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ENDOPHYTES AS NATURAL AGENTS FOR PLANT GROWTH PROMOTION AND PATHOGEN DEFENSE

Suraj Dipak Gabale* and Abhijeet R. Kasarkar
Vivekanand College (An Empowered autonomous Institute),
Kolhapur 416003, M.S., India
*Corresponding author E-mail: surajgabale10@gmail.com

Introduction:

Endophytes are endosymbionts which are most commonly bacteria or fungi—that inhabit plant tissues for part or all of their life cycle without causing any detectable disease symptoms. These microorganisms are widespread and have been documented in every plant species studied so far. Although the mechanisms behind many plant–endophyte interactions remain incompletely understood, such associations are frequently observed to be mutually beneficial.

The association between plants and endophytes has evolved for over 300 million years. This long co-evolution is reflected in the strong host specificity seen in many endophytes. For instance, several *Lophodermium* species are known to colonize only particular hosts within the plant family Pinaceae. The term *endosymbiont* was first introduced by Heinrich Anton de Bary in 1866 to describe an organism that resides within the body or cells of another organism.

Bacterial Endophytes

Common bacterial endophytes

Endophytic bacteria	Host plant
Azorhizobium caulinodans	Rice
Azospirillum brasilense	Banana
Bacillus cereus	Rice
Bradyrhizobium japonicum	Rice
Chromobacterium violaceuma	Rice
Citrobacter sp.	Banana
Enterobacter sakazakiia	Soybean
Herbaspirillum rubrisulbabicans	Sugarcane
Methylobacterium mesophilicuma	Citrus
Pseudomonas cichori	Grapes
Rhizobium radiobacter	Carrot, Rice
Xanthomonas species	Grapes

Bacterial endophytes play a crucial role in promoting plant growth by producing essential phytohormones such as auxins and gibberellins, fixing atmospheric nitrogen, enhancing

phosphate availability, and improving overall nutrient uptake. They also help plants withstand various abiotic stresses, including drought and salinity. In addition, bacterial endophytes contribute to disease control by synthesizing antibiotics, enzymes, and other bioactive compounds that suppress soil-borne pathogens. Through these symbiotic interactions, endophytic bacteria enhance plant physiological functions, resulting in improved growth, vigor, and resilience.

Fungal endophytes

Endophytic fungi colonize both the intercellular and intracellular regions of healthy plant tissues, establishing close and often long-lasting symbiotic relationships with their hosts. These fungi produce a diverse array of antibiotics, enzymes, and other bioactive compounds that not only help them survive in microbe-rich environments but also influence the plant's internal ecosystem. In addition, the secondary metabolites secreted by endophytic fungi can protect the host from bacterial and fungal pathogens, enhance tolerance to environmental stresses, and even stimulate plant growth by modulating nutrient uptake, hormone production, and overall physiological activity. Such multifunctional interactions make endophytic fungi key contributors to plant health and productivity.

Common fungal endophytes

Endophytic fungi	**Host plant**
Alternaria spp.	Soybean
Colletotrichum magna	Tomato
Colletotrichum boninense	Bugweed
Fusarium culmorum	Tomato
Trichoderma homatum	Wheat
Streptomyces hygroscopicus	Rice
Fusarium oxysporum	Cucumber
Penicillium oslonii	Wheat

Transmission of Endophytes

Endophytic microbes can spread through vertical or horizontal transmission:

1. Vertical transmission

This pathway involves the transfer of endophytes from parent plants to their offspring. It typically occurs when fungal hyphae penetrate developing seeds or when they are carried through the plant's pollen.

2. Horizontal transmission

In this mode, endophytes are acquired from the environment through asexual conidia or sexual spores that colonize plant tissues during growth.

Role of Endophytes in Soil

Endophytes—microorganisms that inhabit internal plant tissues without causing disease—play a vital role in soil health and plant productivity. They establish beneficial associations with their host plants and significantly contribute to nutrient cycling, stress tolerance, and overall ecosystem functioning. Their roles can be broadly categorized into plant growth promotion, biosynthesis of bioactive compounds, biocontrol activity, and phytohormone production.

1. Plant Growth Promotion

Endophytic microorganisms enhance plant growth through a combination of direct and indirect mechanisms. These interactions help plants adapt to diverse environmental conditions while improving their growth, productivity, and resilience.

a) Direct Mechanisms

Production of Phytohormones

Many endophytic microbes synthesize key plant hormones such as auxins, gibberellins, and cytokinins. These molecules regulate various physiological processes, including root and shoot elongation, cell division, and tissue differentiation. By influencing these growth pathways, endophytes contribute to stronger roots, healthier shoots, and improved biomass accumulation.

