

ROLE OF ENDOPHYTES IN PLANT DISEASE RESISTANCE

Abstract

A detailed understanding of the mechanism employed by endophytes to protect the plant from diseases is still crucial for both efficacy and marketing fields. The primary purpose of endophytes is to make plants resistant to disease. Endophytes present themselves as a repository of many bioactive metabolites. Phenolic acids, alkaloids, quinones, steroids, saponins, tannins, and terpenoids are among the important bioactive metabolites from endophytes. They are a desirable possibility for the production of antiviral, anticancer, antimalarial, antimalarial, antidiabetic, and anti-inflammatory medicines. The majority of plant diseases are caused by microorganisms, with fungi, bacteria, and viruses coming in second and third. Applying agrochemicals is currently the primary strategy for controlling plant diseases. However, this approach has hazardous effects on both people and animals. The use of biology, which includes the use of bacterial endophytes in the biocontrol of a wide range of plant pathogens, offers an alternative to chemical pest control. Endophytic bacteria are a subclass of endosymbiotic microbes, which are common in plants and establish themselves in the spaces between and within all of the sections of the plant without harming the plant. In plants, endophytes symbolise a universal and fantastical universe. It has been discovered that almost all plant species investigated by various researchers possess one or more endophytes, which defend host plants from pathogen invasion and harmful environmental conditions. In addition to directly inhibiting pathogen growth, they can also support the growth and development of the host plants by producing a variety of metabolites. With the most recent research data, we want to clarify the contribution and important functions of endophytes and their metabolites in this field in this review, which focuses on the biological management of plant

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diseases. The use of endophyte metabolites to promote plant resistance is highly promising. Endophytes produce metabolites that are used to regulate plant disease.

I. INTRODUCTION

Agricultural diseases and pests are one of the biggest dangers to the safety of our food supply. Plant infections are brought on by pests and pathogens, which severely reduce the quality of crops. Agrochemicals are one of the most efficiently used tools in plant disease management. Excessive use of chemical fertilizers harms both the environment and people, causing environmental pollution, pathogen resistance, and ecological system imbalance (Hasan et al, 2013). There are helpful microbes and their metabolites, which act as an environmentally favorable bio-control agents (Vinale et al, 2008). To favour a sustainable ecosystem, we have to minimize or stay away from the overuse of chemical-based fertilisers and pesticides. Microorganisms and their products became one of the most popular research topics is that they are the best alternative for a sustainable ecosystem (Cardoso 2019; Omomowo et al., 2019). Since bacteria and fungi groups of endophytes are prevalent everywhere in plant tissues without causing any harm, the existence of them is frequently advantageous for the host plant. These endophytes can promote tolerance to abiotic stresses, enhance growth, and play an important role in modulating plant immunity and suppressing the colonization process of pathogens (Dini-Andreote 2020). Endophytic bacteria and fungi can cover the same niche as that of fungal and bacterial phytopathogens colonizing inside the plant, so they can be used as proper biological control agents instead of alternative pesticides (Compant et al., 2013). Because of the numerous endophytic microbial functions, they are essential in the agro-food system because of their multiple roles. Endophytes are used to improve the quality of agro-food systems which is nowadays scientific ferments trying to analyze their roles in plant-microbe interactions and plant-pathogen interaction as well (Morelli, et al 2020).

Without any immediate signs of diseases endophytes including bacteria, fungi, and actinomycetes can inhabit different parts of a plant, tissues, and intercellular space (Wilson 1995; Jia et al., 2016). There is a mutually positive interaction between endophytes and plants in the course of co-evolution time, plants produce nutrients for the endophytes, and in return, endophytes maintain the health of the plant through various mechanisms (Khare et al., 2018; Yan et al., 2019). Endophytes create a special ecological niche inside the plant that direct greater favorable influence on plants compared to soil microorganisms. There are research pieces of evidence showing endophytes' direct roles in plant growth promotion, reducing stress and disease resilience in host plants (khan et al., 2009; Ali et al., 2012; Ullah, et al 2019; Gao et al., 2021). Endophytes perform various mechanisms against phytopathogens. They compete for food and niche against the Phyto pathogens, also they secrete various bioactive metabolites and induce plant growth (Benhamou et al., 1996; Dubey et al., 2020; Martines et al., 2020). The endophyte-derived bioactive metabolites maintain plant health by helping the host plants against a number of abiotic as well as biotic stresses. Antimicrobial compounds produced by the endophytes in plant tissues can strongly inhibit phytopathogens. Some endophytic bacteria secrete hydrolases that can break down the cell walls of plant pathogens, while phytohormones secreted by endophytes play a significant role in encouraging plant growth and stress response (Singh et al., 2017; Sturz et al., 2000). *Bacillus*, *Burkholderia*, *Enterobacter*, *Pseudomonas*, and *Streptomyces* are certain groups of useful endophytes that are used in the formulation against various phytopathogens (Jacob et al, 2020). Endophytes can produce different types of metabolites having various biological actions. Alkaloids, polypeptides, polyketides, terpenoids, and other endophyte-produced metabolites play a vital role in both the food and pharmaceutical industries (Dubey et al.,

2020; Kusari et al., 2014; Joseph et al., 2011). Natural antioxidants, anticancer agents, antibiotics, insecticides, and antidiabetic medicines are among the uses for these metabolites (Gouda et al., 2016; Singh et al., 2021). Plant growth-promoting microbes (PGPM) are a group of microorganisms producing antimicrobials and volatile organic compounds that act as elicitors of prime systemic resistance in plants and thereby protect the host plant's health against stress (Enbe et al., 2018). In order to improve crop quality and yield and create a sustainable ecosystem with fewer harmful effects on people and our surroundings, we must conduct more studies on the use of endophyte metabolites as biological control agents in plant disease resistance (Xia 2020).

