



REVIEW ARTICLE

Multifunctional roles of bacterial endophytes in plant growth, immunity and environmental adaptation

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Abstract

Endophytes are microorganisms such as bacteria, fungi, archaea and protists live inside the plant tissues without causing harm. Bacterial endophytes play a pivotal role in promoting plant growth and development. They are distributed across several phyla, including Pseudomonadota, Actinomycetota, Bacillota and Bacteroidota with genera such as *Azoarcus*, *Burkholderia*, *Pseudomonas* and *Herbaspirillum* enhancing plant biomass, root development and stress tolerance. Endophytes support plants by producing phytohormones such as indole-3-acetic acid (IAA), cytokinins, gibberellins, Absciscic acid and ethylene, solubilising phosphate, secreting siderophores and reducing stress-induced ethylene via the enzyme ACC deaminase. Colonisation involves sequential stages, beginning in the rhizosphere, followed by attachment to the rhizoplane and finally entry into internal tissues through natural openings or active mechanisms facilitated by pili, flagella and low-level cell wall-degrading enzymes. Endophytes modulate plant immunity by avoiding strong defence responses and producing antioxidant enzymes. They also enhance resistance to biotic and abiotic stresses, including pathogens, drought, salinity and heavy metals. Genes expressed in endophytes, such as those involved in nitrogen fixation, siderophore synthesis, quorum sensing and stress response, contribute to plant growth promotion. Harnessing bacterial endophytes offers sustainable alternatives to chemical fertilisers and pesticides, supporting environmental friendly agriculture and improved crop resilience under abiotic stress.

Keywords: abiotic stress; endophytic bacteria; phytohormones; rhizosphere

Introduction

The term endophyte comes from the Greek words endon (meaning "within") and phyton (meaning "plant"). Endophytes were originally defined as microorganisms, primarily bacteria and fungi that live inside plant tissues for all or part of their life cycle without causing any harm (1, 2). Over time, this definition was revised by researchers (3, 4). More recently, previous researchers defined endophytes as microorganisms (bacteria, archaea, fungi and protists) inhabiting internal plant tissues, whether beneficial, neutral, or harmful (3). Traditionally, scientists obtained endophytes by surface-sterilising plant tissues and culturing them on nutrient-rich media. In recent years, many endophytes have been identified using culture-independent techniques. These include 16S rRNA gene sequencing, internal transcribed spacer (ITS) region analysis and whole-genome sequencing of endophytic communities (5, 6).

This review focuses on bacterial endophytes that promote plant growth and development. These beneficial endophytes are distributed across endophytes from bacterial phyla like Pseudomonadota, Actinomycetota, Bacillota and Bacteroidota include genera such as *Azoarcus*, *Burkholderia*, *Gluconobacter*, *Klebsiella*, *Pantoea*, *Herbaspirillum*, *Rahnella* and *Pseudomonas* has been shown to enhance plant biomass and height (3, 7-10). Endophytes promote plant growth by producing phytohormones phosphate solubilisation, siderophore secretion and the ability to improve plant tolerance to both biotic and abiotic stresses (11-13). Furthermore, certain bacterial endophytes contain genes required for biological nitrogen fixation, allowing them to convert atmospheric nitrogen (N₂) into plant-available forms such as ammonium and nitrate within the host plant.

The application of bacterial endophytes in agriculture offers significant potential to reduce the environmental damage caused by chemical fertilisers, particularly nitrogen fertilisers. Studies indicate that a large proportion of applied nitrogen is lost to the environment, with only about 17 Tg of every 100 Tg of nitrogen used in global agriculture being taken up by crops (14, 15). Lost nitrogen accumulates in water bodies, leading to algal blooms that harm aquatic ecosystems, while atmospheric nitrogen in the form of ammonia or ammonium contributes to eutrophication in regions downwind of farmland. Elevated atmospheric nitrogen compounds, such as ammonium, nitrate and nitric acid vapors, degrade air quality, reduce visibility and negatively affect plant growth (16, 17). Additionally, soil microorganisms convert excess nitrogen into nitrous oxide, a powerful greenhouse gas. Utilising natural plant symbionts like bacterial endophytes could lower fertiliser requirements and support more environmentally sustainable agricultural practices. Endophyte-derived indole-3-acetic acid (IAA) promotes the formation of lateral and adventitious roots, improving nutrient uptake and root exudation, which in turn supports interactions with beneficial soil microbes (18–21). These bacteria also improve plant resistance to biotic and abiotic stresses by producing antimicrobial compounds, secreting siderophores, competing for nutrients and space and modulating plant defence responses. Additionally, some endophytic bacteria reduce stress-induced ethylene levels in plants through the enzyme ACC deaminase, thereby protecting plants from ethylene-related growth inhibition and damage (22).

