A, Christopher V, Bhore SJ. 2013. Endophytic bacteria as a source of novel antibiotics: An overview. *Pharmacognosy Reviews*. 7: 11- 16. DOI: <https://dx.doi.org/10.4103%2F0973-7847.112833>
- [12] Zhang HW, Song YC, Tan RX. 2006. Biology and chemistry of endophytes. *Natural products report*. 23: 53- 1. DOI: <https://doi.org/10.1039/B609472B>
- [13] Chanway CP. 1998. Bacterial endophytes: ecological and practical implications. 7th international Congress of Plant Pathology. 50: 149- 170.
- [14] Marasco R, Rolli E, Ettoumi B, Vigani G, Mapelli F, Borin S, Abou-Hadid AF, El-Behairy UA, Sorlini C, Cherif A, Zocchi G, Daffonchio D. 2012. A drought resistance-promoting microbiome is selected by root system under desert farming. *PLoS One* 7, e48479. DOI: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0048479>
- [15] Rashid S, Charles TC, Glick BR. 2012. Isolation and characterization of new plant growth-promoting bacterial endophytes. *Applied Soil Ecology*. 61: 217–224. DOI: <https://doi.org/10.1016/j.apsoil.2011.09.011>
- [16] Hardoim PR, van O, Verbeek LS, van E, Isas JD. 2008. Properties of bacterial endophytes and their proposed role in plant growth. *Trends in Microbiology*. 16: 463–471. DOI: <https://doi.org/10.1016/j.tim.2008.07.008>
- [17] Rosenblueth M, Martinez-Romero E. 2004. *Rhizobium etli* maize populations and their competitiveness for root colonization. *Archives of Microbiology*. 181: 337–344 . DOI: <https://doi.org/10.1007/s00203-004-0661-9>

- [18] Ali S, Charles TC, Glick BR. 2012. Delay of flower senescence by bacterial endophytes expressing 1-aminocyclopropane-1-carboxylate deaminase. *Journal of applied Microbiology*. 113: 1139-1144. DOI: <https://doi.org/10.1111/j.1365-2672.2012.05409.x>
- [19] Coutinho BG, Licastro D, Mendonça, a-Previato L, Câmara M, Venturi V. 2015. Plant-influenced gene expression in the rice endophyte *Burkholderia kururiensis* M130. *Molecular Plant-Microbe Interaction*. 28: 10–21. DOI: <https://doi.org/10.1094/MPMI-07-14-0225-R>
- [20] Bashan, Y., & De-Bashan, L. E. (2005). Plant growth-promoting. *Encyclopedia of soils in the environment, 1*, 103-115.
- [21] Kuklinsky-Sobral J, Araujo WL, Mendes R, Geraldi IO, Pizzirani-Kleiner AA, Azevedo JL. 2004. Isolation and characterization of soybean-associated bacteria and their potential for plant growth promotion. 6: 1244-1251. DOI: <https://doi.org/10.1111/j.1462-2920.2004.00658.x>
- [22] Rosenblueth M, Martinez-Romero E. 2006. Bacterial Endophytes and Their Interactions with Hosts. *Molecular Plant-Microbe Interactions*. 19. DOI: <https://doi.org/10.1094/mpmi-19-0827>
- [23] Seghers D, Wittebolle L, Top EM, Verstraete W, Siciliano D. 2004. Impact of agricultural practices on the *Zea mays* L. endophytic community. *Applied and Environmental microbiology*. 70: 1475-1482. DOI: <https://doi.org/10.1128/AEM.70.3.1475-1482.2004>
- [24] Chebotar V, Malfanova N, Shcherbakov A, Ahtemova G, Borisov AY, Lugtenberg B, Tikhonovich I, 2015. Endophytic bacteria in microbial preparations that improve plant development. *Applied biochemistry and microbiology*. 51: 271–277. DOI: <https://doi.org/10.1134/S0003683815030059>
- [25] Chun j, Lee JH, Jung Y, Kim M, Kim BK, Lim YW. 2007. Eztaxon: a web-based tool for the identification of prokaryotes based on 16S ribosomal RNA gene sequences. *International Journal of Systematic and Evolutionary Microbiology*. 57: 2259-2261. DOI: <https://doi.org/10.1099/ijs.0.64915-0>
- [26] Manter DK, Delgado JA, Holm DG, Stong RA. 2010. Pyrosequencing reveals a highly diverse and cultivar specific bacterial endophyte community in potato roots. *Microbial Ecology*. 60: 157-166. DOI: <https://doi.org/10.1007/s00248-010-9658-x>
- [27] Brader G, Compant S, Mitter B, Trognitz F, Sessitsch A. 2014. Metabolic potential of endophytic bacteria. *Current opinion in Biotechnology*. 27: 30-37. DOI: <https://doi.org/10.1016/j.copbio.2013.09.012>
- [28] Glick BR. 2012. Plant growth promoting bacteria: mechanisms and applications. *Scientifica*. 2012: 1-15. DOI: <https://doi.org/10.6064/2012/963401>
- [29] Lacava PT, Azevedo JL. 2013. Endophytic Bacteria: A Biotechnological Potential in Agrobiological System. In: Maheshwari D, Saraf M, Aeron A. (eds). *Bacteria in Agrobiological: Crop Productivity*. Springer, Berlin, Heidelberg. DOI: https://doi.org/10.1007/978-3-642-37241-4_1
