REVIEW

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REVIEW

Exploration of endophytic fungi for applications in agriculture and medicine

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Endophytic fungi are microbes that colonize inner healthy plant tissues without causing any disease symptoms on its host. They have been isolated from every plant species investigated so far. The functional roles of endophytes are manifold. They are known to confer considerable benefits to the host by producing substances that stimulate plant growth, enhanced resistance to biotic and abiotic stresses. Besides they produce secondary metabolites that inhibit both phytopathogens and clinically significant human pathogens. Till recently, 5000+ bioactive metabolites have been isolated from endophytic microbes. Therefore, endophytes are recognized as repository of bioactive metabolites and have been commonly term as "chemical synthesizers" inside the host. Many scientists believe that plants growing in lush tropical rainforests, where competition for light and nutrients is severe, are most likely to host the greatest number of bioactive endophytes than temperate parts of the worlds. Thus, considering the myriad of medicinal plants particularly in biodiversity rich regions, study of endophytic microbes associated with these plant resources might lead to the discovery of new and effective molecules with wide therapeutic applications. In the recent years endophytic microbes have also been proved beneficial in agriculture. Many endophytic microbes have been reported to produce growth hormones, secondary metabolites that inhibit plant pathogens, mitigate biotic and abiotic stresses. Therefore they have been found suitable to apply as bio-inoculants to promote plant growth and health. This review will therefore focus on importance of endophytic microbes and their applications in the field of agriculture and medicine.

Key words: Endophytes, diversity, antimicrobial metabolites,plant growth promotion

INTRODUCTION

As the global population continues to grow the demand for food and other agricultural products will be on an increasing trend. This is more challenging considering the drastic climate change which has led to the compounds issues like loss of soil fertility, pest and pathogens damage, abiotic stress and others.

Further, the emergence of new diseases, multi-drug resistance pathogenic microbes, needs new and therapeutic agents. Thus, research is necessary to solve these ever growing human problems in an innovative and comprehensive manner. Endophytes are microorganisms that colonize inner healthy tissues and establish for all or part of their life cycle without causing any disease symptoms. Endophytes are quite common and found almost in every vascular plant (Rodriguez *et al*. 2009).Although various microbes exist as endophytes but the most commonly studied are the fungi. The frequency and diversity of fungal endophytes present in the host plant might vary based on the location and climatic condition of the area where the host is growing. Study of endophytic microflora had gained tremendous attention because they are the sources of many industrially, agriculturally and medicinally important compounds. Many endophytic microorganisms can produce the secondary metabolites which are similar to the one produced by the plant and can be used as alternate source of novel plant biomolecules which might help in the sustainable utilization and conservation of some of the

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*22nd S.N.Banerjee Memorial Award Lecture of Indian Mycological Society, Department of Botany, University of Calcutta delivered on 24th December 2021 economically important rare and endangered plants. For example Taxol, an anticancer agent obtained from leaves and bark of *Taxus brevifolia*, is a commercially important plant. The fungus *Taxomyces andreanae*, an endophyte isolated from *T. brevifolia*, have been found to produce taxol. Such findings attracted the scientific community of the world towards exploration of endophytes for various bioactive secondary metabolites.

The functional roles of endophytes are manifold. They are known to confer considerable benefits to the host by producing substances that stimulate plant growth, enhanced resistance to biotic and abiotic stress. Besides they produce secondary metabolites that inhibit both phytopathogens and clinically significant human pathogens. Till recently, 5000+ bioactive metabolites have been isolated from endophytic microbes. Therefore, endophytes are recognized as repository of bioactive metabolites and have been commonly term as "chemical synthesizers" inside the host. Many scientists believe that plants growing in lush tropical rainforests, where competition for light and nutrients is severe, are most likely to host the greatest number of bioactive endophytes than temperate parts of the worlds. Thus, considering the myriad of plants species particularly in biodiversity rich regions, study of endophytic microbes associated with these plant resources might lead to the discovery of new and effective molecules with wide therapeutic applications. In the recent years endophytic microbes have also been proved beneficial in agriculture. Many endophytic microbes have been reported to produce growth hormones, secondary metabolites that inhibit plant pathogens, mitigate biotic and abiotic stresses. Therefore they have been found application as bio-inoculants to promote plant growth and health. Further, different enzymes produced by endophytic fungi residing in different plant hosts plays many useful roles like enhanced resistance to different biotic and abiotic stresses by producing various bioactive compounds such as alkaloids, terpens, flavonoids etc. (Firakova *et al*. 2007). Lignocellulolytic enzymes are one of the most important enzymes produced by various groups of fungi, which can degrade lignocellulose compounds. Recently, some endophytic fungi have also been reported to exhibit lignocelluloytic enzymes (Toghueo *et al*. 2017;Kaul *et al*. 2014). Lignocellulose is a collective name of three polymers, cellulose (35-50%), hemicellulose (20-35%) and lignin (10-25%) (Isikgor *et al*. 2015). Cellulase is an industrially important enzyme which can degrade cellulose by hydrolysing â-1,4-glycosidic bonds. Degradation of lignocellulose compounds is very significant because they can be converted to agriculturally important compost.Therefore ,this review will focus on diversity of endophytic fungi in various plant species and their applications in the field of agriculture and medicine. A brief highlight on research outcome of endophytic fungi has been projected and discussed.