Colonisation of plants by endophytes

Endophytic bacteria are a special group of rhizospheric bacteria (23, 24). Unlike rhizobacteria that live on the root surface, endophytic bacteria live inside plant tissues. This gives them an advantage because they remain in close contact with the plant and can directly provide benefits while receiving a steady supply of nutrients. Endophytic bacteria are considered specialised rhizobacteria that first colonise the rhizosphere and then gain the ability to enter plant

roots. Their ability to colonise plants depends on several bacterial characteristics known as colonisation traits, which control the entire colonisation process (25, 26).

Plant colonisation involves complex communication between the plant and bacteria. The process usually begins at the roots, where bacteria recognise specific chemicals released by plant root exudates (Fig. 1). Plants produce these exudates to attract beneficial bacteria for their own advantage (27–29). The sequence of endophytic colonisation is similar to rhizosphere colonisation, but endophytic bacteria require additional environmental and genetic factors to enter the plant interior. Although roots are the main entry point, bacteria can also enter through stems, leaves, flowers and cotyledons. Once inside, endophytic bacteria can spread to nearby plant tissues (30, 31).

Interaction between plant and endophytic bacteria

The molecular interaction between plants and endophytic bacteria is a highly coordinated process involving chemical signalling, immune modulation and metabolic exchange. It begins with plant roots releasing exudates such as sugars, amino acids, organic acids and flavonoids into the rhizosphere. These compounds act as chemo-attractants and signaling molecules that stimulate bacterial chemotaxis and activate genes required for colonisation (32, 33).

Upon reaching the root surface, endophytic bacteria attach using adhesins, flagella, pili and exopolysaccharides. They may produce controlled amounts of cell wall-degrading enzymes, enabling entry through natural openings or intercellular spaces without causing tissue damage. Inside the plant, bacteria must evade or modulate the plant immune system (34). Plants recognise microbial-associated molecular patterns (MAMPs) through pattern recognition receptors, triggering pattern-triggered immunity (PTI). Successful endophytes suppress excessive defense responses by altering their surface molecules or secreting effector proteins, maintaining a balanced association (35).