- [30] Gamalero E, Lingua G, Berta G, Lemanceau P. 2003. Methods for studying root colonization by introduced beneficial bacteria. *Agronomy*. 23: 407–418. DOI: https://doi.org/10.1007/978-90-481-2666-8_37
- [31] Hansen M, Kragelund L, Nybro O, Sorensen J. 1997. Early colonization of barley roots by *Pseudomonas fluorescens* studied by immunofluorescence technique and confocal laser scanning microscopy. *FEMS Microbiology Ecology*. 23: 353–360. DOI: <https://doi.org/10.1111/j.1574-6941.1997.tb00416.x>
- [32] Benizri E, Baudoin E, Guckert A. 2001. Root colonization by inoculated plant growth promoting rhizobacteria. *Biocontrol Sci. Technol*. 11: 557–574. DOI: <https://doi.org/10.1080/09583150120076120>
- [33] Compant S, Brion D, Nowak J, Clement C, Ait Barka E, 2005. Use of plant growth promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. *Applied Environmental Microbiology*. 71: 4951–4959. DOI: <https://doi.org/10.1128/AEM.71.9.4951-4959.2005>
- [34] Whipps JM. 2001. Microbial interactions and biocontrol in the rhizosphere. *J. Exp. Bot*. DOI: https://doi.org/10.1093/jexbot/52.suppl_1.487
- [35] Walker TS, Bais HP, Grotewold E & Vivanco JM. (2003). Root exudation and rhizosphere biology. *Plant physiology*, 132(1), 44-51.
- [36] Hori K, Matsumoto S. 2010. Bacterial adhesion: from mechanism to control. *Biochemical Engineering Journal*. 48: 424-434. DOI: <https://doi.org/10.1016/j.bej.2009.11.014>
- [37] Afzal, I, Shinwari ZK, Sikandar S & Shahzad S. (2019). Plant beneficial endophytic bacteria: Mechanisms, diversity, host range and genetic determinants. *Microbiological research*, 221, 36-49.
- [38] Bohm M, Hurek T, Reinhold-Hurek B. 2007. Twitching motility is essential for endophytic Rice Colonization by the N₂-Fixing Endophyte *Azoarcus* sp. Strain BH72. *The American Phytopathological Society*. 20: 526-533. DOI: <https://doi.org/10.1094/MPMI-20-5-0526>
- [39] Compant S, Clement C, Sessitsch A. 2010. Plant growth-promoting bacteria in the rhizo- and endosphere of plants: Their role, colonization, mechanisms involved and prospects for utilization. *Soil Biology and Biochemistry*. 42: 669-678. DOI: <https://doi.org/10.1016/j.soilbio.2009.11.024>

- [40] Dorr J, Hurek T, Reinhold- Hurek b. 1998. Type IV pili are involved in plant–microbe and fungus–microbe interactions. *Molecular Biology*. 30:7- 17. DOI: <https://doi.org/10.1046/j.1365-2958.1998.01010.x>
- [41] Duijff BJ, Gianinazzi-Pearson V, Lemanceau P. 1997. Involvement of the outer membrane lipopolysaccharides in the endophytic colonization of tomato roots by biocontrol *Pseudomonas fluorescens* strain WCS417r. *New phytologist*. 325-334. DOI: 10.1046/j.1469-8137.1997.00646.x
- [42] Suarez-Moreno ZR, Devescovi G, Myers M, Hallack L, Mendonça-Previato L, Caballero- Mellado J, Venturi V. 2010. Commonalities and Differences in Regulation of N- Acyl Homoserine Lactone Quorum sensing in the beneficial plant- associated Burkholderia species cluster. *Applied Environmental Microbiology*. 76: 4302–4317. DOI: <https://doi.org/10.1128/AEM.03086-09>.
- [43] Compant S, Duffy B, Nowak J, Clement C, Barka EA. 2005. Use of plant growth promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. *Applied environmental Microbiology*. 21: 1- 18. DOI: <https://doi.org/10.1128/AEM.71.9.4951-4959.2005>
- [44] James EK, Gyaneshwar P, Mathan N, Barraquio WL, Reddy PM, Lannetta PPM, Olivares FL, Ladha JK. 2002. Infection and colonization of rice seedlings by the plant growth-promoting bacterium *Herbaspirillum seropedicae* Z67. *Molecular Plant Microbe Interaction*. 20: 526–533. DOI: <https://doi.org/10.1094/MPMI.2002.15.9.894>
- [45] Senthilkumar M, Anandham R, Madhaiyan M, Venkateswaran V, Sa T. 2011. Endophytic Bacteria: Perspectives and Applications in Agricultural Crop Production. In: Maheshwari D. (eds) *Bacteria in Agrobiology: Crop Ecosystems*. Springer, Berlin, Heidelberg. DOI: https://doi.org/10.1007/978-3-642-18357-7_3
- [46] Truyens S, Weyens N, Cuypers A & Vangronsveld J. (2015). Bacterial seed endophytes: genera, vertical transmission and interaction with plants. *Environmental Microbiology Reports*, 7(1), 40-50.