1. The Idea and Kinds of Endophytes

De Bary (1866) defined endophytes as “any organisms that grow in plant tissues” and can be separated from epiphytes, which inhabit plants' surfaces (Bary et al., 1866). Another definition of endophytes was later given, highlighting their beneficial relationship with plants as well as endophytes that occupy their aerial parts and live tissues without causing evident diseases or spreading infections; Mycorrhizal fungi and harmful fungi were avoided (Carroll et al., 1986). Petrini (1991) later broadened Carroll's concept to include any organisms that spend some of their lifecycles in plant tissues while not infecting the host plants by symptoms are considered (Petrini et al., 1991). Endophytes are defined in different ways (Wilson 1995; Stone et al., 2000). There were controversies regarding the concepts of endophytes but majorities of the studies commonly use Petrini's definition (Xia et al., 2022). *Ascomycota*, *Zygomycota*, and *Basidiomycota* are the common groups of fungal endophytes. Fungal endophytes can be divided into two categories based on their evolutionary relationships and life histories: clavicipitaceous endophytes and non-clavicipitaceous endophytes. Clavicipitaceous endophytes are found colonizing within some grasses and another group is found in asymptomatic tissues of nonvascular plants, conifers, ferns, and angiosperms (Rodriguez et al., 2009; Terhonen et al., 2019). The development of medicinal products such as anti-inflammatory, antioxidant, anti-fibrosis, and antiviral drugs mostly uses bioactive fungal endophytes. The isopestacin produced by the fungal endophyte *Pestalotiopsis* microspore has antioxidant properties (Strobel et al., 2002). *Taxomyces andreanae* is an important fungal endophyte from which the anticancerous drug taxol is extracted (Prakash et al., 2016). Podophyllotoxin made from *Alternaria tenuissima* exhibits good antitumor activity (Liang et al., 2016).

Multiple kinds of gram-positive and gram-negative endophytic bacteria exist, including *Bacillus*, *Agrobacterium*, *Brevibacterium*, *Pseudomonas*, etc (Sun et al., 2013). One of the recent studies by Liu et al reveals there are many endophytes in a variety of rice among which dominant endophytic bacteria are *Proteobacteria*, *Bacteroidetes*, and *Firmicutes* (Liu et al., 2021). The endophytic bacterial diversity in plants is directly impacted by environmental growth-related factors such as plant growth phases, location, climate, and the host plant (Afzal et al., 2019). Many endophytic actinomycetes have been isolated from a variety of plants, especially those that grow in mangrove and tropical rainforests. (Qin et al., 2010). Roots are the primary location of endophytic actinomycetes in plants, as compared with any other portion. The main sources of bioactive compounds and antibiotics are thought to be the genera *Streptomyces* and *Micromonospora*. Products such as Munumbicin D isolated from *Streptomyces* NRRL 30562 where coronamycin from *Streptomyces* sp. MSU-2110 (Zin et al., 2017). There remain many endophytic microbe

species that need to be investigated and characterized. There are still a lot of endophytes to find and study (Xia et al., 2022).

II. THE FUNCTION OF ENDOPHYTES AND THEIR BY-PRODUCTS IN THE CONTROL OF PLANT DISEASES.

By releasing a variety of metabolites endophytes can either directly or through indirect means enhance the host plant's resistance to stresses, endophytes act as possible biological disease controllers in plants by making the host plant helpful and limiting plant illnesses. Rice blast caused by *Pyricularia oryzae* Cav., a well-researched fungal pathogen, may be successfully controlled by the use of endophytic microorganisms (Widiantini et al., 2017). The *Populus alba* which is a fungal endophyte increases the host's resistance to the disease *Venturia tremulae*. (Martínez et al., 2018). Romeralo et al. (2015) isolated a number of endophytes and demonstrated their capacity to protect Aleppo pine (*Pinus halepensis*) from *Gremmeniella abietina*. The plant European ash (*Fraxinus excelsior*) affected with the pathogen *Hymenoscyphus fraxineus* can be treated with the help of endophytic microbes by the generation of toxins or activation of the host defence response (Schlegel et al., 2016). Endophytes are a diverse group of bacteria that asymptotically colonize inside plant tissues. According to numerous studies, endophytes directly produce bioactive secondary metabolites that protect their host plants against herbivores and pathogenic microorganisms, improving the fitness of their host plants. Additionally, it is becoming more and more clear that endophytes are able to biosynthesize medicinally significant "phytochemicals," which are exclusively produced by their host plants (Ancheeva et al., 2020).

The biocontrol functions of endophytes and their metabolites against plant diseases are frequently discussed and stated in the scientific community, which indicates that researchers are becoming more and more interested in this topic. Important mechanisms of endophytes in plants are (1) Endophyte's competition with pathogens over niche and nutrition, (2) Systemic resistance induction in host plants, (3) Generating antimicrobial compounds, (4) Lytic enzyme secretion, (5) Synthesizing plant hormones and growth-promoting regulators for plants. Despite this, there are still many issues to be resolved. Here is an outline of the key strengths, upcoming potentialities, and limitations of using endophytes and their derivatives in the treatment of diseases (Xia et al., 2022).

1. Endophyte's Competition with Pathogens over Niche and Nutrition

Colonization in plant tissues is one of the basic traits of endophytes (Latz et al., 2018). Endophytes frequently get into the host plant as spores by penetrating the epidermal layer or through the invasion of stomata similar to how pathogenic bacteria attack plants. By consuming nutrients, these beneficial "endophyte-guests" selectively inhabit the pathogen occupying invading sites in plants. It helps to prevent further pathogen invasion by limiting the available nutrients. (Rodriguez et al., 2009). Employing the endophyte *Bacillus subtilis* which belongs to bacteria (Ehrenberg) created a control system that showed significant potential for lowering *Fusarium moniliforme* invasion and mycotoxin accumulation. Because these two bacteria shared a similar biological niche in maize (Bacon et al., 2001). Furthermore, endophytes and pathogenic microorganisms compete with one another for

nutrients, which leads to the lowering of growth rates of pathogens. A strong indicator of nutrient competition is the release of high-affinity iron molecules such as siderophores and peptides. Some *Pseudomonas* species adopted this tactic to biocontrol the *Fusarium oxysporum* f.sp. *dianthi* (Fod)-caused carnation fusarium wilt (Duijff et al., 1993). When these useful microbes present in host plants are inhabiting the same ecological niche as that of pathogens they are able to compete for resources and nutrients (Xia et al., 2022). It was demonstrated that competition for iron was the cause of the rice endophyte *Streptomyces sporocinereus* OsiSh-2's significant antagonistic activity toward *Magnaporthe oryzae* (Zeng et al., 2018).

Endophytes compete with harmful microorganisms for nutrients and niches, or they exclude those microbes from certain niches, protecting the plants from disease as a result. (Liarzi et al., 2013). If there are numerous infections present there can be limits, and it might not function (Lahlali et al., 2013). This issue can be resolved by inoculating host plants with endophytes in advance and in large quantities using a variety of techniques. These methods include seed coating, dipping the root, soil soaking, and foliar spraying. Also, the technique of combining the right endophytes or microbes rather than relying just on one kind can also be adapted (O'Callaghan et al., 2016; Griffin 2014). Table 1 lists important metabolites isolated from the endophytes and their role in plant disease management.

