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Endophytic microorganisms in plant health and disease management

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Abstract

Endophytic microorganisms, comprising bacteria, fungi and actinomycetes, colonize the internal tissues of plants without causing visible disease symptoms. The term *endophyte* was introduced by Anton de Bary in 1866 to describe organisms inhabiting plant tissues. These microorganisms play significant roles in plant growth, development and stress tolerance through various beneficial activities, including phytohormone production, biological nitrogen fixation, phosphate solubilization, siderophore production and nutrient mobilization. They also contribute to disease management through direct antagonism, production of antimicrobial compounds and activation of plant defence mechanisms, particularly systemic acquired resistance (SAR) and induced systemic resistance (ISR). Furthermore, endophytes enhance plant tolerance to various biotic and abiotic stresses, including pathogen attacks, drought and salinity. Their diverse metabolic capabilities and ecological functions make them valuable resources for sustainable crop production and improved plant health management.

Keywords: Endophytes, phytohormone, stress tolerance, SAR, ISR

Introduction

Endophytic microorganisms reside in healthy plant tissues which includes roots, stems, seeds and leaves without causing disease symptoms or disrupting the plant's physiological functions. The term "endophyte" (where "endo" means within and "phyto" means plant) was introduced by Anton de Bary, a pioneer in plant pathology, in 1866 to describe "any organism growing within plant tissues." True endophytes do not harm their host plants; in fact, several organisms that are known to be pathogens in one species can exist in another without causing disease functioning as endophytes. For instance, *Fusarium species* are responsible for head blight in cereals, have also been found living in carrots without inducing any harm (Louarn *et al.*, 2013) and barley pathogen *Ramularia collocygni* can exist as a harmless endophyte in other cereal species. (Kaczmarek *et al.*, 2017). Endophytes are known to play very important roles in the plant growth by producing secondary metabolites, nutrient assimilation, and the suppression of disease symptoms. Endophytic microorganisms, comprising bacteria, actinomycetes and fungi, establish close associations with their host plants, enabling them to colonize internal plant tissues while benefiting from a protected niche that protects them from adverse environmental fluctuations (Passari *et al.*, 2017).

According to Smith *et al.*, 2008 endophytic microorganisms are associated with majority of plant species with a total number approximately 300,000 plant species. The presence of endophytes is considered a common feature of natural plant systems and the protocol for isolation of endophytes is mentioned in Fig. 1. According to Partida-Martínez and Heil (2011), plants lacking endophytic associations are relatively uncommon in nature and may have reduced capacity to withstand environmental stresses and defend themselves against pathogenic organisms. Over the past decade, endophytes have been traced to the chloroplasts and mitochondria of plants, indicating they share a common genetic background with their host (Wen 2004); this concept is referred to as the endogenous hypothesis, which posits that endophytes originate from within the plant. In contrast, the exogenous hypothesis says that endophytes originate from outside the plant, entering through root wounds, induced channels, or the surface (Li, 2005). Endophytes

have been isolated from various plant parts, such as meristem, scale primordia, resin ducts, leaf segments with midribs, roots, leaf blades, stems, petioles, bark, and buds (Fig.1). Endophytes transmitted through seeds, or via the gaps between root hairs and epidermal cells in case of bacterial endophytes. *Aspergillus* species, *Penicillium* species, *Alternaria infectoria*, *Colletotrichum gloeosporioides*, *Nigrospora oryzae*, *Phomopsis* species, *Guignardia* species and *Rhizoctonia* species are among the most often identified endophytes. Few of the isolated endophytes are mentioned in Fig. 2. In addition, several novel bacterial endophytes have been characterized, including those from *Arthrobacter*, *Actinobacter*, *Aeromonas*, *Enterobacter*, *Agrobacterium*, *Alcaligenes*, *Bacillus*, *Flavobacterium*, *Azospirillum*, *Azotobacter*, *Pseudomonas*, *Burkholderia*, *Beijerinckia*, *Erwinia*, and *Rhizobium* genera, among others (Gray and Smith 2005).

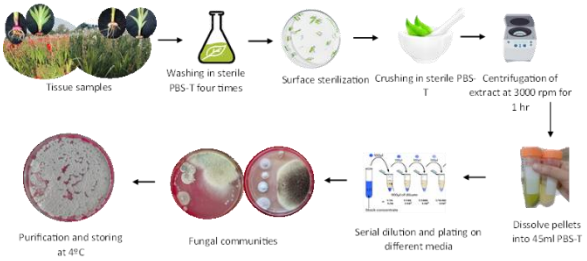


Fig. 1. Schematic representation of the isolation of endophytic fungi from internal plant tissues.

Role of Endophytes in Disease Management

Endophytes help plants manage diseases by stimulating the production of different metabolites in response to biotic and abiotic stresses. They improve plant health through three main mechanisms: biofertilization, phytostimulation, and biocontrol (Bloemberg and Lugtenberg 2001). Chemicals produce by endophytes help the host plants while inflicting no harm. These substances improve the plant's ability to fight disease and may be used to treat cancer, diabetes, and viral infections. Other physiologically active compounds generated by endophytic microorganisms, such as alkaloids, terpenoids, steroids, peptides, polyketones, quinols, flavonoids, phenols, and the insecticide azadirachtin, are being investigated for their applications in medicine, agriculture, and industry (Molina *et al.*, 2012). Fungal endophytic species are a natural source of a variety of chemicals, including flavonoids, terpenoids, phenols, saponins, alkaloids, sugars, tannins, and substances that inhibit nematodes (Bogner *et al.*, 2017). Endophytic bacteria, on the other hand, have a variety of beneficial effects, including increasing nitrogen fixation, solubilizing phosphate, producing phytohormones, and reducing ethylene biosynthesis in response to abiotic stresses (such as pH, temperature, and osmotic pressure) as well as biotic stresses (from fungi, bacteria, nematodes, and insects).

