INNOVATIVE ROLE OF ENDOPHYTES IN MANAGEMENT OF ECONOMICALLY IMPORTANT DISEASES OF DIFFERENT CROPS

Abstract

Endophytic microbes, which live in the tissues of living plants, are understudied yet have the potential to yield new natural compounds that could be used in agriculture. According to this theory, the microbe receives nutrients from the plant while the microbe itself may create substances that defend the host plant from pests including animals, insects, and other microorganisms. Since these fungi and bacteria have been researched for biological control and manufacture of chemicals with pharmacological qualities, studies on microbes from plant species are now more common. They are distinct from epiphytic microorganisms, which reside on the surface of plant organs and tissues, and they differ from phytopathogenic microorganisms in that they are not harmful, do not infect plants, and do not cause illness. A single endophytic fungal species often colonizes each host in these systems, and these fungi appear to have experienced extensive coevolution with their hosts moreover these fungi are typically transferred vertically which incites this transmission pattern and expected to encourage positive interactions with the host plants. However, endophytic relationships in grasses can have a variety of outcomes, from parasitic microbes to highly mutualistic microbes. Beneficial effects for hosts consist of elevated tolerance to drought , inhibition of herbivorous insects , defense against parasites such as , and resistance towards pathogenic fungi. In the host plant, endophytic bacteria can infiltrate and spread throughout the entire organism, aggressively colonizing the apoplast, conducting vessels, and occasionally intracellular regions. These endophytic bacteria can therefore function as biological control agents against pathogens since this colonization creates an ecological niche that is comparable to that inhabited by plant pathogens. In this regard, endophytic microbes' ability to control plant diseases has been shown in a number of

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I. INTRODUCTION

Fungi and other plant infections are the most apparent concerns to the production of sustainable food. Fungicide efficacy is declining, and there are dangers related to residues incurred by pesticides on leaves and fruit. These factors have brought attention to the importance of efficient and secure alternative management methods. Endophytes have drawn more attention recently as a potential complement to or substitute for chemical control. A practical alternative to host-plant resistance and pesticide-based pest and disease control is the strategic use of naturally occurring organisms to reduce pest populations and raise agricultural output. According to Wagenaar and Clardy (2001), in terms of variety and medicinal potential, endophytic bacteria are among the largest and most therapeutically capable microbial species and they are capable to establish and grow between the intercellular spaces in the higher plants. Most of the beneficial endophytic microbes are those of fungal and bacterial species which protrude inside the host tissues internally without inflicting their hosts any obvious harm (Petrini, 1991). Furthermore, because they are connected to actively growing tissues and may benefit the health of the plant in some way, endophytic microbes are not regarded as saprophytes. Endophytes can be found in a variety of plant tissue types and can colonize the plant in a systemic way with the advent of biofilms or bacterial colonies while latently existing inside vascular tissue, or within cells or in intercellular spaces (Ulrich *et al*., 2008). Endophytic microbes, which live in the tissues of living plants, are understudied yet have the potential to yield new natural compounds that could be used in agriculture. According to this theory, the microbe receives nutrients from the plant while the microbe itself may create substances that defend the host plant from pests including animals, insects, and other microorganisms (Yang *et al*., 1994). Since these fungi and bacteria have been researched for biological control and manufacture of chemicals with pharmacological qualities, studies on microbes from plant species are now more common. They are distinct from epiphytic microorganisms, which reside on the surface of plant organs and tissues, and they differ from phytopathogenic microorganisms in that they are not harmful, do not infect plants, and do not cause illness (Hallmann *et al*., 1997). In the host plant, endophytic bacteria can infiltrate and spread throughout the entire organism, aggressively colonizing the apoplast, conducting vessels, and occasionally intracellular regions (Quadt-Hallmann *et al*., 1997a, 1997b). These endophytic bacteria can therefore function as biological control agents against pathogens since this colonization creates an ecological niche that is comparable to that inhabited by plant pathogens (Hallmann *et al*., 1997). In this regard, endophytic microbes' ability to control plant diseases has been shown in a number of pathosystems (Narisawa *et al*., 1998). This suppression may be regulated by a number of ways, including antibiosis (Sturze *et al*., 1996), competition for nutrients (Puentea *et al*., 2009), stimulation of plant defense response (M'Piga *et al*., 1997), and indirect regulation by the pathogen itself (Sturze *et al*., 1996). Additionally, more recently, their potential for accelerating the degradation of a number of contaminants has been looked into (Doty, 2008). Numerous studies have shown that endophytic microbes are capable of producing a wide range of bioactive substances (Huang *et al*., 2001). Molecular markers also offer enormous data sources that can help researchers create tools to track the genetic and environmental fate of these agents. Examples of relationships between endophytic bacteria and plants, particularly those that lead to the control of diseases, will be the main emphasis of the current review. This review aims to offer more insight into the fact that there are