2. Systemic Resistance Induction in Host Plants

The two crucial plant responses to parasite or pathogen attacks are systemic acquired resistance (SAR) and systemic induced systemic resistance (ISR). Systemic acquired resistance (SAR) is typically based on salicylic acid (SA) signalling, whereas induced systemic resistance (ISR) is typically dependent on jasmonic acid (JA) and ethylene (ET) signalling. SA system mediates resistance to biotrophic pathogens. Predominantly Jasmonic acid or Ethylene pathway regulates resistance from necrotrophic pathogens (Robert-Seilaniantz et al., 2011; Ghorbel et al., 2021; Van der Ent et al., 2009). The signalling interaction between these channels shows that induced systemic resistance (ISR) and Systemic acquired resistance (SAR) cannot be separated from one another. Induced systemic response regulated by some endophytes may depend on the Systemic acquired pathway instead of the Jasmonic acid or Ethylene pathways (Kloepper et al., 2006). Plant hormones such as methyl jasmonate (MeJA), as well as brassinosteroids (BRs), are also involved in the plant defence system (Robert-Seilaniantz et al., 2011; Soler et al., 2013).

Endophytes promote plant resistance in order to manage plant diseases, and this has inspired a lot of research. Compared to uninfected plants, endophyte-inoculated plants typically have better resistance to diseases. The introduction of endophytes in a particular area within the host plant showed they can greatly reduce the disease rate when pathogens are spread in multiple parts. Both *Penicillium citrinum* LWL4 as well as *Aspergillus terreus* LWL5 belong to fungal endophytes present in the sunflower family's (*Helianthus annuus* L.) significantly boosted resistance to stem rot within the host plant induced by pathogen *Sclerotium rolfsii* (Waqas et al., 2015). A bacterial endophyte called *Azospirillum* sp. B510, which has been identified in rice (*Oryza sativa* cv. Nipponbare), can make the host resistant to bacterial blight and rice blast disease (Kusajima et al., 2018). Similar to this the rice-isolated *Bacillus* strain YC7010T was developed as a new BCA to protect from the disease rice bacterial blight (Chung et al., 2015).

There are several pathogenesis-related genes like PR1, PR2, and PR3 and phenylpropanoid pathway genes like chalcone synthase CHS as well as phenylalanine ammonia-lyase gene PAL which have important roles in phytoalexin biosynthesis are upregulated by endophytes. So that we can understand Endophytes have a significant role in the prevention and management of plant diseases. They can also alter plant cell wall callose deposition, and stomatal closure hence increasing the levels of defense-related antioxidant enzymes within the plant to protect from diseases (Howlader et al., 2020; Kavroulakis et al., 2007; Boava et al., 2011). High concentrations of polyphenol oxidase (PPO), peroxidase, and phenylalanine ammonia-lyase (PAL) were found in tomato plants after treatment with two endophytic bacteria. The host plants' systemic defences against pathogens have been stimulated by these substances (Akram et al., 2011). The latest research showed that ZhiNengCong (ZNC), isolated from endophytic fungi *Paecilomyces Variotii* SJ1, is an extremely potent immunological stimulant in tobacco plants (Peng et al., 2020).

There are numerous endophyte metabolites that function as elicitors. These bioactive substances function as a possible alternative option to controlling plant diseases. The secondary metabolites of a few non-endophytic bacteria are currently attracted in research because studies proved that they help in plant resistance. By generating secondary metabolites such as fengycin, surfactin, and 2,3-butanediol, *Bacillus amyloliquefaciens* SQR9, which was isolated from cucumber rhizosphere, promotes resistance through different channels of signalling (Wu et al., 2018). The most important secondary metabolite, C15 surfactin A from the soil-isolated *Bacillus velezensis* HN-2 exhibits excellent antibacterial action against *Xanthomonas oryzae* pv. *Oryzae* (Xoo), in addition successfully started rice resistance to pathogens (Jin et al., 2020). The glycoprotein GP-1 produced by the soil-isolated *Streptomyces* sp. ZX01, which led to the early induction of plant immune responses in tobacco is a remarkable milestone in research (Han et al., 2020). These results are crucial for the use of endophyte metabolites in promoting plant resistance (Xia et al., 2022).

3. Endophytic metabolites and their antimicrobial properties

Endophytes are recognized for their capacity to synthesize a large variety of secondary metabolites that have antifungal and antibacterial activities. These varieties of secondary metabolites can efficiently reduce infections (Gunatilaka 2006). It was reported that an endophytic fungus from the Pacific yew, *Taxus brevifolia*, could produce the same chemical as its host. This study stimulated scientists to look at more biologically active substances in plant endophytes (Stierle et al., 1993). *Bacillus amyloliquefaciens* CGMCC 5569 is an endophytic bacteria present in Chinese pharmaceutical plant *Ginkgo biloba*. Lipopeptide which is an antibacterial compound found in the fermentation broth of this endophytic bacterium successfully suppressed the growth of *Lasiodiplodia rubropurpurea* and *L. theobromae* (Yuan et al., 2012). According to some studies, the endophytic fungus WF4, which was isolated from the crop finger millet, produced antifungal compounds that had an adverse impact on *F. graminearum* (Mousa et al 2015). *Vochysia divergens* is a medicinal plant collected from Brazil. Endophytic actinomycete strain LGMB491 which is closely related to *Aeromicrobium ponti* isolated from *V. divergens*. And this endophytic actinomycete strain LGMB491 produced four key metabolites that have antibacterial effects on *Staphylococcus aureus* (Gos et al., 2017). Endophytic *Bacillus* and *Streptomyces*, have been found to be the predominant manufacturers of antimicrobial substances within different gram-positive bacteria isolated from various environments (Ek-Ramos et al., 2019).

4. Metabolites from Endophytes and their Lytic enzyme activity

Lytic enzymes that hydrolyse polymers are produced by the majority of bacteria (Gao et al., 2010). Endophytes have the ability to release a variety of compounds, such as proteins, DNA, cellulose, chitin, hemicellulose and cellulose (Tripathi et al., 2008). Significant enzymes produced by endophytes support hydrolysis of the plant cell wall to colonize on the plant surface. Enzymes such as these can play an indirect role in lowering the number of phytopathogens and the breakdown of fungal cell walls. There are many different kinds of enzymes, some of which include 1, 3-glucanases, chitinases, cellulases, and hemicellulases. When 1, 3-glucanase genes in a strain of *Lysobacter* enzymogenes were subjected to mutation, the biocontrol ability against *Pythium*-caused sugar beet damping-off disease as well as tall fescue leafspot disease was lowered (Gao et al., 2010). Disease which is known as cocoa witch broom can be treated by lytic enzymes produced by *Streptomyces* (Macagnan et al., 2008). Although enzymes might not be the only thing that can operate as an antagonist, when combined with other processes, they can strengthen antagonistic activity. It is reported that Pectinase also helps to reduce pathogenesis (Babalola, 2007).