Nitrogen Fixation

A number of endophytic bacteria possess the ability to fix atmospheric nitrogen (N_2) into ammonia (NH_3), which plants can readily absorb. This process significantly enhances soil fertility and reduces the dependence on synthetic nitrogen fertilizers. *Examples include: Azospirillum*, *Herbaspirillum*, *Azoarcus*, *Burkholderia*, *Bacillus*, and *Enterobacter* species.

Phosphate Solubilization

Certain endophytes can convert insoluble forms of phosphate into bioavailable forms through organic acid production and enzyme secretion. This facilitates improved phosphorus uptake, an essential element for plant metabolism, energy transfer, and reproductive growth. *Common examples: Bacillus* spp., *Pseudomonas* spp.

Enhanced Nutrient and Water Uptake

Endophytes often produce enzymes such as cellulases, pectinases, and proteases that support colonization and create microchannels within plant tissues. This enhances nutrient flow and root surface area. Some strains also promote the formation of fine roots and root hairs, improving water uptake and helping plants withstand drought conditions.

Stress alleviation and metabolic support

Many endophytes aid in the synthesis of osmoprotectants and stress-responsive molecules that allow plants to maintain physiological functions under saline, drought, or temperature stress.

They may also influence the expression of plant genes associated with metabolism, nutrient transport, and defense pathways.

Together, these direct benefits position endophytes as sustainable biological alternatives to conventional chemical fertilizers.

b) Indirect Mechanisms

Endophytes also promote plant growth indirectly by enhancing plant defense and maintaining a healthier rhizosphere environment.

Induced Systemic Resistance (ISR)

Endophytic microorganisms activate plant defense pathways, increasing resistance against pathogens and environmental stresses. This helps plants allocate more energy toward growth and development.

Suppression of Pathogens

By colonizing plant tissues and occupying ecological niches, endophytes limit the entry and spread of harmful microbes. Their metabolic activities help create unfavorable conditions for pathogenic organisms, thereby reducing disease incidence.

2. Bioactive Compounds Produced by Endophytes

Endophytes synthesize a wide variety of secondary metabolites, including quinolones, tannins, alkaloids, phenolic acids, terpenoids, saponins, and xanthones. These bioactive compounds exhibit antimicrobial, antioxidant, antifungal, and growth-promoting properties.

In plants, these metabolites:

- Protect against fungal and bacterial pathogens
- Enhance tolerance to oxidative stress
- Facilitate improved nutrient acquisition
- Promote growth and developmental processes

Beyond agriculture, these compounds hold significant potential in pharmaceutical, food, cosmetic, and biotechnological industries due to their therapeutic properties.

3. Endophytes as Biocontrol Agents

Endophytes act as effective natural biocontrol agents by producing antibiotic-like molecules that inhibit the growth of pathogenic microorganisms. They also modulate plant defense signaling pathways, particularly through the induction of jasmonic acid (JA) and ethylene, which are critical regulators of resistance:

- Ethylene regulates processes such as fruit ripening, flower opening, leaf abscission, and stress responses.
- Jasmonic acid (JA) contributes to defense against necrotrophic pathogens and regulates plant responses to both biotic and abiotic stresses.

Additionally, many endophytes synthesize siderophores, which bind iron and increase its availability to beneficial microbes. This competitive advantage helps them colonize the root environment effectively while suppressing harmful organisms.

Through these combined actions, endophytes significantly reduce disease pressure and support sustainable crop protection.

4. Phytohormone Production by Endophytes

Phytohormone production is one of the most important contributions of endophytic microorganisms. These hormones regulate plant growth, development, and stress responses.

Auxins (Indole-3-Acetic Acid, IAA)

IAA regulates cell elongation, root initiation, shoot development, and fruit set. Endophytic production of IAA enhances root system architecture, improving nutrient and water uptake.

Gibberellic Acid (GA)

GA promotes cell division, seed germination, stem elongation, and fruit development. It also helps break seed dormancy, ensuring proper plant establishment.

Cytokinins

Cytokinins control cell differentiation, delay leaf senescence, and promote root and shoot growth. Their balanced interaction with auxins determines overall plant morphology.

Other Hormones

Many endophytes also produce abscisic acid (ABA) and salicylic acid (SA), which play key roles in stress tolerance, stomatal regulation, and pathogen defense.

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