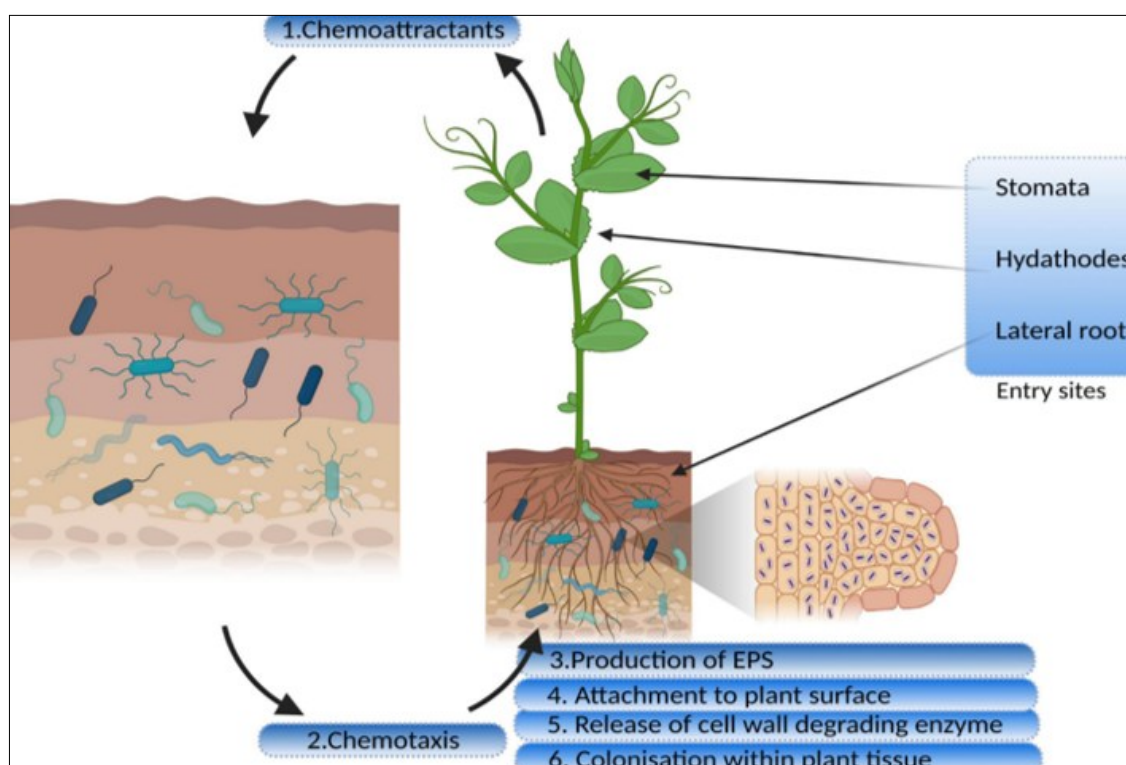


Fig. 1. Interaction and colonisation of plant growth-promoting endophytic bacteria in the host plant (EPS, exopolysaccharides), adapted from (32).

Horizontal and vertical transfer

Horizontal and vertical transfer describe two major modes by which endophytic bacteria are transmitted between plants and across generations. Horizontal transfer occurs when plants acquire endophytic bacteria from the external environment, particularly from soil and the rhizosphere. Plant roots secrete exudates such as sugars, amino acids and organic acids that attract beneficial microbes through chemotaxis. Bacteria attach to the root surface using adhesins and exopolysaccharides, then enter plant tissues through natural openings, wounds, or intercellular spaces (36). Molecular recognition between plant receptors and bacterial surface molecules allows compatible strains to colonise internal tissues without triggering strong defence responses. Horizontal transfer increases microbial diversity within plants and enables them to recruit beneficial bacteria under changing environmental conditions (37).

In contrast, vertical transfer involves the direct transmission of endophytic bacteria from parent plants to their offspring. This occurs through seeds, pollen, or vegetative propagation. During seed development, bacteria colonise reproductive tissues and become incorporated into the embryo or seed coat (34). As a result, seedlings inherit specific endophytes already adapted to the host plant. Vertical transfer ensures early colonisation, stable symbiosis and consistent benefits such as enhanced growth, nutrient acquisition and stress tolerance. Together, horizontal and vertical transfer maintain both adaptability and continuity in plant-endophyte associations (38).

Rhizosphere colonisation by the endophytic bacteria

Rhizosphere colonisation is highly competitive for endophytic bacteria because they must compete for space and nutrients (39). Only bacteria that can successfully colonise the rhizosphere, whether beneficial or harmful, can survive and influence plant growth. Certain bacterial traits, such as motility and the ability to produce polysaccharides, play an important role in successful colonisation, as shown in species like *Alcaligenes faecalis* and *Azospirillum brasilense* (31, 39).

The number of bacteria in the rhizosphere usually ranges from 10^7 to 10^9 colony-forming units per gram of soil, while bacterial populations on the root surface (rhizoplane) range from 10^5 to 10^7 per gram of fresh root weight (26, 40). Studies using advanced detection techniques have shown that after inoculation, bacteria first establish themselves in the rhizosphere. They then attach to root surfaces, form chains of cells and gradually spread across the root. This process leads to the formation of micro-colonies or biofilms on the rhizoplane. Rhizoplane colonisation has been observed both in laboratory-grown plants and in plants grown in natural soil (41).

To provide benefits to the host plant, bacteria must effectively colonise both the rhizosphere and rhizoplane while competing with other microorganisms (42). Colonisation is not evenly distributed along the root system; bacterial density varies depending on the root zone (25). This uneven colonisation is influenced by factors such as root exudate composition, bacterial movement and attachment, quorum sensing, growth rate, nutrient uptake efficiency and the production of substances that suppress competing microbes (25). Endophytic bacteria release various metabolites and signaling compounds inside plant tissues that help them survive and promote plant growth. These bacterial exudates influence plant physiology, immunity and nutrient status. For successful colonisation, bacteria must also adapt their metabolism to the nutrients released by plant

roots. This adaptation has been shown in studies where bacteria increased the expression of genes related to metabolism and stress response while colonising the plant rhizosphere (43).