Seed, stem, root, foliage, as well as other tissue parts of the host plant, are the primary sites for the extraction of endophytes. Different types of enzymes including Cellulases, Chitinases, β -1, 3- glucanases as well and pectinases are produced by endophytes (Gao et al., 2010; Ben 2019; Rajulu et al., 2010). Such enzymes from endophytes have the ability to break down the pathogen cell wall as well as prevent spore germination. These enzymes have the power to degrade the cell wall of pathogens or prevent spore germination. Hence it is a powerful method for suppressing phytopathogens and providing the host with biotic stress resistance. From the *Ammodendron bifolium* plant, forty-five endophytic bacteria were isolated. In these 45 endophytes, it was found that 40% of the endophytic bacteria were significantly involved in the production of amylase and cellulose. The majority of the remaining 53.3% of the recovered bacteria showed lipase activity, with only 13.3% of them exhibiting protease activity (Zhu et al., 2018). *Plectosporium tabacinum* is a pathogenic organism which is controlled by endophyte *Actinoplanes missouriensis* through several mechanisms such as degrading the hyphae, by inducing plasmolysis and cell wall lysis (El-Tarabily 2003). Numerous lytic enzymes generated by *Streptomyces* served as antagonistic agents against *M. pernicioso* in Witches' broom disease of cocoa (Macagnan et al., 2008).

To increase host disease resistance in plants, genes responsible for chitinase of several bio-control bacteria have recently been cloned and inserted into host plants (Cook 1993). In order to facilitate colonisation in host plants, endophyte *Bacillus cereus* XB177R from the eggplant (*Solanum melongena* L.) produces endoglucanase and pectinase enzymes (Achari et al., 2018). Understanding the capacity to produce various metabolites possessing lytic enzyme activity, numerous endophytes were isolated and identified to increase the host resistance over phytopathogens. The lytic enzymes' potential role in inducing systemic plant resistance to pathogens is still not known. When such enzymes are integrated with other mechanisms, they typically exhibit substantially stronger antagonistic actions. Metabolites from endophytes are excellent substitute sources for many extracellular hydrolytic enzymes as well as microbial production of enzymes. Additionally, microbial enzyme production holds the promise of creating agricultural systems that are sustainable (Khan et al., 2017).

5. Plant Growth Promotion and Endophytic Metabolites

Enhancing plant growth is one of the important approaches employed by plants to defend themselves from pathogen invasions thereby increasing their resistance to various stresses (Kuldau et al., 2008). Endophytes and their metabolites are well known for promoting plant growth. On the one hand, endophytes significantly increase plants' ability to absorb and use nutrients including nitrogen, phosphorus, as well as potassium. In particular diazotrophic bacteria, an endophyte linked to gramineous plants, produces ammonia by fixing atmosphere nitrogen which improves host development and resistance to disease. Particularly, diazotrophic bacteria which is an endophyte associated with gramineous plants convert atmospheric nitrogen into ammonia by nitrogen fixation, which promotes host growth and disease resistance. Endophyte *Paenibacillus polymyxa* P2b-2R found in lodgepole pine seedlings helped corn seedlings grow 52% longer while obtaining 30% of their total foliar nitrogen directly from the atmosphere. of their foliar nitrogen from the atmosphere and grow 52% longer (Puri et al., 2016). Whereas endophytes have also been found to stimulate the growth of plants by the release of hormones such as ethylene, auxin, cytokinin and gibberellin. With the help of secondary metabolites released by the endophytic bacteria such as *Staphylococcus*, *Azotobacter*, and *Azospirillum* can regulate both the development as well as growth of the host plant (Hallmann et al., 2016). 46 actinomycetes were isolated using tissue samples of 15 distinct tea varieties most of which were capable of producing IAA (Shan et al., 2018). Different plants have been discovered to have more growth-promoting endophytes (Eid et al., 2021; Krause et al., 2006; Tian et al., 2017; Borah et al., 2020). Hence it is proved that endophytes' support of plant growth can indirectly shield host plants from diseases (Xia et al., 2022).

Growth regulators and phytohormones are generally chemically manufactured or derived from plants in the agricultural sectors. Microbial fermentation has a higher degree of practical usefulness and is an efficient technique that can increase productivity and lower manufacturing costs for metabolite plants. Few products have been mass-produced commercially even after several publications demonstrating successful manufacturing of plant metabolites from in vitro endophytes. The question of whether host plants or endophytes produce bioactive metabolites must also be considered. Plant-endophyte interaction processes are not fully understood. The domestic plant-endophyte distribution is disturbed when endophytes are isolated and cultivated in vitro apart from the host. Further research is required to clarify the proportional contributions of "host plants" along with endophytes in the manufacture of particular metabolites. (Xia et al., 2022).

III. WHY DO ENDOPHYTES HELP PLANTS?

The process behind the plant growth promotion activities that are regulated by endophytes is not fully understood (Hardoim et al., 2008). Growth and development of the host plant are promoted by endophytes either directly or indirectly. Since endophytes begin their journey as rhizosphere bacteria to the plant it has been suggested that they may maintain their traits inside the plant. Most endophytes can be grown and survive without hosts in the rhizosphere. Their beneficial functions are related to bacteria present in the rhizosphere. The majority of endophytes can be cultivated and can live outside of hosts in the rhizosphere, their processes of benefit appear connected to rhizosphere bacteria (Yadav et al., 2017). Let's

discuss direct mechanisms or we can call endophytes-pathogens interactions and indirect mechanisms or enhanced plant defence (Arnold et al., 2003).