- [47] Agarwal VK, Sinclair JB. 1996. Principles of seed pathology. Lewis Publication, Boca Raton, Florida. DOI: <https://doi.org/10.1201/9781482275650>
- [48] Gillis M, Kersters B, Hoste D, Janssens D, Kroppenstedt M, Stephan MP, Teixeira KRS, Doberiner J, Dey Ley J. 1989. *Acetobacter diazotrophicus* sp. nov., a nitrogen- fixing acetic acid bacterium associated with sugarcane. *International journal of Systematic Bacteriology*. 39: 361- 364. DOI: <https://doi.org/10.1099/00207713-39-3-361>
- [49] Van Peer R, Schippers B. 1992. Lipopolysaccharides of plant growth promoting *Pseudomonas* sp. strain WCS417r. *Phytopathology*. 81: 728- 734. DOI: <https://doi.org/10.1007/BF01996325>
- [50] Ramesh, R., Joshi, A. A., & Ghanekar, M. P. (2009). Pseudomonads: major antagonistic endophytic bacteria to suppress bacterial wilt pathogen, *Ralstonia solanacearum* in the eggplant (*Solanum melongena* L.). *World Journal of Microbiology and Biotechnology*, 25, 47-55.
- [51] Mavingui P, Laguerre G, Berge O, Heulin T. 1992. Applied and environmental microbiology. Genetic and Phenotypic Diversity of *Bacillus polymyxa* in Soil and in the Wheat Rhizosphere. 58: 1894 – 1903. DOI: <https://doi.org/10.1128/aem.58.6.1894-1903.1992>
- [52] Sharma V & Salwan R. (2018). Biocontrol potential and applications of Actinobacteria in agriculture. *In New and future developments in microbial biotechnology and bioengineering (pp. 93-108)*. Elsevier.
- [53] Li HY, Wei DQ, Shen M et al. 2012. Endophytes and their role in phytoremediation. *Fungal Diversity*. 54: 11–18 . DOI: <https://doi.org/10.1007/s13225-012-0165-x>
- [54] Franco- Correa M, Quintana A, Duque C, Suarez C, Rodriguez MX, Barea JM. 2010. Evaluation of actinomycete strains for key traits related with plant growth promotion and mycorrhiza helping activities. *Applied Soil Ecology*. 45: 209- 217. DOI: <https://doi.org/10.1016/j.apsoil.2010.04.007>
- [55] Gopalakrishnan S, Srinivas V, Alekhya G, Prakash B, Kudupa H, Varshney RK. 2015. Evaluation of *Streptomyces* sp. obtained from herbal vermicompost for broad spectrum of plant growth promoting activities in chickpea. *Organic Agriculture*. 5: 123- 133. DOI: <https://doi.org/10.1007/s13165-015-0099-1>
- [56] Gopalakrishnan S, Vadlamudi S, Bandikinda P, Sathya A, Vijayabharathi R, Rupela O, Kudapa H, Kat ta K, Varshney RK. 2015. Evaluation of *Streptomyces* strains isolated from herbal vermicompost for broad spectrum of plant- growth promoting activities in chickpea. *Organic Agriculture*. 5: 123- 133. DOI: <https://doi.org/10.1016/j.micres.2013.09.008>
- [57] Rungin S, Indananda C, Suttiviriya P, Kruasuwan W, Jaemsang R, Thamchaipenet A. 2012. Plant growth enhancing effects by a siderophore producing endophytic streptomycete isolated from a Thai jasmine rice plant (*Oryza sativa* L. cv. KDML105). *Antonie Leeuwenhoek*. 102: 463- 472. DOI: <https://doi.org/10.1007/s10482-012-9778-z>
- [58] Nimnoi P, Pongslip N, lomyong S. 2014. Co- inoculation of soybean (*Glycine max*) with actinomycetes and *Bradyrhizobium japonicum* enhances plant growth, nitrogenase activity and plant nutrition. *Journal of Plant nutrition*. 37: 432- 446. DOI: <https://doi.org/10.1080/01904167.2013.864308>

- [59] Tokala R, strap J, Jung CM, Crawford DL, Salove MH, Deobald LA, Bailey JF, Morra MJ. 2002. Novel plant microbe rhizosphere interaction involving *Streptomyces lydicus* WYEC 108 and the pea plant (*Pisum sativum*). *Applied Environmental Microbiology*. 2161- 211. DOI: <https://doi.org/10.1128/AEM.68.5.2161-2171.2002>
- [60] Harikrishnan H, Shanmugaiah V, Balasubramanian N, Sharma MP, Kotchoni SO. 2014a. Antagonistic potential of native strain *Streptomyces aurantiogriseus* VSMGT1014 against Sheath Blight of rice disease. *World journal of Microbiology and Biotechnology*. 30: 3149- 3161. DOI: <https://doi.org/10.1007/s11274-014-1742-9>
- [61] Harikrishnan H, Shanmugaiah V, Balasubramanian N. 2014b. Optimization for production of indole acetic acid (IAA) by plant growth promoting *Streptomyces* sp. VSMGT1014 isolated from rice rhizosphere. *International journal of current microbiology and applied sciences*. 3: 158- 171.