Root colonisation by the endophytic bacteria

Endophytic bacteria translocation is the movement of bacteria inside plant tissues from one part to another, such as from roots to stems, leaves, flowers, or seeds. This allows the bacteria to colonise various plant organs and provide benefits like growth promotion, nutrient acquisition and stress tolerance throughout the plant (33, 34).

After establishing themselves in the rhizosphere and on the root surface, endophytic bacteria enter plant roots and colonise internal tissues, where their population usually ranges from 10^5 to 10^7 cfu per gram of fresh tissue (39). Entry into the plant begins with bacterial attachment to root cell surfaces, which is aided by structures such as polysaccharides, pili and adhesins (44, 45). Bacteria then move toward natural entry points like lateral root junctions and wounds, often using twitching motility driven by type IV pili (46). Each endophytic bacterium follows a specific colonisation pattern and prefers particular sites on the root. Once attached, bacteria penetrate the root using either passive or active mechanisms. Passive entry occurs through natural openings, root tips, or damaged areas. Active entry involves specialised bacterial features, including lipopolysaccharides, flagella, pili, quorum sensing and motility, which help bacteria attach, move and multiply inside the plant (45–49).

Endophytic bacteria may also produce small amounts of cell wall-degrading enzymes such as pectinases and cellulases to assist in penetration and internal spread (50). Unlike pathogenic bacteria, endophytes produce these enzymes at low levels, helping them avoid triggering plant defence responses (51). Another strategy to remain undetected is maintaining low population densities inside plant tissues compared to pathogens. Successful endophytic colonisation depends on bacterial genetic traits and effective communication between the plant and bacteria. The plant also influences this process by releasing specific root exudates and activating selective defense responses, which help determine which bacteria are allowed to become endophytes (52, 53).

Beneficial roles of endophytes

Fertile soil and a stable climate are essential for agriculture. However, modern agriculture faces serious challenges due to environmental pollution, plant diseases, pests and climate change. Global climate change has increased abiotic stress such as drought, high temperatures, soil salinity and oxidative and osmotic stress (29, 54, 55). Traditional methods used to manage these stresses, including mutation breeding and genetic modification, have shown limited success under field conditions (56). Endophytic microorganisms offer a promising alternative because they live inside plant tissues and can consistently support plant growth. Endophytes promote plant growth by producing phytohormones such as IAA, 1-aminocyclopropane-1-carboxylate deaminase (ACC deaminase) and siderophores and solubilising phosphate. These activities improve water and nutrient uptake by plants (57, 58). Endophytes also protect plants by producing antimicrobial compounds and strengthening plant immune responses, thereby reducing pathogen attacks. Their use can significantly decrease dependence on chemical fertilisers and pesticides, helping to reduce environmental pollution. As a result, endophytes can function as both biofertilisers and biological pest-control agents (59). In the context of climate change, developing

crops tolerant to abiotic stresses like drought, salinity, cold and heat is highly important. The stress tolerance provided by endophytes is often greater than that achieved through plant genetics alone, making them valuable tools for sustainable agriculture (60).

Endophytic bacteria can degrade cellulose, hemicellulose and lignin, thereby contributing to nutrient cycling. They can enhance plant biometric traits, increase crop yield, suppress pathogens and promote overall plant growth. They also contribute to bioremediation, produce bioactive compounds-particularly from medicinal plants and trigger induced systemic resistance (61).

Regulation of the host plant's immune system by endophytes

To successfully colonise plants, endophytes must overcome the plant's immune defences. Plants recognise microbes through conserved molecules called microbe- or pathogen-associated molecular patterns (MAMPs or PAMPs), which are detected by pattern recognition receptors (PRRs) on plant cell surfaces. Common microbial molecules involved in this recognition include flagellin, elongation factor Tu, lipopolysaccharides, peptidoglycan and bacterial enzymes such as superoxide dismutase (60–64). Endophytic bacteria avoid triggering strong immune responses by producing MAMPs that are either not recognised by plant receptors or that induce only weak defence reactions compared to pathogens. Some fungal endophytes further escape detection by modifying chitin molecules using chitin deacetylase enzymes, preventing activation of plant defences (65).

Endophytes also protect themselves from plant defence responses, such as oxidative bursts, by producing antioxidant enzymes, including superoxide dismutase, catalase, glutathione S-transferase, peroxidase and alkyl hydroperoxide reductase. In addition, bacterial secretion systems can influence plant immune responses. While pathogenic bacteria commonly use type III and type IV secretion systems to deliver effector proteins into plant cells, these systems are generally absent or occur at very low levels in endophytic bacteria, helping them maintain a non-pathogenic relationship with the host plant (66, 67).