1. Directly Beneficial Mechanism

By supplying antibacterial metabolites, nitrogen-fixing properties, insecticidal by-products, iron chelators as well as phosphate solubilizing chemicals production etc plant endophytes can significantly assist plants (Yadav et al., 2017). Additionally, endophytes have an impact on plant growth by synthesizing phytohormones, and siderophores, generating systemic tolerance by the formation of 1-aminocyclopropane-1-carboxylase deaminase and inducing systemic resistance and antagonism. Additionally, a number of sulphur-oxidizing endophytes can convert sulphur into sulphate, which is then utilized by plants (Knoth 2014). Furthermore, endophytes are abundant sources of phytochemicals that prevent plant diseases from spreading. Endophytes produce plant metabolites and they are the strong source of physiologically active secondary metabolites. There are mainly two types of mechanisms Direct and Indirect mechanisms discussed below benefit the host plant (Chen 2011; Benhamou et al., 1998; Brader 2014; Schulz et al., 2002)

Recent research on endophytes found they can enhance the host's potential ability to resist diseases and lower the damage resulting from harmful pathogens (Ganley et al., 2008; Mejia et al., 2008). New methods employed by endophytes to lessen the impacts of infections have been described in certain research, and endophytes, pathogens, and plant regulators are still poorly understood at this time (Ganley et al., 2008). Endophytes directly produce antibiotics that assist in inhibiting infections in the direct mechanism. The process of direct interactions between endophytes and pathogens is complicated and prone to species-specific association (Arnold et al., 2003). Several examples of direct mechanisms employed by endophytes are provided below ((Yadav et al., 2017).

Phytohormone production: The process of phytohormone generation by endophytes is widely accepted for promoting plant development and structural changes in the plant. Due to this property endophytes are significant in the field of sustainable agriculture (Yadav et al., 2017). The production of phytohormones by endophytes in host plants has similarities to how rhizobacteria promote plant growth (Sturz et al., 2000). They stimulate the growth of non-legumes by accelerating their growth through the production of hormones such as auxins, gibberellic acid and ethylene (Yadav et al., 2017). Endophytes generate phytohormones that can affect the morphology as well as structure of plants. Also, endophytes stimulate the growth of host plants. Because of this characteristic, endophytes have been successful in the area of agricultural sustainability (Sturz et al., 2000). The method of plant growth promotion by rhizobacteria is almost similar to the method adopted by endophytes in the generation of phytohormones in the host plant. Endophytes protect and promote the growth of non-leguminous plants by releasing hormones like Gibberellic acid, auxins, indole acetic acid and ethylene (Khan et al., 2014; Dutta et al., 2014; Khan et al., 2014; Patel 2014; Babalola 2010; Kang et al., 2012).

Indole acetic acid (IAA) which is a phytohormone stimulates plant extension, cell division, differentiation, seed and tuber germination, root and xylem development, lateral initiation, rate of vegetative growth, adventitious root formation along with pigment and metabolite biosynthesis responses to gravity, light, and fluorescence, photosynthesis as well

as resistance to extreme temperatures (Gao et al., 2010). IAA secreted by bacteria promotes plant growth by changing the amount of auxin secreted within the plant and all of these physiological processes mentioned above can be sometimes slowed down. IAA released from endophytic bacteria can expand the surface area of roots thereby allowing the plants to absorb more nutrients from the soil. IAA can enhance the size of bacterial cell walls and exudate secretion to deliver more nutrients to help the growth of other beneficial bacteria present in the rhizosphere. IAA secreted by bacterial endophytes is considered to be the main effector molecule which is involved in the mechanism of Phyto stimulation, plant-microbe interaction and pathogenesis (Gao & Tao 2012). A number of studies have shown endophytic actinomycetes generate substances that promote plant growth, including IAA. These substances help plants in the formation and lengthening of adventitious roots (de Oliveira et al., 2010; Shimizu 2011).

Nitrogen Fixation: Plants require a continuous source of nitrogen since they can't reduce atmospheric nitrogen. Since their availability nitrogen is considered to be the most restrictive nutrient for plant growth. Because plants are unable to reduce atmospheric N, they need a constant external supply of N. The potential for biological N fixation as a solution for chemical fertilizers is significant. Agriculture may benefit from a number of symbiotic prokaryotic endophytes that can fix atmospheric nitrogen. Nitrogen can be delivered to plants directly by diazotrophic endophytes. Researchers have focused on free-living, nitrogen-fixing endophytic bacteria for the past few seasons (Yadav et al., 2017). Legume-Rhizobium symbiosis is still the focus of international research focusing on Legume-Rhizobium symbiosis to increase the efficiency of N₂ fixation by genome and plant manipulation (Reis 2004).

Production of siderophores: Some endophytes create siderophores, which are tiny molecules that act as iron-chelating agents in plants and deprive irons of pathogens (Compant, 2005). Catecholate, hydroxamate, and/or phenolate kinds are among the siderophores made by endophytes that have bio-controlling qualities (Rajkumar et al., 2010). Moreover, siderophores support plants which are deficient in iron and help in nitrogen fixation since diazotrophs require both Fe⁺⁺ and Mo compounds for the working and production of nitrogenase (Kraepiel 2009). There are researches which validate endophytes' capacity to eradicate insects (Azevedo et al., 2000). Some endophytes thicken the endodermal cell wall to prevent pests from penetrating the stele (Gao et al., 2010). Others produce secondary metabolites that destroy insects. Although some harmful metabolites can be linked to endophytes such as pyrrolopyrazine alkaloids, alkaloids, peramine ergot alkaloids, ergovaline along with pyrrolizidine (Wilkinson et al., 2000). When bacteria promote plant growth, Fe²⁺ is converted into Fe³⁺ siderophore complex in the bacterial membrane. Later this Fe³⁺ siderophore enters the cell with the help of endophytes via a gating mechanism (Gao et al., 2010). The level of soluble metals increases when siderophores are able to bind to the metal surface (Rajkumar et al., 2010). When the heavy metal contamination is lowered, plants use a variety of processes to absorb iron from bacterial siderophores including the exchange of ligands or absorbing the siderophore-Fe complexes directly by using of iron chelates (Schmidt, 1999). *Pseudomonas* strain GRP3 which is a siderophore-generating endophyte tested in *Vigna radiata* to check iron nutrition. 45 days later plant started exhibiting a reduction in chlorotic symptoms and iron levels. When compared with the control plant, the strain GRP3-treated plant had higher levels of both chlorophyll a and chlorophyll (Sharma et al., 2003). Few endophytes belong to the group actinomycetes involved