- [62] Prieto P, Schiliro E, Maldonado-Gonzalez M, Valderrama R, Barroso-Albarracín JB, Mercado-Blanco J. 2011. Root hairs play a key role in the endophytic colonization of olive roots by *Pseudomonas* spp. with biocontrol activity. *Microbial Ecology*. 62: 435-45. DOI: 10.1007/s00248-011-9827-6
- [63] Krause A, Ramakumar A, Bartels D, Battistoni F, Bekel T, Boch J, Böhm M, et al. 2006. Complete genome of the mutualistic, N₂-fixing grass endophyte *Azoarcus* sp. strain BH72. *Nature Biotechnology*. 24: 1385-1391. DOI: <https://doi.org/10.1038/nbt1243>
- [64] Han J-I, Choi H-K, Lee S-W, Orwin PM, Kim J, Laroe SL, Kim T-G, et al. 2011. Complete genome sequence of the metabolically versatile plant growth-promoting endophyte *Variovorax paradoxus* S110. *Journal of Bacteriology*. 193: 1183-1190. DOI: <https://doi.org/10.1128/JB.00925-10>
- [65] Kaneko T, Minamisawa K, Isawa T, Nakatsukasa H, Mitsui H, Kawaharada Y, Nakamura Y, et al. 2010. Complete genomic structure of the cultivated rice endophyte *Azospirillum* sp. B510. *DNA Res.*: 17: 37-50. DOI: <https://doi.org/10.1093/dnares/dsp026>
- [66] Taghavi S, Garafola C, Monchy S, Newman L, Hoffman A, Weyens N, Barac T, Vangronsveld J, van der Lelie D. 2009. Genome survey and characterization of endophytic bacteria exhibiting a beneficial effect on growth and development of poplar trees. *Applied Environmental Microbiology*. 75: 748-757. DOI: <https://doi.org/10.1128/AEM.02239-08>
- [67] Pedrosa FO, Monteiro RA, Wasseem R, Cruz LM, Ayub RA, Colauto NB, Fernandez MA, et al. 2011. Genome of *Herbaspirillum seropedicae* strain SmR1, a specialized diazotrophic endophyte of tropical grasses. *PLoS genetics* 7: e1002064. DOI: <https://doi.org/10.1371/journal.pgen.1002064>
- [68] Taghavi S, van der Lelie D, Hoffman A, Zhang Y-B, Walla MD, Vangronsveld J, Newman L, Monchy S. 2010. Genome sequence of the plant growth promoting endophytic bacterium *Enterobacter* sp. 638. *PLoS genetics* 6: e1000943. DOI: <https://doi.org/10.1371/journal.pgen.1000943>
- [69] Bertalan M, Albano R, de Padua V, Rouws L, Rojas C, Hemerly A, Teixeira K, et al. 2009. Complete genome sequence of the sugarcane nitrogen-fixing endophyte *Gluconacetobacter diazotrophicus* Pal5. *BMC Genomics* 10: 450. DOI: <https://doi.org/10.1186/1471-2164-10-450>
- [70] Deng Y, Zhu Y, Wang P, Zhu L, Zheng J, Li R, Ruan L, Peng D, Sun M. 2011. Complete genome sequence of *Bacillus subtilis* BSn5, an endophytic bacterium of *Amorphophallus konjac* with antimicrobial activity for the plant pathogen *Erwinia carotovora* subsp. *carotovora*. *Journal of Bacteriology*. 193: 2070-2071. DOI: <https://doi.org/10.1128/JB.00129-11>
- [71] Weilharter A, Mitter B, Shin MV, Chain PSG, Nowak J, Sessitsch A. 2011. Complete genome sequence of the plant growth-promoting endophyte *Burkholderia phytofirmans* strain PsJN. *Journal of Bacteriology*. 193: 3383-3384. DOI: <https://doi.org/10.1128/JB.05055-11>
- [72] O' Sullivan DJ, O' Gara F. 1992. Traits of fluorescent *Pseudomonas* spp. Involved in suppression of plant root pathogens. *Microbiology Review*. 56: 662- 66. DOI: <https://doi.org/10.1128/mr.56.4.662-676.1992>
- [73] Sivan A, Chet I. 1992. Microbial control of plant diseases. In *Environmental microbiology*. 335- 354.
- [74] Cook RJ. 1993. Making greater use of introduced microorganisms for biological control of plant pathogens. *Annual Review of Phytopathology*. 31: 53- 80. DOI: <https://doi.org/10.1146/annurev.py.31.090193.000413>.