Regulation of plant growth by endophytes

Endophytes produce many bioactive compounds that regulate the growth of their host plants. Bacterial endophytes enhance plant growth by producing phytohormones that alter root structure, resulting in improved water and nutrient uptake. Most plant growth-promoting bacteria possess important traits such as the production of important compounds which are useful for growth (68).

Indole-3-acetic acid

IAA is a major plant hormone that plays a key role in plant growth and development. It regulates cell division, elongation and differentiation, particularly in roots (69, 70). Many root-associated bacteria, including species of *Pseudomonas*, *Enterobacter* and *Azospirillum*, are capable of producing IAA (71). Low concentrations of bacterial IAA stimulate root elongation and branching, whereas excessive levels may cause abnormal plant growth (72, 73).

1-Aminocyclopropane-1-carboxylate deaminase

Ethylene is a plant hormone that can suppress plant growth, especially under stress conditions. The ACCD is an enzyme that lowers ethylene levels by breaking down its precursor, ACC (72, 74). This reduction in ethylene promotes plant growth and helps plants tolerate stress. During this process, ACC is converted into ammonia and α -ketobutyrate, which can be further used by bacteria (75). Bacteria producing ACCD also contribute to phytoremediation,

detoxification of heavy metals and protection against plant pathogens. Additionally, they help reduce environmental stress effects and delay plant aging. The ACCD activity has been reported in bacteria such as *Pseudomonas putida*, which has been shown to enhance plant growth (72–77).

Phosphate solubilisation

Phosphorus is the second most important nutrient for plant growth after nitrogen. In soil, phosphorus is mainly present in insoluble mineral or organic forms that plants cannot easily absorb due to low mobility (78, 79). To overcome this limitation, microorganisms release organic acids such as acetic, citric, succinic and oxalic acids, which convert insoluble phosphate into soluble forms that plants can utilise (80). Phosphate-solubilising bacteria (PSB) make phosphorus available through mechanisms such as soil acidification, chelation, ion exchange and the production of polymeric substances. Bacterial genera such as *Pseudomonas* and *Bacillus* are well-known phosphate solubilisers. The activity of these bacteria improves phosphorus availability in soil and reduces the need for chemical phosphate fertilisers in agriculture (78, 81, 82).

Siderophore production

Siderophores are small molecules produced by bacteria and fungi that strongly bind iron. Based on their chemical structure, siderophores are classified into carboxylate, hydroxamate, catecholate and mixed types (71, 83). In soil, iron is often present in insoluble forms that plants cannot absorb easily. Siderophore-producing bacteria make iron available by binding ferric ions and transporting them into cells or by activating iron-uptake systems (84, 85). Siderophore production enhances plant growth by improving iron availability and suppresses plant pathogens by reducing the amount of iron accessible to them (69, 71, 83). In addition, these compounds can bind toxic heavy metals such as chromium, lead and mercury, making siderophore-producing bacteria useful in bioremediation. The Chrome Azurol Sulphonate (CAS) assay is commonly used to detect siderophore production in microorganisms. Using this method, endophytic bacterial strains such as *Bacillus subtilis* and *Bacillus megaterium* have been shown to produce siderophores under iron-limited conditions (84–87).

Regulation of plants growth mechanism and genes involved by endophytes

Endophytes are beneficial bacteria and fungi that colonise internal plant tissues and regulate plant growth through hormonal modulation, nutrient mobilisation and molecular signaling. One major mechanism involves phytohormone production. Many bacterial endophytes synthesise IAA through genes such as *ipdC* and *iaaM/iaaH*, influencing plant auxin-responsive genes including *ARF*, *AUX1* and *PIN*, thereby stimulating root elongation and branching (88). Cytokinin biosynthesis via the *ipt* gene promotes shoot growth by regulating plant response regulators (ARR), while gibberellin biosynthetic genes such as *cps* and *ga20ox* affect stem elongation through modulation of DELLA proteins (88, 89).