Endophytic bacteria produce extracellular enzymes that are required for plant colonization. These enzymes are useful in fermentation, biotechnology applications and food production. Notably, fungi such as *Sebacina vermifera*, *Piriformospora indica*, and several species of *Colletotrichum* and *Penicillium* have been identified as having improved plant growth-promoting properties, particularly under unfavourable conditions.



Fig. 2. Cultural characteristics of few fungal endophytes cultured on potato dextrose agar (PDA).

Plant growth-promoting microorganisms (PGPM) help in plant development by producing phytohormones such as indole-3-acetic acid (IAA), cytokinins and gibberellins, sideways siderophore production, also improve nutrient availability by solubilizing phosphate, enhancing nutrient acquisition and promoting biological nitrogen fixation. Furthermore, certain PGPM suppress plant pathogens through antagonistic activities and by activating plant defence responses, a phenomenon referred to as induced systemic resistance (ISR).

Endophytic microorganisms have been reported to possess siderophore-producing capabilities, these compounds exhibit a strong affinity for iron and facilitate its acquisition by microbial cells (Kannahi and Senbagam, 2014). Based on their chemical structures, bacterial siderophores are broadly classified into four major groups: catecholate, salicylate, hydroxamate and carboxylate. In addition, salicylic acid (SA) plays an important role in plant growth influencing root initiation, flowering, seed germination stomatal regulation. It also contributes to plant adaptation by modulating defence responses against biotic and abiotic stresses (Klessig *et al.*, 2016).

They are also explored as biological control agents thereby providing an alternative to conventional chemical-based management. For instance, *Beauveria bassiana*, an entomopathogenic fungus capable of establishing an endophytic association, has been investigated for the management of borer pests in sorghum.

Certain endophytic microorganisms help in degrading toxic compounds under heavy metal exposure. Among fungal endophytes, two isolates of *Pestalotiopsis microspora* have been reported to degrade polyester polyurethane (PUR). They also enhance host plant defense through activating induced systemic resistance ISR, salicylic acid (SA), jasmonic acid (JA) and ethylene (ET). While SA is primarily associated with systemic acquired resistance (SAR), JA and ET are important regulators of ISR, although considerable interaction occurs between these signalling pathways. An early demonstration of ISR-mediated disease protection was reported by Kloepper and Ryu (2006), who described the ability of the endophytic bacterium *Pseudomonas fluorescens* 89B-61 to protect cucumber plants against anthracnose.

Furthermore, they help plants withstand adverse environmental conditions by producing various metabolites and biochemical compounds. In cucumber plants subjected to sodium chloride and drought stress, the inoculation with *Phoma glomerata* and *Penicillium species* significantly enhanced nutrient assimilation while also reducing sodium toxicity compared to uninoculated plants (Waqas *et al.,* 2012).

One of the key roles of endophytes is their ability to fix nitrogen, along with other benefits such as pathogen suppression, phytohormone production, and nutrient supply. Several root endophytes, including *Azoarcus spp*., *Acetobacter diazotrophicus*, and *Herbaspirillum spp.*, are capable of nitrogen fixation.

Heavy metal toxicity is a significant abiotic stress that can lead to a loss of 25–80% in various cultivated crops. Bacterial endophytes play a crucial role in the immobilization and mobilization of metal cations, which influences the availability of these cations to plants (Pandey *et al.,* 2016). In soil contaminated with cadmium (Cd), the dark septate endophyte (DSE) *Exophiala pisciphila*, associated with the roots of *Zea mays*, exhibited enhanced activity of antioxidant enzymes (Wang *et al.*, 2016).

Nutrient deficiency is another major abiotic constraints, endophytic microorganisms can mitigate nutrient limitations by facilitating the acquisition and availability of essential macro- and micronutrients. Nitrogen-fixing endophytes utilize carbon compounds released through root exudates to support biological nitrogen fixation, thereby contributing to the nitrogen supply required for plant metabolism and amino acid synthesis. Certain endophytic microorganisms also produce hydrolytic enzymes that facilitate the breakdown of complex organic polymers, including cellulose, lignin and hemicellulose, contributing to organic matter decomposition and nutrient cycling (He *et al.,* 2012).

Conclusion

Around 300,000 plant species host one or more endophytes, each contributing uniquely to enhancing plant growth and protecting against various biotic and abiotic stresses. Given the growing emphasis on environmental sustainability, food security, and sustainable agriculture, it is crucial to harness beneficial endophytes. These microorganisms can improve both the yield and quality of plant products by producing a range of biologically active metabolites that positively influence plant physiological processes. They also offer protection against pathogens and can remediate toxic residues from insecticides, herbicides, and heavy metals. Additionally, endophytic microorganisms stimulate the immune system of host plants. They present an alternative strategy for enhancing the resilience of plants to various stresses, including drought, salinity, temperature fluctuations, nutrient deficiency and heavy metal contamination.

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