endophytes in nature, the products they produce, and how some of these organisms are starting to exhibit some promise for the management of plant pests and diseases.

II. FUNGAL ENDOPHYTES

Endophytic fungi are different in terms of taxonomy and biology, yet they all have the same characteristic of invading internal plant tissues without clearly harming their host (Wilson, 1995). The most well-known of these are those belonging to the Clavicipitaceae (Ascomycota), which are endophytes of numerous temperate grasses. A single endophytic fungal species often colonizes each host in these systems, and these fungi appear to have experienced extensive coevolution with their hosts. According to Clay and Schardl (2002) and Saikkonen*et al*. (2004), these fungi are typically transferred vertically (from mother to children by seeds). According to Herre *et al*. (1999), this transmission pattern is expected to encourage positive interactions with the host plant. However, endophyte relationships in grasses can have a variety of outcomes, from parasitic (such as choke disease) to highly mutualistic (Clay and Schardl, 2002). Beneficial effects for hosts consist of elevated tolerance to drought (Arechavaleta *et al*., 1989), inhibition of herbivorous insects (Breen, 1994; Rowan and Latch, 1994), defense against parasites such as (Pedersen *et al*., 1988; West *et al*., 1988; Kimmons *et al*., 1990), and resistance towards pathogenic fungi (Gwinn and Gavin, 1992; Bonos *et al*., 2005; Clarke *et al*., 2006). Endophytes, which are found in some tropical grasses, also fit this description (Kelemu *et al*., 2001). Endophytes have been found to mediate anti-pathogen defense in nongramineous hosts as well. Beans and barley, for instance, have been proven to be protected by endophytic fungus. (Boyle *et al*., 2001) from fungal diseases, as well as tomatoes (Hallman and Sikora, 1995), bananas (Pocasangre *et al*., 2001; Sikora *et al*., 2008), from nematodes. Even though there is growing evidence that endophytic fungus can lessen pathogen damage to grasses and other host plants, it is unclear how broadly these fungi play this role in natural systems or whether they can be used as a biocontrol method to safeguard crops.

1. **How Fungal Endophytes can Affect Plant Disease:** There is growing indication in recent years that endophytic microorganisms play a part in how the interaction of pathogen and plant result in disease. They may prevent the growth of pathogens through a variety of methods, which have been seen. For instance, plant defense mechanisms may be stimulated by some endophytic species in order to resist the attack by the pathogen; a few have been reported to inhibit thr pathogenic growth by producing selective antibiotic types; and a few resident endophytic species may bring about competition for the incoming pathogen for nutrient sources and space; and finally, certain parasites of plant pathogenic organisms are known to exhibit endophytic behavior.

III. INTERACTIONS WITH PLANT PATHOGENIC FUNGI

The production of antibiotics is widespread among endophytic species (Strobel, 2002; Schulz and Boyle, 2005; Wang *et al*., 2007). Several species of plant pathogenic fungi have been noticed to be restricted in their growth by liquid extracts from endophyte cultures (Liu *et al*., 2001; Park *et al*., 2005; Inácio *et al*., 2006; Kim *et al*., 2007). Such chemicals might serve as a defense tactic against fungal diseases if they were created by endophytes in plants. Following the use of endophytic culture filtrates and endophyte inoculation experiments, observations of plant defense against pathogenic fungi suggest that the endophyte may create