Endophytes also regulate stress hormones. The *acdS* gene encodes ACC deaminase, which lowers ethylene levels by degrading ACC, influencing plant ethylene signaling genes like *EIN2* and *ETR1* and enhancing growth under stress. Nutrient acquisition is improved through nitrogen fixation genes (*nifH*, *nifD* and *nifK*) and phosphate-solubilising genes (*gcd* and *pqq*), which upregulate plant transporters such as *NRT*, *AMT* and *PHT1* (29, 90). Additionally, endophytes activate defense pathways via *NPR1* and *WRKY*

transcription factors, inducing systemic resistance. Through coordinated hormonal regulation, gene expression modulation and stress tolerance mechanisms, endophytes significantly enhance plant growth and productivity (91, 92).

Regulation of host genetic and phenotypic expression

Resistance to biotic stress

Endophytes can suppress the growth of plant pathogens and trigger induced systemic resistance (ISR) in their host plants. They influence plant gene expressions, which affects physiological responses and defence mechanisms (93–97). Endophytic bacteria produce volatile organic compounds (VOCs) with broad-spectrum antimicrobial activity (98). Gibberellin-producing endophytes enhance resistance to pathogens and insects through salicylic acid and jasmonic acid signalling pathways. Plants hosting endophytes often show higher cellulose content, denser leaves and tougher foliage, which also contributes to pathogen resistance. Overall, endophytes and plants function synergistically to mitigate biotic stress (60, 99).

Resistance to abiotic stress

Abiotic stresses such as drought, extreme temperatures, salinity, heavy metal toxicity and oxidative stress negatively affect plants (100, 101). Endophytes help plants cope with these stresses by activating stress-responsive genes, producing antioxidant molecules and synthesising protective metabolites (102, 103). They also influence phytohormones like abscisic acid (ABA), which regulates stomatal closure and plant growth, by modulating ABA biosynthesis and signaling pathways (104–106). Certain endophytes, such as *Trichoderma harzianum*, increase the expression of genes like aquaporins, dehydrins and malondialdehyde to reduce stress effects in plants like rice. Endophytic bacteria reduce metal toxicity through mechanisms such as extracellular precipitation, intracellular accumulation, sequestration, or conversion of metals into less toxic forms. They also enhance plant antioxidant enzyme activity to prevent oxidative damage. Additionally, genes in some endophytes, such as *Pseudomonas punonensis* D1-6, can provide herbicide resistance to their host plants (107–108).

Bacterial genes expressed in the endosphere

Endophytic bacteria colonize the plant interior and promote growth using a variety of traits. These traits have been studied using methods such as gene deletion, complementation, real-time PCR, in vivo expression technology (IVET), reporter gene systems, gene overexpression, gene introduction and RNA-seq transcriptome analysis (109, 111–114). Many studies focus on *Bacillus phytofirmans* strain PsJN, a model endophyte that effectively colonizes both the rhizosphere and endosphere (113–116). This strain promotes growth in multiple plants, including *Arabidopsis thaliana*, grape, maize, potato, switchgrass, tomato and wheat. It also enhances plant tolerance to abiotic stresses like drought and chilling and protects against biotic stresses by inhibiting fungal pathogens (58, 117). Some bacterial genes involved in endosphere colonisation, host interaction and promotion of plant growth were shown in Table 1.

Practical applicability

Bacterial endophytes offer a sustainable alternative to chemical fertilisers and pesticides in agriculture. Their ability to enhance nutrient use efficiency, stimulate plant growth and improve stress tolerance supports environmentally friendly farming systems. By reducing reliance on synthetic inputs, they help mitigate soil degradation and minimise environmental pollution while maintaining crop productivity.

Future scope

Future research should focus on large-scale field validation, formulation development and strain-specific compatibility with different crops and soil types. Advances in genomics, metagenomics and bioengineering may further improve the efficiency and stability of endophytic inoculants. Exploring multi-strain consortia and climate-resilient endophytes could enhance their effectiveness under changing environmental conditions, contributing to long-term agricultural sustainability.