in the production of siderophores are *Streptomyces* sp. UKCW/B, *Streptomyces* sp. GMKU 3100, *Streptomyces* sp. mhcr0816, as well as *Nocardia* sp (Singh & Dubey 2018). Similar to this, *S. acidiscabies* E13 can act as an excellent generator of siderophore that promotes *Vigna unguiculata* growth when there is stress due to the presence of nickel (Sessitsch et al., 2013). 1-Aminocyclopropane-1-Carboxylate (ACC) Utilization: The plant's growth and development are mainly controlled by the vital metabolite ethylene (Khalid et al., 2006). Almost all plants emit this crucial hormone, which is recognized for promoting plant growth. It is influenced by many abiotic as well as biotic processes from the soil and it enhances physiological changes in the majority of the plants. Adverse environmental factors like disease, saline conditions, water scarcity and heavy metal pollution increase ethylene levels in plants which negatively affects plant growth and changing cellular processes. This leads to defoliation thereby reducing agricultural products (Bhattacharyya & Jha 2012). *Achromobacter*, *Acinetobacter*, *Agrobacterium*, *Bacillus*, *Enterobacter*, *Pseudomonas*, *Serratia*, *Ralstonia*, *Alcaligenes*, *Burkholderia*, and *Rhizobium* are numerous endophytes belong to bacterial species that can synthesise ACC deaminase (Kang et al., 2012). Bacterial endophytes trap ethylene precursor of ACC thereby converting into ammonia and 2-oxobutanoate (Arshad et al., 2007). ACC deaminase secreted by the plants helps them to withstand challenges like radiation, heavy metals, high light intensity, wounds, high levels of salt concentration, flooding resistance by the stress from polyaromatic hydrocarbons, attacks from insects, drought, and severe temperature (Lugten and Kamilova, 2009).

Competition with pathogen: Endophytes exploit competition as a potent barrier against pathogen colonization within the host tissue (Martinuz et al., 2012). Systemically or locally endophytes can colonize within plant tissues (Latz et al., 2018). By colonizing within the plant tissues endophytes hide nutrients as well as occupying space where pathogens exist (Rodriguez et al., 2009). It was found that when endophytes are destructed from the mango leaves by the application of fungicides, it allows other specific pathogenic fungi to enter into the niche within the host plant. A mechanism for competition is present in almost all endophytes, yet it typically works when combined with other processes instead of working by itself. Endophytes often use limited control strategies within specific areas so that they have to actively colonise all parts within the host plant where pathogens are most susceptible to occupy and attack. But the colonization of *Heteroconium chaetospora* endophyte within the root of oilseed rape couldn't protect from clubroot disease (Lahlali et al., 2014). Endophyte as a biocontrol agent time fails to compete with the pathogen when they are present in high number. Endophytes reduce diseases within the plants by competing with the pathogen. Symptoms caused by the pathogen *Phytophthora* sp. successfully decreased when treated with endophytes from cacao tree leaves. However, it was discovered that some of the endophytes can produce extra active metabolites proving that there are other strategies to treat plant diseases other than the competition method. (Arnold et al., 2003).

2. Antibiotics by Endophytes

Endophytes can generate secondary metabolites with antibacterial and antifungal properties. These secondary metabolites support the prevention of the growth of phytopathogens (Gunatilaka, 2006). There are different kinds of Studies that identified endophyte metabolites as having commercial values. Endophytes are mainly studied because of their ability to prevent various phytopathogens by using several bioactive substances (Suryanarayanan, 2013; Daguerre et al., 2016). It has been discovered that a number of

endophyte metabolites have antibacterial properties. Some of them include flavonoids, phenols, peptides, quinones, alkaloids, terpenoids, polyketides and steroids (Mousa and Raizada, 2013; Lugtenberg et al., 2016). When more than one different microbial strain is found in a single plant increases the production of several metabolites by both endophytes and the host to control the attack of harmful pathogens (Kusari et al., 2012). The host plant as well as the endophytes opt for alternate paths to enhance the production of metabolites; in other cases, they use induced metabolism to help metabolize one another's products (Kusari et al., 2012; Ludwig 2015). Many studies revealed that most of the endophytes cannot generate the compounds independently by themselves (Heinig et al., 2013). Endophyte *Phomopsis cassia* found from the *Cassia spectabilis* can produce five derivatives. These derivatives have antifungal properties over *Cladosporium cladsporioides* as well as *Cladosporium sphaerospermum*. Also, these compounds exhibit similarity with compounds 3,11,12-trihydroxycadalene and cadinane sesquiterpenes (Silva et al., 2006). Alkaloids are compounds to control the growth of pathogens. To prove this there is an example of a new alkaloid altersetin which separated from endophyte *Alternaria spp.*, can powerfully act against pathogenic gram-positive bacteria (Hellwig et al., 2002). Volatile oil is another metabolite that demonstrated antibiosis. In vitro isolated *Artemisia annua* fungal endophytes prevented the growth of the many phytopathogenic organisms by synthesising two specific antifungal compounds including n-butanol and ethylacetate (Liu et al., 2001). Studies found that Anti-fungal protein generated by *Epichlo festucae* can repress the growth of pathogen *Sclerotinia homoeocarpa* within the plant *Festuca rubra* (Tian et al., 2017). And it is one of the special characteristics of fescues to prevent pathogens. *Paraconiothyrium* strain SSM001 acts against dangerous wood-decaying fungus by associating with the process of generation of taxol in the Yew tree (*Taxus spp.*) against harmful wood-decaying fungus (Rafiqi et al., 2013; Soliman et al., 2015)

When it comes to preventing the spread of above-ground fungal infections, the emission of volatile chemicals by bacteria associated with plants has come to the fore in some instances (Köberl et al., 2013; Bailly and Weisskopf, 2017; Garbeva and Weisskopf 2020). Both *Bacillus subtilis* as well as *Bacillus cereus* strains were found in the grapevine leaf microbiome and it is thought that these strains are able to limit the growth of *Phytophthora infestans* by releasing volatile chemicals such as pyrazines, chalconoids, and tryptophan derivatives. Bioactive diterpenoid cryptotanshinone production is stimulated by endophytes present in *Salvia abrotanoides* plants. Research reveals that endophytes can hijack the host's metabolic setup and establish an interesting foundation for both agriculture as well as pharmaceutical fields by utilizing beneficial pharmaceutical plant's ability to produce bioactive metabolites (Morelli et al., 2020).

3. Indirect Mechanisms

Plants can overcome different harmful biotic and environmental challenges, including pathogenesis, hypersaline conditions, cold, and drought. Endophytes provide indirect processes that facilitate plants in overcoming such challenges. According to the concept of process-induced systemic resistance (ISR), some endophytes that may have originated from plant infections have the ability to trigger similar plant defences as pathogens. Some of these mechanisms are discussed below (Yadav 2017). In order to survive in harsh environments like drought, salt stress, and cold, plants use a variety of strategies. The formation of phytoalexins, cellular necrosis, and the hypersensitive response are a few of the quickly

apparent biochemical and morphological alterations that have been reported. Innate resistance generated for pathogen resistance in long-term evolution includes both non-specific (generic) and particular resistance. One or a few infections can be prevented by those with specific resistance, whereas many pathogens can be prevented by those with non-specific resistance. Endophytes produce secondary metabolites and have improved resistance, which strengthens the plant's defence system (Fadiji and Babalola 2020).