an antifungal chemical or a material that activates the plant's defensive mechanisms. When only endophytic culture filtrates were administered to the plants, the same protective result was seen (Dingle and McGee, 2003; Istifadah and McGee, 2006). This is true for wheat *Phoma* endophytes such as *Chaetomium*. Reduced severity of foliar disease brought on by *Puccinia* and *Pyrenophora* spp. was noticed when these types of fungi were previously inoculated in plants. The effects of culture filtrates on plant pathogens were not examined in these investigations. When a combination of six species of endophytes periodically isolated from cacao (*Theobroma cacao* L.) trees was utilized in inoculation on leaves of endophyte-free seedlings of this specific kind of plant, the severity of a leaf disease caused by a *Phytophthora* sp. decreased substantially in endophyte-inoculated leaves. The same plant's endophyte-inoculated and non-inoculated leaves showed different disease severity, ruling out the possibility of an induced plant resistance mechanism. According to Arnold *et al*. (2003), the defense against a pathogen in this particular incidence might be the outcome of direct conflict between the pathogen and endophytes already present in the leaves. For example, the majority of the tissue that is susceptible to infection may already be infected, or endophytes may create zones of inhibition that prevent the entry of other fungi. Plant biochemistry may change as a result of endophyte infection, inducing defensive mechanisms against pathogens. The root endophyte *Piriformospora indica* has a diverse range of hosts, including *Arabidopsis* and a number of cereal species. In addition to an increase in production and tolerance to salt stress, barley plants injected with this endophyte have demonstrated resistance to a vascular [*Fusarium culmorum* (W.G. Sm.) Sacc.] and a leaf pathogen [*Blumeria graminis*(DC.) Speer] (Waller *et al*., 2005). Because the defensive reaction in the pathogen-inoculated plants leads to the death of host cells, the defense towards the leaf pathogen seemed to be offered through a process of induced resistance. Mycoparasites may be present in some endophytes. In recent years, it has been demonstrated that the endophyte *Acremonium strictum* is a mycoparasite of the potato disease *Helminthosporium solani* which has been isolated frequently from *Dactylis glomerata* L. and other grasses (Sánchez Márqueze *et al*., 2007). *Festuca rubra* L. cultivars infected by *Epichlo festucae* have shown a considerable improvement in resistance to the *Sclerotinia homoeocarpa* causing dollar spot disease (Clarke *et al*., 2006). A range of turfgrass species have cultivars with Epichlo and Neotyphodium endophytes that are currently available on the market. These endophytes' ability to spread vertically has made it possible to produce infected seed on a large scale. Use of insecticides and fungicides in lawns may be reduced as a result of the application of such symbiotic cultivars since cultivars infected with Neotyphodium and Epichlo have demonstrated enhanced defense against herbivores, plant diseases, and various situations of abiotic stress (Brilman, 2005). Other endophyte species may in the future use similar uses. The research mentioned above imply that the endophytic mycobiota connected to a host plant may play a role in how some pathogen attacks turn out. In light of this, a source of organisms with potential applications for mitigating disease in that plant species may be found in the endophytic assemblage of that species. Only a small percentage of the numerous species that are able to penetrate and infect a plant, known as pathogens, can result in disease. This demonstrates that endophyte pathogens participate in a portion of the plant disease cycle. It appears that the majority of fungi linked with plants behave as endophytes, although fungi can function as pathogens once they enter a plant as well. Plant pathologists might benefit from knowing the distinction between pathogen- and endophyte-caused infection processes. Some research aimed at addressing this issue mentions both fungal and host properties. For instance, a pathogen like *Colletotrichum magna* can become a mutualistic endophyte by undergoing a single locus mutation (Freeman and Rodriguez, 1993). However, some isolates

of the aforementioned species may act as an endophyte in some species of other plant families or as a pathogen in cucurbits (Redman *et al*., 2001).