Conclusion

Endophytic bacteria are integral components of the plant microbiome, inhabiting internal plant tissues without causing harm and often providing significant benefits to their hosts. These microorganisms, including bacteria from diverse phyla such as Proteobacteria, Actinobacteria, Firmicutes and Bacteroidetes, promote plant growth and development through multiple mechanisms. They produce phytohormones such as indole-3-acetic acid (IAA), cytokinins and gibberellins; solubilise phosphate; secrete siderophores; fix atmospheric nitrogen; and modulate plant stress responses. By regulating hormone levels, enhancing nutrient uptake and activating plant defense systems, endophytes enable plants to withstand both biotic and abiotic stress, including drought, salinity, extreme temperatures and pathogen attack. Successful colonisation of the rhizosphere, rhizoplane and internal tissues depends on bacterial traits such as motility, adhesion, secretion systems, enzyme production, quorum sensing and specific interactions with root exudates. Endophytes also regulate host immune responses to prevent strong defense activation, thereby maintaining a stable symbiotic association while conferring growth and stress tolerance benefits. The genetic basis of these interactions has been characterised in model endophytes such as *Burkholderia phytofirmans* PsJN, which possesses genes for 1-aminocyclopropane-1-carboxylate deaminase (ACCD) activity, siderophore production, nitrogen fixation and stress response. These traits support effective colonisation, improved nutrient acquisition, enhanced plant resilience and overall growth promotion.

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Authors' contributions

BJN, GR contributed to writing the original draft, visualisation, formal analysis, data curation and conceptualisation. MRD contributed to reviewing and editing, supervision, resources and formal analysis. PVKR, MSP, CSR, DJR, PAB contributed to the formal analysis and manuscript review. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

Table 1. Genes involved in endospheric colonisation, host interaction and promotion of plant growth

Sl.No	Bacteria	Gene	Function	References
1	<i>Burkholderia phytofirmans</i> PsJN	<i>Acds</i> (ACC deaminase)	Stress reduction	(109, 110)
2	<i>Burkholderia phytofirmans</i> PsJN	<i>iacC</i>	IAA degradation	(110)
3	<i>Burkholderia phytofirmans</i> PsJN	<i>N</i> -acyl-homoserine lactone synthase	Quorum Sensing	(110)
4	<i>Herbaspirillum seropedicae</i> ; <i>Bradyrhizobium</i>	<i>nifH</i> ((nitrogenase)	Nitrogen fixation	(118, 119)
5	<i>Azoarcus</i> sp. strain BH72; <i>Bacillus</i>	<i>eglA</i> ; <i>eglS</i> (endoglucanase)	Systemic colonisation	(120, 121)
6	<i>Bacillus</i>	Pectinase	Systemic colonisation	(121)
7	<i>Pseudomonas</i> sp., <i>Rhodococcus</i> sp.	<i>alkB</i> (alkane monooxygenase)	Diesel degradation	(123)
8	<i>Pseudomonas</i> sp. strain G	<i>carAB</i>	Pathogen cell-cell signaling disruption	(124)
9	<i>Burkholderia</i> sp. KJ006	<i>aiiA</i> (N-acyl-homoserine lactonase)	Pathogen quorum sensing disruption	(125)
10	<i>Pseudomonas stutzeri</i> A15	Multiple genes	Stress response, chemotaxis, metabolism and global regulation	(126)
11	<i>Enterobacter ludwigii</i> ; <i>Pseudomonas</i> sp. strain ITRI53, <i>Pantoea</i> sp. strain BTRH7	<i>CYP153</i> genes (alkane degradation)	Petroleum hydrocarbon defradation	(127, 111)
12	<i>Azoarcus</i> sp. strain BH72	<i>pilT</i> (type IV pili)	Endophytic colonisation by Twitching Motility	(46)
13	<i>Pseudomonas fluorescens</i> strain WCS417r	O-antigenic side chain	Attachment	(48)
14	<i>Burkholderia phytofirmans</i> PsJN	Multiple genes	Transcription regulation, general metabolism (sugars, amino acids, lipids and nucleotides), energy production, cellular homeostasis, cell redox homeostasis, ECF group IV sigma factors	(113)
15	<i>Burkholderia phytofirmans</i> PsJN	Ferritin	Iron storage	(112)
16	<i>Burkholderia phytofirmans</i> PsJN	<i>TonB</i> -dependent siderophore receptor	Siderophore mediated iron uptake	(112)
17	<i>Burkholderia phytofirmans</i> PsJN	<i>L</i> -ornithine5-monooxygenase	Siderophore synthesis	(112)
18	<i>Serratia marcescens</i> (KR-27), <i>Klebsiella aerogenes</i> (KL-4) and <i>Lelliottia amnigena</i> (KS-7)	indole acetic acid (IAA) and siderophores	Abiotic stress tolerance	(103)
19	<i>B. seminalis</i> 869T2	Phytohormone responses and reduce oxidative stress damage genes	Abiotic stress tolerance	(128)

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