4. Induction of Plant Resistance

Numerous research studies have focused on the approach that plants react to attacks from parasites and diseases using various levels. The two resistance patterns that have garnered the most interest from researchers are induced systemic resistance (ISR) and systemic acquired resistance (SAR). Salicylic acid-mediated Systemic acquired response triggered by microbial infections and associated with the production of PR proteins. But ethylene or jasmonic acid-regulated Induced systemic response produced by some non-pathogenic rhizobacteria cannot be linked to the development of pathogenesis-related (PR) proteins (Tripathi et al., 2008). Invading cells are directly lysed by those enzymes including 1, 3-glucanases as well as chitinases produced by PR proteins which also strengthen cell wall borders and increase resistance to infection and cell death (Gao et al., 2010). ISR generated by endophytes has also been linked to an increased expression of genes involved in pathogenesis. *Fusarium solani*, a significant endophyte found in tomato roots, induces ISR over the pathogen *Septoria lycopersici* responsible for foliar infections in tomatoes thereby activating PR genes such as PR7, and PR5 within the roots (Kavroulakis et al., 2007). According to Redman et al. (1999), when both *Cucumis sativus* and *Citrullus lanatus* inoculated along with a non-pathogenic mutant strain of *Colletotrichum magna* resulted in the production of large amounts of lignin deposition, peroxidase along with phenylalanine ammonia-lyase. All of them assist to defend the plant from the disease brought on by *Fusarium oxysporum* and *Colletotrichum orbiculare*. *Neotyphodium lolii* reduced leaf lesions with their ability to attack four different pathogens. These endophytes within the host plant increased peroxidase and superoxide dismutase activities (Tian et al., 2008).

5. Plant Secondary Metabolite Stimulation

Although secondary metabolites from plants serve only a few roles throughout the plant lifespan, they are necessary for the plant's ability to adapt to its surrounding climate (Bourgau et al., 2001). Phytoalexins are molecules belonging to low molecular weight antibacterial compounds which are different from all other secondary metabolites produced within plants because they contain different compounds such as flavonoids, terpenoids etc. When fungus attack *Orchis morio* and *Loroglossum hircinum* corresponding to this action first phytoalexins are produced. However, results of subsequent studies revealed that during abiotic stress conditions including salinity stress, heavy metal pollution UV light etc., phytoalexins are produced (Gao et al., 2010). There are studies about the mechanisms of pathogens resulting in the production of phytoalexins (Pedras et al., 2008). A relatively unexplored area of study is the formation of secondary metabolites in plants which is controlled by endophytes. The elicitors of *Fusarium E5* were found to be able to increase the production of triterpene and dipertene in *E. pekinensis* cell suspensions. Supernatants of suspensions culture of endophytes from *Taxus cuspidate* supernatants led to higher paclitaxel synthesis as compared to the control (Li Y and Tao, 2009). Elicitor endophyte with co-

culturing is a viable strategy for enhancing plant resistance and secondary metabolite production in plants. Endophytic colonisation caused plant cells to produce hydrolase, which inhibited the growth of fungi and allowed endophytes to function as elicitors by producing hydroxylation. Glycoprotein, polysaccharides, and lipopolysaccharides are examples of elicitors that activate plant defence mechanisms and boost the secretion of secondary metabolites from plants, thereby reducing pathogen attack. There is, unfortunately, little data on how endophytes persist within the host plant during the synthesis of significant amounts of secondary metabolites (Gao et al., 2010)

6. Plant Growth Promotion and Physiology

Endophytes can frequently help the host plant's defence mechanism against bacterial plant pathogens by having control over the plant's physiology. (Gimenez et al., 2007). During the development period of plants, they acquire strength as well as tolerance against different biotic as well as abiotic stimuli. It can be one of the techniques employed by plants to defend themselves against diseases (Kuldau and Bacon, 2008). Studies demonstrated plants exhibit improvement in growth and drought resistance when endophytes are present (Gao et al., 2010) along with resistance to soil tolerance (Malinowski et al., 2004). Several chemicals can help plants grow and one endophyte, *Colletotrichum sp.*, which is separated from the plant *A. annua*, makes an ingredient indole acetic acid (IAA) that can control plant growth. According to studies, *Fusarium sp.* E5 extracts produced auxin. The release of phytohormones can be thought of as another mechanism used by endophytes (Dai et al., 2008). Therefore, we can assume that endophytic stimulation of plant development will indirectly protect the plant from infections.

7. Hyperparasites and Predation

With the help of hyperparasites protecting the host plant is another strategy adopted by the endophytes. In this method, endophytes directly attack recognized disease or their propagules (Tripathi et al., 2008). Endophytic fungi trap the pathogens by twisting and entering the infection hyphae and creating lyase, which dissolves the pathogen's cell wall. *Trichoderma sp.* can trap and penetrate the hyphae of plant pathogen *Rhizoctonia solani* where it can be linked to biocontrol efforts. The reduction of plant pathogens through microbial predation is another technique. The majority of endophytes show their predatory traits in nutrient-poor environments. *Trichoderma sp.* secretes an array of enzymes that have the ability to dissolve pathogenic fungi (Grosch et al., 2006).

IV. A CROSS-TALK WITH PLANTS' DEFENSE PATHWAYS

One of the most difficult findings regarding the research on endophytes is that plant growth-promoting bacteria (PGPB) strains can activate plant defence mechanisms (Ma, 2017). Systemic resistance (ISR) induced by PGPB is linked to the increased expression of genes in the ethylene and jasmonic acid metabolic pathways (Pangesti et al., 2016). ISR is frequently accompanied by biochemical reactions that can increase the production of reactive oxygen species (ROS) and phenolic compounds along with morphological changes including callose deposition and lignin in those tissues where endophytes are colonized (Benhamou, 1996; Constantin et al., 2019). When *Paenibacillus* strains (such as PB2) were employed to eradicate *Mycosphaerella graminicola*, they activated the up-regulation of several genes,

including pathogenesis-related proteins (PR1) and chitinases, which are normally regarded as indicators of SAR (systemic acquired resistance) (Van et al., 1998; Samain et al., 2017). The distinctive induced resistance that gives wheat a long-lasting resistance is fascinating since it may be a more common phenomenon that has been seen in other PGPB taxa, such as *Bacillus* and *Pseudomonas* (Park and Kloepper, 2000; Trostel et al., 2008; Samain et al., 2017). Its mechanism of action, which seems to be significantly impacted by the pathogen strain, the plant growth period, and its genotype, has to be explored (Morelli et al., 2020).