1. **Interactions with Nematodes:** Grass infected by *Neotyphodium* endophytes exhibits inhibitory effects against a few species of migratory and sedentary endoparasites (West *et al*., 1988; Kimmons*et al*., 1990). Unlike roots, aerial tissues are infected by neotyphodium species. As a result, it was assumed that the inhibitory effects seen in infected plants were caused by the translocation of fungal alkaloids to roots. This was confirmed by the discovery that some naturally occurring Neotyphodium strains with low levels of ergot alkaloids do not exhibit the same level of protection against Pratylenchus sp. as strains that produce ergot alkaloids (Timper *et al*., 2005). In contrast, other studies revealed that there is very little ergot alkaloid translocation to roots, and research with mutant Neotyphodiums that had their pathway for ergot alkaloid synthesis disrupted suggested that ergot alkaloids are not the ones that control nematode populations in endophyte-infected plants (Panaccione *et al*., 2006). However, Neotyphodium species do produce various types of alkaloids with antiherbivore activity, and roots infected with Neotyphodium do undergo chemical modifications like the synthesis of phenolic compounds (Malinowski and Belesky, 2000). In conclusion, host plants are protected against a variety of nematode species by Neotyphodium endophytes, but the exact mechanism by which this protection occurs is still a mystery. Another category of endophytes known to be involved in antinematode activity is non-pathogenic strains of Fusarium oxysporum isolated from plant roots. Meloidogyne incognita is inhibited by F. oxysporum culture filtrates, suggesting that fungal toxins may be the underlying cause of interaction (Hallmann and Sikora, 1996). The suppression of nematodes by Fusarium, however, seems to involve a process that is more intricate than a toxin-operated system. Banana plants were grown in a divided root system as part of an experiment, and the plants showed resistance to Radopholus similis Cobb, Thorne in the root half that had not been injected with a Fusarium endophyte. The mechanism of resilience to the nematode pathogen in this case seemed to be a phenomena of systemic plant resistance brought on by the endophyte (Vu *et al*., 2006). Nematophagous fungi, which can live in plant roots as endophytes, may also play a role in endophytic fungal-mediated plant protection (Bordallo *et al*., 2002). A few entomophagous fungus species, such as Beauveria bassiana (Bals.-Criv.) Vuill., Torrubiella confragosa Mains, and Metarhizium anisopliae (Metschn.) Sorokin, have been isolated from a variety of host plants, and it appears that endophytic activity can be a feature of their life cycle (Bills, 1996). To sum up, it is quite likely that fungal endophytes influence how nematode infections in plants turn out, and some endophytes may be useful for nematode protection in agricultural settings.

2. **Interactions with Bacteria and Viruses:** There haven't been as many studies done on how endophytes affect bacterial and viral infections as there have been with other plant pathogens. Endophyte culture extracts have been shown to have bactericidal effects, and these effects do not appear to be different from those seen for fungi or nematodes (Wang *et al*., 2007). In terms of viruses, Lolium pratense infected by Neotyphodium had a lower incidence of Barley Yellow Dwarf Virus (BYDV) than endophyte-free plants. Toxic fungal alkaloids may be the cause of this effect as BYDV is spread by aphid vectors; in fact, aphid reproduction was lower in endophyte-infected plants than in endophyte-free plants (Lehtonen *et al*., 2006). Endophytes and viruses have a different link that is highly intriguing. It was discovered that a Curvularia endophyte of the plant Dichantelium

lanuginosum (Elliott) Gould gave the plant resistance to high soil temperatures. Further investigation of this system revealed that a virus affecting the endophyte was a significant contributor to the plants' apparent heat tolerance. Furthermore, tomato plants could benefit from the virus-infected endophyte's ability to tolerate heat (Márqueze *et al*., 2007). Another virus known as Epichlo Festucae Virus 1 (EfV1) infects the grass endophyte Epichlo Festucae asymptomatically; however, in this instance, it is unknown if the virus' presence in the endophyte impacts the plant host (Romo *et al*., 2007).

IV. BACTERIA ENDOPHYTES

Endophytic bacteria have the ability to enter the host plant and spread throughout it, actively populating the apoplast, conducting vessels, and occasionally intracellular regions (Quadt-Hallmann *et al*., 1997a, 1997b). Endophytic bacteria inhabit an ecological niche that is comparable to plant pathogens, particularly vascular wilt pathogens, which may favor them as potential biocontrol agents. Additionally, recent results from intense research on rhizosphere biocontrol agents have demonstrated that the presence of six rhizobacteria caused cucumbers to develop systemic resistance and displayed both exterior and internal root colonization (Kloepper *et al*., 1992b). Since the control agent might circumvent adverse circumstances in one habitat by fleeing into the other habitat, using an additional microbial habitat for biocontrol objectives may improve overall disease management and enhance control consistency.