- [75] Glick BR. 1995b. The enhancement of plant growth by free- living bacteria. *Canadian Journal of microbiology*. 41: 109- 117. DOI: <https://doi.org/10.1139/m95-015>
- [76] Brown ME. 1974. Seed and root bacterization. *Annual Review of Phytopathology*. 12: 181- 197. DOI: <https://doi.org/10.1146/annurev.py.12.090174.001145>
- [77] Compant S, Nowak BJ, Clement C, Ait Barka E. 2005. Use of plant growth promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action and future prospects. *Applied Environmental Microbiology*. 71: 4951- 4959. DOI: <https://doi.org/10.1128/AEM.71.9.4951-4959.2005>

- [78] Compant S, Reiter B, Sessitsch A, Nowak J, Clement C, Barka EA, 2005. Endophytic colonization of *Vitis vinifera* L. by plant growth promoting bacterium *Burkholderia* sp. strain PsJN. *Applied and endophytic microbiology*. 71. DOI: 1685- 1693. <https://doi.org/10.1128/AEM.71.4.1685-1693.2005>
- [79] Jog R, Nareshkumar G, Rajkumar S. 2016. Enhancing soil health and plant growth promotion by actinomycetes.33- 45. DOI: https://doi.org/10.1007/978-981-10-0707-1_3
- [80] Viaene T, Langendries S, Beirinckx S, Maes M, Goormachtig S. 2016. *Streptomyces* as a plant's best friend?. *FEMS Microbiology Ecology*. 92. DOI: <https://doi.org/10.1093/femsec/fiw119>
- [81] Sturz AV, Nowak J. 2000. Endophytic communities of rhizobacteria and the strategies required to create yield enhancing associations with crops. *Applied Soil Ecology*. 15: 183- 190. DOI: [https://doi.org/10.1016/S0929-1393\(00\)00094-9](https://doi.org/10.1016/S0929-1393(00)00094-9)
- [82] Pangesti N, Pineda A, Pieterse C, Dicke M, Van Loon JJA. 2013. Two- way plant mediated interactions between root- associated microbes and insects: From ecology to mechanisms. *Frontiers in Plant Science*. 4: 414. DOI: <https://doi.org/10.3389/fpls.2013.00414>
- [83] Kumar, V., & Nautiyal, C. S. (2022). Plant abiotic and biotic stress alleviation: From an endophytic microbial perspective. *Current Microbiology*, 79(10), 311.
- [84] Goodfellow M, Simpson KE. *Ecology of Streptomyces*.1987. *Frontiers in applied microbiology*. 2: 97-125.
- [85] Alam M, Dahrni S, Khaliq A, Srivastava SK, Samad A, Gupta MK. 2012. A promising strain of *Streptomyces* sp. with agricultural traits for growth promotion and disease management. *Indian journal of experimental microbiology*. 50: 559- 568.
- [86] Procopio RE, Silva IR, Martins MK, Azevedo JL, Araujo JM. 2012. Antibiotics produced by *Streptomyces* . *The Brazilian Journal of Infectious Diseases*. 16: 466- 471. DOI: <https://doi.org/10.1016/j.bjid.2012.08.014>
- [87] Lifshitz R, Kloepper JW, Kozlowski M, Simonson C, Carlson J. Tipping Em, Zaleska I. 1987. Growth promotion of canola (rapeseed) seedlings by a strain of *Pseudomonas putida* under gnotobiotic conditions. *Canadian Journal of Microbiology*. 33: 390- 395. DOI: <https://doi.org/10.1139/m87-068>
- [88] Glick BR, Jacobson CB, Schware MMK, Pastenak JJ. 1994a. 1- Aminocyclopropanr- 1- carboxylic acid deaminase mutants of plant growth promoting rhizobacterium *Pseudomonas putida* GR12- 2 do not stimulate canola root elongation. *Canadian Journal of Microbiology*. 40: 911- 915. DOI: <https://doi.org/10.1139/m94-146>
- [89] Lugtenberg B, Malfanova N, Kamilova F, Berg G. 2013. Plant growth promotion by microbes. In: *Molecular microbial ecology of the rhizosphere*; de Bruijn FJ, Ed. 2013. ch 53, Wiley-Blackwell, Hoboken, NJ, USA . 561-73.
- [90] Pliego C, Kamilova F, Lugtenberg B. 2011. Plant Growth-promoting bacteria: Fundamentals and exploitation. In: *Bacteria in Agrobiolgy: Crop Ecosystems*; Maheshwari DK, Ed. Springer, Germany. 295-343. DOI: https://doi.org/10.1007/978-3-642-18357-7_11
- [91] Rodriguez H, Frago R. 1999. Phosphate-solubilising bacteria and their role in plant growth promotion. *Biotechnology Advances*. 17: 319-39. DOI: [https://doi.org/10.1016/S0734-9750\(99\)00014-2](https://doi.org/10.1016/S0734-9750(99)00014-2)
- [92] Spaepen S, Vanderleyden J, Okon Y. 2009. Plant growth-promoting actions of rhizobacteria. *Annual Botanical Research* . 51: 283-320. DOI: [https://doi.org/10.1016/S0065-2296\(09\)51007-5](https://doi.org/10.1016/S0065-2296(09)51007-5)
- [93] Khalid A, Tahir S, Arshad M, Zahir ZA. 2004. Relative efficiency of rhizobacteria for auxin biosynthesis in rhizosphere and non rhizosphere soils. *Australian Journal of Soil Research*. 42: 921-6. DOI: <https://doi.org/10.1071/SR04019>
- [94] Vendan RT, Yu YJ, Lee SH, Rhee YH. 2010. Diversity of endophytic bacteria in ginseng and their potential for plant growth promotion. *Journal of Microbiology*. 48: 559-65. DOI: <https://doi.org/10.1007/s12275-010-0082-1>
- [95] Sessitsch A, Coenye T, Sturz AV, Vandamme P, Barka EA, Salles JF, Elsas JDV, Faure D, Reiter B, Glick BR, Wang-Pruski G, Nowak J. 2005. *Burkholderia phytofirmans* sp. nov., a novel plant-associated bacterium with plant-beneficial properties. *International journal of systematic and evolutionary microbiology*. 55. DOI: <https://doi.org/10.1099/ijs.0.63149-0>
- [96] Sun Y, Cheng Z, Glick BR. 2009. The presence of a 1-aminocyclopropane-1-carboxylate (ACC) deaminase deletion mutation alters the physiology of the endophytic plant growth-promoting bacterium *Burkholderia phytofirmans* PsJN, *FEMS Microbiology Letters*. 296: 131–136. DOI: <https://doi.org/10.1111/j.1574-6968.2009.01625.x>
- [97] Singh, R. P., Shelke, G. M., Kumar, A., & Jha, P. N. (2015). Biochemistry and genetics of ACC deaminase: a weapon to “stress ethylene” produced in plants. *Frontiers in microbiology*, 6, 937.