The duration of the resistance effect to pathogen-induced biotic stressors that endophytes may activate is actually an important aspect of management approaches. Plants primed with *Rhizobium etli* appear to develop a transgenerational defence memory, which is important in showcasing the skill of *R. etli* one of the common symbionts in beans can activate plant defence mechanisms against the pathogen *Pseudomonas syringae* pv. *Phaseolicola* (Diaz et al., 2019). According to previous research, transcription factors previously implicated in the stimulation of the PR gene expression and independent of the ethylene signalling pathway appear to be responsible for the tenacity of this ability from generation F1 (Huang et al., 2016). Associative symbioses in various helpful bacteria have been extensively researched recently (Ahemad and Kibret, 2014; Coutinho et al., 2015). Only a small number of studies have examined their effects on the transcriptional response of plants. Two similarly related PGPBs with diverse phylogenetic and ecological histories produce different transcriptional controls (King et al., 2019) depending on the model of symbiosis made up of rice and *Burkholderia sensu lato* (s.l.) (Cottyn et al., 2001; Mannaa et al., 2019). The jasmonic acid signalling pathway was differentially expressed by each strain, and intriguingly, these variations have been linked to various colonisation methods (King et al., 2019). In plants exposed to PGPB, biochemical changes are frequently accompanied by anatomical modifications. According to research, *Gluconacetobacter diazotrophicus* can cause many structural alterations in the infected seedlings of *Arabidopsis thaliana* by depositing callose (Rodriguez et al., 2009). Studies revealed that sclerosis found in the root, stem as well as in leaf tissues strengthens the plant cell wall thereby helping to resist colonisation by the wilt disease-causing *Ralstonia solanacearum* (Morelli et al., 2020).

Tables 1: Metabolites produced by the endophytes in plant disease management

Host Plant	Endophyte	Response	Compounds	Reference
Tomato	<i>Bacillus sp.</i> 2P2	Activating plant resistance	No data	(Sahu et al., 2019)
Strawberry, Chilli, Persimmon, Tomato	<i>Bacillus cereus</i> BCM2, <i>B.cereus</i> SZ5, <i>B.altitudinis</i> CCM7	Niche exclusion of pathogen	No data	(Hu et al., 2017)
Tobacco	<i>Paecilomyces variotii</i> SJ1	Activating plant response	ZNC, ZhiNeng	(Peng et al., 2020)

Rice	<i>Streptomyces albidoflavus</i> OsiLf-2	Activating plant resistance, Lytic enzyme action, And anti-microbial action	Antimicrobial enzymes Cell wall degrading enzyme	(Gao et al., 2020)
<i>Vigna mungo</i> L.	<i>Klebsiella pneumoniae</i> HR1	Lytic enzyme action and plant growth promotion	Hydrolytic enzymes, siderophore, IAA, protease of plant growth	(Dey et al., 2019)
Sweet pea	<i>Streptomyces sp.</i> P4	Lytic enzyme action	Chitinase	(Tang-um and Niamsup, 2012)
Some poaceae plants	<i>Pseudomonas</i> , <i>Micrococcus</i> , <i>Paenibacillus</i> , <i>Streptococcus</i> , <i>Curtobacterium</i> , <i>Chryseobacterium</i> , <i>Bacillus</i>	Lytic enzyme action	Lipases, proteases, amylases, cellulases, pectinases, xylanases	(Dogan and Taskin, 2021)
<i>Cinnamomum loureiroi</i>	<i>Neopestalotiopsis sp.</i> , <i>Diaporthe sp.</i>	Anti-microbial action	Eugenol, myristaldehyde, lauric acid, caprylic acid	(Tanapichat sakul et al., 2019)
<i>Cassia spectabilis</i>	<i>Phomopsis cassia</i>	Antimicrobial action	Anti-fungal compounds	(Silva et al., 2006)
<i>P. sativum</i> , <i>B. oleracea</i> , <i>C. annuum</i>	<i>Pseudomonas aeruginosa</i> H40, <i>Stenotrophomonas altophila</i> H8, <i>Bacillus subtilis</i> H18	Activation of plant resistance Anti-microbial action	Anti-fungal compounds	(Selim et al., 2017)
<i>Moringa peregrina</i>	<i>Proteus mirabilis</i> , <i>Bacillus</i>	Anti-microbial action	Ethyl acetate, chloroform, methanol	(Aljuraifani et al., 2019)
Black pepper	<i>Pseudomonas putida</i> BP25	Anti-microbial action	Volatile substances	(Sheoran et al., 2015)

V. CONCLUSIONS

Research on plant-microbe interactions has greatly evolved. Endophytes are naturally occurring agents that decrease plant diseases by colonising plant tissues. Endophytes are successful since they are capable of producing a wide variety of metabolites. Such metabolites are prospective resources with a wide range of biological functions, and they are becoming more and more significant in several sectors. In this chapter, we covered the

various functions of endophytes and metabolites for the biocontrol of plant diseases. Endophytes have much significance as bioresources for future agricultural development since they are capable of reducing the number of plant diseases and improving host plant physiology. As we have mentioned, one of the strategies by which endophytes defend plant pathogens by inducing plant resistance. Additionally, a number of metabolites from endophytic bacteria can resist plant diseases. In comparison to chemical pesticides and traditional bioformulations, using endophytes and their metabolites for plant protection has many benefits. Instead of just having poisonous qualities, the metabolites of plant endophytes have a variety of bioactive components that improve the host's defence against infections. Even though endophytes sometimes fail to resist a high number of plant pathogens still they are promising tools to resist many plant diseases. Endophytes should be utilized in agricultural fields to boost the yield of various crops. Endophytes obligately colonize in species-specific plant sections. It is crucial to discover novel endophyte strains with as many beneficial characteristics as possible to boost agricultural output. Endophytes significantly contribute to the overall growth of plants. Endophytes promote plant growth by rejecting infections. They are beneficial organisms to improve the host plant's capacity to fight against numerous diseases. Endophytes can help to maintain the health of host plants by lowering the frequency of pathogenic attacks and diseases. These useful microbes use a variety of strategies to stop pathogens from infecting their host plants. Since they may produce a lot of secondary compounds, they can modify the plant's environment to prevent infections. A number of diseases and associated symptoms can be minimized when treated with endophytes and their metabolites, according to studies, since they operate as a powerful barrier against pathogens by using their resources within the host plant. Therefore, one of the most promising methods for developing green pesticides in the future is to use one or more naturally occurring active compounds from these endophytes.

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