Fungal Disease Suppression by Endophytes

1. **Wilt Diseases:** Studies on wilt diseases of various commercial and food crops are the focus of studies involving endophytic microbes as agents of biocontrol. Endophytic bacteria isolated from potato tubers demonstrated in vitro antibiosis against *F. avenaciarum, F. sambucinum* and *F. oxysporum*. The antimicrobial activity of the isolates reduced significantly with depth of their site of isolation from the tuber surface. In an effort to fight against pathogenic onslaught, it's possible that plants embraced bacteria (Sturze *et al*., 1999). According to Brooks *et al*. (1994), endophytic bacteria isolated from live oak stems exhibited in vitro antagonistic activity against the pathogen that causes oak wilt, *C. fagacearum*. Crown loss was dramatically decreased after a pre-inoculation with the endophytic isolates *P. putida* and *P. denitrificans*. Spanish oak stems were given injections of Bacillus species, which allowed *Pseudomonas* species to colonize the plants more successfully (Brooks *et al*., 1994). The prevalence and severity of *V. dahliae and F. oxysporum* f. sp*. lycopersici* diseases in these crops were reduced by over seventy-five percent as a result of endophytic bacteria derived from rape and tomato plants, while the plant height and shoot dry weight were raised (Nejad and Johnson, 2000). In addition to hydrogen cyanide, these strains also create additional volatile compounds. According to Hall *et al*. (1986), *Bacillus* spp. found in xylem channels decreased the percentage of silver maple stem colonization by *V. dahlia*.

2. **Rots and Damping-off Diseases:** When used as a seed treatment, endophytic bacteria isolated from rice seeds colonized the stellar region of the root and displayed potent anti-fungal action against *R. solani*, *Pythium myrotylum, Guamanomyces graminis,* and *Heterobasidium annosum* (Mukhopadhyay *et al.,* 1996). In addition, from the 170 endophytic bacterial strains isolated from cotton, 40 strains protected cotton plants from

R. solani infection (Chen *et al.*, 1995). Two endophytic bacterial strains isolated from cotton that were antagonistic to *R. solani* in vitro diminished infection of cotton plants from *R. solani* infection by 60% (Qui *et al.*, 1990). *Phytophthora infestans* was inhibited by endophytic bacteria found in potato tubers (Sturze *et al.*, 1999). The antagonistic potential of endophytic *Bacillus* and *Pseudomonas* spp. isolated from plants and seeds of several crops was examined (Pleban *et al.,* 1995). These pathogenic fungi included *P. ultimum, R. solani,* and *S. rolfsii.* When *B. cereus* strain 65 was put to cotton, radioactive labeling revealed that it remained there for 16 days. Up to 72 days after being introduced into the root and stem, the bacteria were still present at concentrations of 2.8 x 105 and 5 x l04 CFU g^{-1} fresh weight of root and stem tissue, respectively. When injected into the plant during the seed germination stage, *B. cereus* strain 65 and other endophytic bacterial strains examined showed greater than 50% protection against *R. solani* and *S. rolfsii* infection in cotton and bean seedlings. The crude production of extracellular proteins dramatically reduced the spore germination of *F. oxysporum* f.sp. *meloni*, and strain 65 developed a 36 kD achitinolytic enzyme known as chitobiosidase (Pleban *et al.*, 1997). *P. fluorescens* successfully colonized the root tips of beans after being isolated from the interior tissues of apple plantlets that had been micropropagated. The chiA gene, which codes for Serratia marcescens' main chitinase, was cloned into this strain, and the recombinant strain, when administered to bean seedlings, effectively protected them from *R. solani*. This indicates that internal colonization by P. fluorescens was crucial for disease control (Downing and Thomson, 2000). The addition of this bacteria to soil did not give protection.

3. **Galls and Abnormal Growth:** From the woody tissues of lemon and sour orange, Lima *et al*. (1994) identified 160 bacterial strains, of which 55 were hostile to *Phoma tracheiphila*, the causative agent of citrus malsecco disease. By injecting them into the stem of sour orange seedlings 15 days prior to pathogen inoculation, nine of the most potent antagonistic strains were examined for disease control. Significantly reducing disease symptoms and maintaining higher populations in the interior tissues of the host plant were achieved by three isolates of *B. subtilis* and one isolate of *P. fluorescens* (Lima *et al.,* 1994).