- [98] Del Carmen Orozco-Mosqueda, M., Glick, B. R., & Santoyo, G. (2020). ACC deaminase in plant growth-promoting bacteria (PGPB): An efficient mechanism to counter salt stress in crops. *Microbiological Research*, 235, 126439.
- [99] Abeles FB, Morgan FW, Salveit ME. 1992. Ethylene in plant biology. 2nd edition. Academic press. San Diego. 414.
- [100] Stearns JC, Glick BR. 2003. Transgenic plants with altered ethylene biosynthesis or perception. *Biotechnological Advances*. 21, 193- 210. DOI: [https://doi.org/10.1016/S0734-9750\(03\)00024-7](https://doi.org/10.1016/S0734-9750(03)00024-7)
- [101] Hyodo H, tanaka K, Suzuki T. 1991. Wound- induced ethylene synthesis and its involvement in enzyme induction in mesocarp tissue of *Cucurbita maxima*. *Postharvest Biology and Technology*. 1: 127- 136. DOI: [https://doi.org/10.1016/0925-5214\(91\)90004-U](https://doi.org/10.1016/0925-5214(91)90004-U)
- [102] Morgan PW, Drew MC. 1997. Ethylene and plant responses to stress. *Physiology plantarum*. 100: 620-630. DOI: <https://doi.org/10.1111/j.1399-3054.1997.tb03068.x>
- [103] Van Loon LC, Fontaine JJH. 1984. Accumulation of 1- (malonylamino) cyclopropane- 1 – carboxylic acid in ethylene- synthesizing tobacco leaves. *Plant growth Regul.* 2: 227- 234. DOI: <https://doi.org/10.1007/BF00124771>
- [104] Karthikeyan B, Joe MM, Islam R, Sa T. 2012. ACC deaminase containing diazotrophic endophytic bacteria ameliorate salt stress in *Catharanthus roseus* through reduced ethylene levels and induction of antioxidative defense systems. *Symbiosis*. 56: 77- 86. DOI: <https://doi.org/10.1007/s13199-012-0162-6>
- [105] Shcherbakov AV, Bragina AV, Kuzmina EY, et al. 2013. Endophytic bacteria of *Sphagnum* mosses as promising objects of agricultural microbiology. *Microbiology*. 82: 306-15. DOI: <https://link.springer.com/article/10.1134/S0026261713030107>
- [106] Idriss EE, Makarewicz O, Farouk A, et al. 2002. Extracellular phytase activity of *Bacillus amyloliquefaciens* FZB45 contributes to its plant growth-promoting effect. *Microbiology*. 148: 2097-109. DOI: <https://doi.org/10.1099/00221287-148-7-2097>
- [107] Rodriguez H, Fraga R, Gonzalez T, Bashan Y. 2006. Genetics of phosphate solubilization and its potential applications for improving plant growth promoting bacteria. *Plant Soil*. 287: 15-21. DOI: <https://doi.org/10.1007/s11104-006-9056-9>
- [108] Mercado-Blanco J, Bakker PAHM. 2007. Interactions between plants and beneficial *Pseudomonas* spp.: exploiting bacterial traits for crop protection. *Antonie Van Leeuwenhoek*. 92: 367-89. DOI: <https://doi.org/10.1007/s10482-007-9167-1>
- [109] Hofte M. 1993. Classes of microbial siderophores. Iron chelation in plants and soil microorganisms. In: Barton LL, Hemming BC, Eds. Academic Press: San Diego . 3-26.
- [110] Leong J. 1986. Siderophores: their biochemistry and possible role in the biocontrol of plant pathogens. *Annual Review of Phytopathology*. 24: 187-209. DOI: <https://doi.org/10.1146/annurev.py.24.090186.001155>
- [111] Neilands JB, Leong SA. 1986. Siderophores in relation to plant growth and disease. *Annual Review of Plant Physiology*. 37: 187-208. DOI: <https://doi.org/10.1146/annurev.pp.37.060186.001155>
- [112] Loper JE, Buyer JS. 1991. Siderophores in microbial interactions on plant surfaces. *Molecular Plant Microbe Interaction*. 4: 5-13.