4. **Leaf Spots and Leaf Blights:** There have been few attempts to use endophytic microbes as biocontrol agents for the diseases leaf spot and leaf blight. In an in vitro bioassay, Bacillus subtilis, which was isolated from the xylem fluid of chestnut trees, inhibited the growth of the chestnut blight pathogen Cryphonectria parasitica and decreased the lesion areas on stems (Wilhelm *et al.*, 1998). Additionally, according to Wilhelm *et al*. (1998), B. subtilis caused the synthesis of acidic chitinase and -1,3-glucanase in chestnut. According to Krishna Murthy and Gnanamanickam (1997), Pseudomonas species caused systemic resistance in rice against R. solani-associated sheath blight illnesses. This bacterium wasn't present on the plant's exterior, but its presence inside the stem prevented illness from spreading. 8 bacteria and 24 fungi were identified to be antagonistic to P. infestans in the tomato phyllosphere, rhizosphere, and endosphere during a survey of antagonistic microorganisms (Garita *et al.*, 1988), indicating the endophytic nature of antagonistic organisms. One of the most thoroughly developed systems for biological control employing rhizosphere isolates is utilized to treat crown gall produced by Agrobacterium tumefaciens (Kerr, 1980). For their antagonistic action against a variety of

tumerogenic *A. tumefaciens* biovar 3 strains, endophytic bacteria isolated from the xylem sap of grapevine plants were tested (Bell *et al*., 1995).

Despite variation with regard to in vitro antibiosis, 24 of the 851 strains had a strong inhibitory effect on the grapevine gall-producing *A. vitis*. These microorganisms were identified as *Pseudomonas* spp., *Rahnella aquatilis*, and E. agglomerans. The number of colonies of Agrobacterium strains in situ were significantly reduced by an isolate of P. corrugata, Further tests with the chardonnay grape variety, where galled vine incidence was moderate, revealed that three endophytic bacterial strains significantly reduced disease susceptibility. However, these strains proved useless in defending vines where gall incidence was high (Bell *et al*., 1995). These results also imply that the host genotype has a significant role in how well endophytic bacteria function as biocontrol agents.

5. **Nematode Diseases:** Since nematode wounds encourage the establishment of bacterial colonies of the root surface and their entrance into the root tissue, endophytic microorganisms have an extra benefit over nematodes (Bookbinder *et al*., 1982; Khan, 1993). The density and variety of the total endophytic bacteria increased after Meloidogyne incognita was injected into cotton and cucumber plants. A model system involving the interaction of Meloidogyne with the endophytic bacterium E. asburiae Strain JM22 was employed to make the determination (Hallman *et al*., 1998). JM22 was found in abundance on the surface of nematode galls, particularly where the root epidermis had been damaged by gall expansion.

Electron microphotographs of the area around galls revealed a buildup of bacterial cells near necrotic plant cells (Hallman *et al*., 1998). Chitin (1% w/w) soil amendment shielded cotton from plant-parasitic nematode infection (Hallman *et al*., 1999). When the bacterial and endophytic microbial populations in soils with and without chitin amendments were contrasted. The *B. cepacia* populations were determined to be the identical in both soils, but only the soil that had been modified with chitin did it successfully colonize the internal tissues of cotton (Hallman *et al*., 1999). After being isolated from cotton and cucumber plants, the seven endophytic bacteria *Aerococcus viridans*, *B. megaterium*, *B. subtilis*, *P. chlororaphis*, *P. vesicularis*, *S. marcescens*, and *Sphingomonas paucimobilis* significantly shielded cucumber seedlings from M. incognata infection (Hallman *et al*., 1995).

V. EFFECTS OF ENDOPHYTIC MICROORGANISMS TOWARDSPATHOGENS

In fact, extensive research has demonstrated the ability of endophytic microbes to suppress nematodes (Hallman *et al*., 1998) and diseases (Duijff *et al*., 1997; Sturz and Matheson, 1996). Shimanuki (1987) demonstrated that timothy (*Phleum pratense*) plants infected with the choke fungus, *Epichloe typhina*, were resistant to the fungus *Cladosporium phlei*, marking the first instance of an endophyte having an impact on a plant disease. In some circumstances, they can also hasten the emergence of seedlings, encourage plant establishment in challenging environments, and improve the growth and development of plants (Lazarovits and Nowak, 1997; Pillay and Nowak, 1997). According to studies (Hallman *et al*., 1997; Stoltzfuse *et al*., 1998), a number of bacterial endophytes have been shown to promote plant development and health. As a result, they may be significant sources

of biocontrol agents. For instance, many endophytic bacteria, such as many strains of *Pseudomonas* sp., *Curtobacterium luteum*, and *Pantoea agglomerans*, suppress *Erwinia carotovora* (Sturze *et al*., 1999). In addition, Wilhelm *et al*. (1997) showed that *Bacillus subtilis* strains isolated from the xylem sap of healthy chestnut trees have antifungal activity against the *Cryphonectria parasitica* that causes chestnut blight. Endophytic bacteria are an appealing alternative for biological control agents because they are in close contact with the plant and have the capacity to promote growth and inhibit plant disease. For instance, according to studies performed by Sturz *et al.* (1999), 61 of 192 endophytic isolates of bacteria from potato stem tissues were successful biocontrol agents against Clavibacter *michiganensis subsp. sepedonicus.* Endophytic bacteria in oak have been found to be physiologically active against the pathogen *Ceratocystis fagacearum,* which causes oak wilt (Brooks *et al*., 1994).

According to Coombs and Franco (2003), Sessitsch *et al*. (2001), and Xaio *et al*. (2002), many of the physiologically active endophytes and root-colonizing microorganisms that have been isolated or found belong to the actinobacterial phylum, notably the genus Streptomyces. The first actinobacterial endophyte discovered is a nitrogen-fixing actinobacterium from the genus Frankia that associates with eight different species of angiosperms to generate actinorhizae (Provorov *et al*., 2002). *Streptomyces, Microbispora, Micromonospora,* and *Nocardioides* are the main genera of endophytic actinobacteria that have been previously isolated using culture-dependent techniques (Coombs and Franco, 2003). Many of these isolates, including *Rhizoctonia solani, Pythium spp., and Gaeumannomyces graminis* var *tritici*, were able to reduce fungal pathogens of wheat both in vitro and in vivo, indicating their potential application as biocontrol agents (Coombs *et al*., 2003).

VI. MECHANISMS OF DISEASES CONTROL DISPLAYED BY ENDOPHYTES

In this regard, endophytic microbes' ability to control plant diseases has been shown in a number of pathosystems (Narisawa *et al*., 1998). The pathogen inside the plant may be directly controlled via antibiosis and competition for resources, or indirectly by inducing a plant's response to resistance (M'Piga*et al*., 1997). Endophytes vary from mycorrhizae in that they lack external hyphae, typically occurring in above-ground plant tissues but rarely in roots (for instance, dark septate endophytic fungus have been recovered from diverse plants).

It is generally believed that endophyte-host interactions involve an appropriate amount of antagonism and showcase great phenotypic plasticity in comparison to plant pathogens, even though some root endophytic fungi need plant cellular death for the spread during the course of mutualistic symbiosis with the host plant (Deshmukh et al., 2006). Only a small number of texts discuss the secondary metabolism of plants that is mediated by fungi. Because there are literally millions of different biological niches (higher plants) that endophytes occupy and because they flourish in so many different odd habitats, endophytes are currently thought of as an amazing source of bioactive natural compounds. The originality and biological activity of the products linked to endophytic bacteria may thus be governed by these biotypical features, which suggest that they can play a significant role in plant selection. Following inoculation with a leaf fungal endophyte, peppermint growth and terpene production of in vitro created plants (Menthapiperita) reveal modification of the essential oil profile by fungal infection. The results of the other study demonstrated that after being

inoculated with an endophytic bacterium that has a wide host range, *Euphorbia pekinensis*' weight of roots, seedlings, and terpene production increased. According to Wang *et al*. (2006), microbial elicitor produced from various fungal endophytes also encourages biomass and causes the development of terpenoids (artemisinin) in plant suspension cells. It appears plausible that both fungal endophytes and mycorrhizal fungi may cause a particular augmentation of the MEP pathway metabolic flux in plants.