- [113] Krechel A, Faupel A, Hallmann J, Ulrich A, Berg G. 2002. Potato associated bacteria and their antagonistic potential towards plant pathogenic fungi and the plant-parasitic nematode *Meloidogyne incognita* (Kofoid and White) Chitwood. *Canadian Journal of Microbiology*. 48: 772-86. DOI: https://doi.org/10.1007/978-3-642-20332-9_3
- [114] Lugtenberg B, Kamilova F. 2009. Plant-growth-promoting-rhizobacteria. *Annual Review Microbiology*. 63: 541-56. DOI: <https://doi.org/10.1146/annurev.micro.62.081307.162918>
- [115] Haas D, Defago G. 2005. mBiological control of soil-borne pathogens by fluorescent pseudomonads. *Nat Rev Microbiology*. 3: 307-19. DOI: <https://doi.org/10.1038/nrmicro1129>
- [116] Lugtenberg B, Malfanova N, Kamilova F, Berg G. 2013. Microbial control of plant root diseases. In: *Molecular microbial ecology of the rhizosphere*; de Bruijn FJ, Ed. 2013; ch 54, Wiley-Blackwell, Hoboken, NJ, USA. 575-86.
- [117] Berg G. 2009. Plant-microbe interactions promoting plant growth and health: perspectives for controlled use of microorganisms in agriculture. *Applied Microbiology and Biotechnology* . 84: 11-8. DOI: <https://doi.org/10.1007/s00253-009-2092-7>
- [118] Borriss R. 2011. Use of plant-associated *Bacillus* strains as biofertilizers and biocontrol agents in agriculture. In: Maheshwari DK, Ed. *Bacteria in Agrobiolgy: Plant Growth Responses*. Springer-Verlag; Berlin, Heidelberg: 41-76. DOI: https://doi.org/10.1007/978-3-642-20332-9_3
- [119] Kloepper JW, Ryu CM, Zhang S. 2004. Induced systemic resistance and promotion of plant growth by *Bacillus* spp. *Phytopathology*. 94: 1259- 1266. DOI: <https://doi.org/10.1094/PHYTO.2004.94.11.1259>

- [120] Ryu CM, Farag MA, Hu CH, Reddy MS, Wei HX, Pare PW, Klopper JW. 2003. Bacterial volatiles promote growth in Arabidopsis. Proceedings of the National Academy of Sciences of the United States of America. 100: 4927- 4932. DOI: <https://doi.org/10.1073/pnas.1332575100>
- [121] Raaij makers JM, de Bruijn I, Nybroe O, Ongena M. 2010. Natural functions of lipopeptides from *Bacillus* and *Pseudomonas*: more than surfactants and antibiotics. FEMS Microbiology Review. 2010; 34: 1037-62. DOI: <https://doi.org/10.1111/j.1574-6976.2010.00221.x>
- [122] Romero D, de Vicente A, Rakotoaly R, et al. 2007. The iturin and fengycin families of lipopeptides are key factors in antagonism of *Bacillus subtilis* toward *Podosphaera fusca*. Molecular Plant Microbe Interaction. 20: 430-40. DOI: <https://doi.org/10.1094/MPMI-20-4-0430>
- [123] Thomashow LS, Weller DM. 1996. Current concepts in the use of introduced bacteria for biological disease control: mechanisms and antifungal metabolites. In: Stacey G, Keen NT, Eds. Plant-Microbe Interaction. Chapman and Hall: New York . vol. 1. 187- 235. DOI: https://doi.org/10.1007/978-1-4613-1213-0_6
- [124] Berg G, Hallmann J. 2006. Control of plant pathogenic fungi with bacterial endophytes. In: Microbial root endophytes. Schulz B, Boyle C, Sieber T, Eds. Springer-Verlag, Berlin Heidelberg . 53-69. DOI: https://doi.org/10.1007/3-540-33526-9_4
- [125] Kloepper JW, Ryu C-M. 2006. Bacterial endophytes as elicitors of induced systemic resistance. In: Microbial root endophytes; Schulz B, Boyle C, Sieber T, Eds. Springer-Verlag: Berlin Heidelberg. 33-52. DOI: https://doi.org/10.1007/3-540-33526-9_3
- [126] Audenaert K, Pattery T, Cornelis P, Höfte M.2002. Induction of systemic resistance to *Botrytis cinerea* by *Pseudomonas aeruginosa* 7NSK2: Role of salicylic acid, pyochelin, and pyocyanin. Molecular Plant Microbe Interaction. 15: 1147-56. DOI: <https://doi.org/10.1094/MPMI.2002.15.11.1147>
- [127] Van Aken B, Yoon JM, Schnoor JL. 2004. Biodegradation of nitrosubstituted explosives 2, 4, 6-trinitrotoluene, hexahydro-1, 3, 5- trinitro-1, 3, 5-triazine, and octahydro-1, 3, 5, 7-tetranitro-1, 3, 5-tetrazocine by a phytosymbiotic *Methylobacterium* sp. associated with poplar tissues (*Populus deltoides* x *nigra* DN34). Applied Environmental Microbiology. 70: 508-17. DOI: <https://doi.org/10.1128/AEM.70.1.508-517.2004>
- [128] Pieterse CMJ, Leon-Reyes A, Van der Ent S, Van Wees SCM. 2009. Networking by small-molecule hormones in plant immunity. Nature Chemical Biology. 5: 308-16. DOI: <https://doi.org/10.1038/nchembio.164>
- [129] Sturz, A. V., Christie, B. R., & Nowak, J. (2000). Bacterial endophytes: potential role in developing sustainable systems of crop production. *Critical reviews in plant sciences*, 19(1), 1-30.