Traditional Chinese medicine frequently treats traumatic and visceral hemorrhages with the crimson resin of Dracaena cochinchinensis. Chemical analyses have shown that several flavonoids are present in the resin (Zhenget *et al*., 2004). Additionally, endophytic actinomycetes may influence plant growth by improved secondary metabolite (anthocyanin) synthesis or nutrient assimilation. In addition, one key strategy for combating phytopathogens is the synthesis of antimicrobial compounds such antibiotics and HCN (Blumer and Haas, 2000). Sesquiterpenes, chokols, hydroxyl-unsaturated lipids, phenolic glycerides, and an aromatic sterol are only a few of the substances produced in the mycelial-choked heads of timothy that Koshino *et al*. (1989) reported as being poisonous to some fungi. Endophytes produce a variety of volatile chemicals that efficiently inhibit and kill specific other fungus and bacteria (Strobel *et al*., 2001). Most of these substances have been discovered using gas chromatography-mass spectrometry, manufactured or obtained, and then combined artificially. The volatile chemicals that the fungus produced that acted as antibiotics were duplicated by this mixture. The recently described *Muscodor roseus* was twice collected from Australian Northern Territory tree species. According to Woraponget *et al*. (2002), this fungus is just as effective as *Muscodor albus* at inhibiting and killing test microorganisms in a lab setting. In culture, a different endophytic streptomycete (NRRL 30566) from the Northern Territory of Australia's Grevillea tree (*Grevillea pteridifolia*) produces brand-new antibiotics known as kakadumycins (Castillo *et al*., 2003). Alanine, serine, and an unidentified amino acid are all present in each of these antibiotics according to the nature of their amino acids. Colletotric acid, a metabolite of the endophytic fungus *Colletotrichum gloeosporioides* found in *Artemisia mongolica*, exhibits antibacterial efficacy both against bacteria and the fungus *Helminthsporium sativum* (Zouet et., 2000). The bioactive compounds produced by a different Colletotrichum sp., isolated from *Artemisia annua*, also demonstrated a range of antibacterial activity. According to Yue *et al*. (2000), some chemicals produced by cultures of the *Epichloe* and *Neotyphodium* species exhibit antifungal activity against the pathogen that causes chestnut blight, *Cryphonectria parasitica*, and they may have a similar effect on other diseases.

The chemicals in this investigation that showed the strongest antifungal action were a sesquiterpene, a diacetamide, and the indole derivatives indole-3-acetic acid and indole-3-ethanol. According to van Weeset *et al*. (1999), indirect disease management is accomplished by processes that influence the plant immune response, such as the creation of systemic acquired resistance.

VII. GENETIC AND ENVIRONMENTAL MODIFICATIONS INFLUENCING DISEASES CONTROL BY ENDOPHYTES

Cultivation-based techniques have been the mainstay of endophyte identification (Bell *et al*., 1995). Molecular methods based on the rRNA gene as a phylogenetic marker (Amann*et al*., 1995) offer a potent way to get beyond cultivation-related problems. In order

to analyze genetic variation in endophytes and host plants and to gain insight into the connection between endophyte and host plant variation and the variability of agronomic parameters, molecular markers are used (Gamper*et al*., 2008). In order to better understand the molecular processes involved in the formation of plant endophytic associations, researchers have worked to date (Bailey *et al*., 2006). Rapid characterisation of microbial communities is made possible by methods like terminal restriction fragment length polymorphism (T-RFLP) analysis and denaturing gradient gel electrophoresis (Smalla *et al*., 2001). The SSR markers are useful for determining genetic variation within and between endophyte species, as shown by comparison with data from amplified fragment length polymorphism (AFLP) data. The assessment of endophyte diversity in a pool of perennial ryegrass germplasm with a global distribution is presented following the discovery of these markers for the sensitive detection of endophytes in plants. Recently, Garbeva*et al*. (2001) used PCR-denaturing gradient gel electrophoresis to monitor endophytic populations of potatoes. The results showed the presence of a variety of organisms belonging to many unique phylogenetic groupings. Their findings also revealed that potato had nonculturable endophytes.

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