- [130] Kloepper JW, Ryu CM. 2006. Bacterial Endophytes as Elicitors of Induced Systemic Resistance. In: Schulz BJE, Boyle CJC, Sieber TN (eds) Microbial Root Endophytes. Soil Biology, vol 9. Springer, Berlin, Heidelberg. DOI: https://doi.org/10.1007/3-540-33526-9_3
- [131] Sturz AV, Christie BR, Nowak J. 2000. Bacterial endophytes: potential role in developing sustainable systems of crop production. *Critical Reviews in Plant sciences*. 19: 1- 30. DOI: <https://doi.org/10.1080/07352680091139169>
- [132] Barka EA, Nowak J, Clement C. 2006. Enhancement of Chilling Resistance of Inoculated Grapevine Plantlets with a Plant Growth-Promoting Rhizobacterium, ---- Strain PsJN. Applied and Environmental Microbiology. 72 : 7246 – 7252. DOI: <https://doi.org/10.1128/AEM.01047-06>
- [133] Fernandez O, Theocharis A, Bordiec S, Feil R, Jacquen L, Clement C, Fontaine F, Barka EA. 2012. *Burkholderia phytofirmans* PsJn acclimates grapevine to cold by modulating carbohydrate metabolism. *Molecular Plant Microbe Interactions Journal*. 25: 496- 504. DOI: <https://doi.org/10.1094/MPMI-09-11-0245>
- [134] Jha Y, Subramanian RB, Patel S. 2011. Combination of endophytic and rhizospheric plant growth promoting rhizobacteria in *Oryza sativa* shows higher accumulation of osmoprotectant against saline stress. *Acta Physiologiae Plantarum*. 33: 797- 802.
- [135] Tuteja N. 2007. Chapter Twenty-Four - Mechanisms of High Salinity Tolerance in Plants, Editor(s): Dieter Häussinger, Helmut Sies. *Methods in Enzymology*. Academic Press. 428: 419-438. DOI: [https://doi.org/10.1016/S0076-6879\(07\)28024-3](https://doi.org/10.1016/S0076-6879(07)28024-3).
- [136] Eljounaidi K, Lee SK, Bae H. 2016. Bacterial endophytes as potential biocontrol agents of vascular wilt diseases – Review and future prospects. *Biological Control*. 103: 62-68. DOI: <https://doi.org/10.1016/j.biocontrol.2016.07.013>.
- [137] Wang X, Liang G. 2014. Control efficacy of an endophytic *Bacillus amyloliquefaciens* strain BZ6- 1 against peanut bacterial wilt *Ralstonia solanacearum*. *Biomed. Res. Int*. 465435.

- [138] Hu HQ, Li XS, He H. 2010. Characterization of an antimicrobial material from a newly isolated *Bacillus amyloliquefaciens* from mangrove for biocontrol of Capsicum bacterial wilt. *Biological control*. 54: 359-365. DOI: <https://doi.org/10.1016/j.biocontrol.2010.06.015>
- [139] Mercado- Blanco J, Rodriguez- jurado D, hervas A, Jimenez- Diaz RM. 2004. Suppression of Verticillium wilt in olive planting stocks by root- associated flurescent *Pseudomonas* spp. *Biological Control*. 30: 474- 486. DOI: <https://doi.org/10.1016/j.biocontrol.2004.02.002>
- [140] Schiliro E, Ferrara M, Nigro F, Mercado- Blanco J. 2012. Genetic responses induced in olive roots upon colonization by the biocontrol endophytic bacterium *Pseudomonas fluorescens* PICF7. *PLoS One* 7, e48646. DOI: <https://doi.org/10.1371/journal.pone.0048646>
- [141] Ting ASY, Meon S, Kadir J, Radu S, Singh G. 2008. Endophytic microorganisms as potential growth-promoters of Banana. *Biocontrol*. 53: 541- 553. DOI: <https://doi.org/10.1007/s10526-007-9093-1>
- [142] Cunningham SD, Berti WR, Huang JW.1995. Phytoremediation of contaminated soils. *TIBTECH*. 13: 393-7. DOI: [https://doi.org/10.1016/S0167-7799\(00\)88987-8](https://doi.org/10.1016/S0167-7799(00)88987-8)
- [143] Barac T, Taghavi S, Borremans B, et al. 2004. Engineered endophytic bacteria improve phytoremediation of water-soluble, volatile, organic compounds. *Nature Biotechnology*. 22: 583-8. DOI: <https://doi.org/10.1038/nbt960>
- [144] Bashan Y. 1998. Inoculants of plant growth promoting bacteria for use in agriculture. *Biotechnology Advances*. 16: 729- 770. DOI: [https://doi.org/10.1016/S0734-9750\(98\)00003-2](https://doi.org/10.1016/S0734-9750(98)00003-2)
- [145] Bashan Y, Holguin G. 2002. Plant growth promoting bacteria: a potential tool for arid mangrove reforestation. *Trees structure and Function*. 16: 159- 166. DOI: <https://doi.org/10.1007/s00468-001-0152-4>
- [146] Bashan Y, Bashan LE, Moreno M. 2001. Environmental applications of plant growth promoting bacteria of the genus *Azospirillum* . *Plant pathogenic bacteria*. 68- 74. DOI: [10.1007/978-94-010-0003-1_12](https://doi.org/10.1007/978-94-010-0003-1_12)