Diversity of endophytic fungi across plant species

Endophytic fungi are known to be ubiquitous and found to be associated with almost all the plant species of the planet. They have been isolated from all vascular plant investigated so far (Sturzand Nowak, 2000; Arnold *et al*. 2000). However, tropical and subtropical plants have been reported to have higher endophytic fungal assemblages (Suryanarayanan and Rajagopal, 2000). This might be due to favorable climatic conditions such as increased rate of precipitation, humidity and nutrient availability in tropics. Tropical rainforest are one of the most biologically diverse terrestrial ecosystems on the planet. This region harbors the maximum plant species in the world. However, very few of them have been studied for endophytic fungi. Thus, there exist great opportunity to explore those cryptic fungi which might contribute substantially to global fungal diversity. Endophytic fungal diversity has been studied from various healthy tissues of the host such as leaves, petioles, barks, stems, roots and seeds. Some common plant species investigated for endophytic fungi are *Azadirachta indica, Aegle marmelos, Holarrhena antidysenterica, Teminalia arjuna, Ocimum sanctum, Vitex negundo, Emblica officinalis, Coffea robusta* etc. Several fungal species have been reported as endophytes. Many of them closely resemble plant pathogenic fungi. Some of the common fungi isolated as endophytes are *Acremonium* sp., *Alternaria alternata, Arthrinum* sp., *Aspergillus niger, Aspergillus fumigatus, Chaetomium globosum, Cladosporium* sp., *Colletotrichum* sp., *Curvularia* sp., *Diaporthe* sp., *Fusarium* spp., *Muscodor albus, Nigospora* sp., *Penicillium* sp., *Pestalotiopsis* sp., *Phomopsis* sp., *Phyllosticta, Rhizoctonia* sp., *Trichoderma* sp., *Xylaria* sp., and many more. Some plant species along with their associated endophytic fungi is presented in Table 1.

We also studied diversity of endophytic fungi from various plant species. *Taxus baccata* a well known anticancer plant was investigated for endophytic fungi. Bark of *T. baccata* collected from Arunachal Pradesh, India revealed rich diversity of endophytic fungi. The dominant endophytic fungi isolated from the collected samples were *Alternaria alternata,Chaetomium globosum, Fusarium moniliforme, Gliocladium* sp. *Nigrospora oryzae, Penicillium* sp., *Trichoderma viridae* and sterile mycelia (Tayung and Jha, 2010). Endophytic fungi were also studied from three ethno-medicinal plants namely *Andrographis paniculata, Acorus calamus*, and *Drynaria quercifolia* collected from Similipal Biosphere Reserve, India. The isolated endophytic fungal genera were *Alternaria, Aspergillus, Curvularia, Fusarium* and *Penicillium* (Mohanta *et al*. 2008). Endophytic fungi were studies from an invasive plant, *Ipomea carnea*. A total of 69 isolates belonging to ten taxa comprising 1.45% Zygomycetes, 10.14%Coelomycetes, 62.32% Hypomycetes, 18.84% sterile mycelia and 7.25% unidentified species were obtained from leaves, stems and seeds. Speciesof *Curvularia, Aspergillus, Fusarium, Colletotrichum* and sterile fungus were isolated as dominant endo-phytes. Colonization frequency of *Curvularia* (7.25%) was highest which was isolated from all the tissues. Furthermore, endophytic fungi were also studied from two ethnomedicinal plants namely *Solanum rubrum* and *Morinda pubescence*.A total of 458 endophytic isolates were obtained from leaves, stems and fruit tissues. The dominant endophytic fungi belong to genera *Aspergillus, Colletotrichum*, *Curvulari a*nd Mycelia sterilia (Jena and Tayung, 2013). Recently endophytic fungi from three medicinal plants of NE India were investigated. Altogether, 56 endophytic fungal isolates were obtained from surface-sterilized leaf fragments of *Houttuynia cordata*. The endophytes consisted of fungi belonging to genera *Colletotrichum*, *Curvularia*, *Bipolaris*, *Corynespora*, and *Pseudozyma* and non-sporulating fungi categorized as mycelia sterilia. (Talukdar *et al*., 2020). In another study, a total of 84 endophytic fungal isolates were isolated from 150 segments of leaf tissues of *Eyngium foetidum* (Fig.1). Dominant endophytes were found to be fungi belonging to the genus *Colletotrichum*, followed by non-sporulating members grouped under mycelia sterilia. Other fungal genera that were isolated as endophytes were *Scopulariopsis*, *Cladosporium*, *Stemphylium*, *Penicilllium* and *Alternaria*. Again from healthy leaves tissue of *Zanthoxylum oxyphyllum* a medicinal plant widely been used by the local tribal communities of Assam, *Colletotrichum* species was isolated as dominant endophytes along with other fungal genera like *Fusarium*, *Curvularia*, *Aspergillus*, *Corynespora* and isolatesbelonging non-sporulating fungi categorised as Mycelia Sterilia (Talukdar and Tayung, 2021). Besides, endophytic fungi were also isolated from orchid tissues, seeds of *Cassia alata, Oryza sativa* seeds and lichen thalli (Padhi and Tayung, 2015; Roy *et al*., 2021).The list of plant species investigated for endophytic fungi along with its associated endophytes is presented in Table 2. Tropical and sub-tropical rainforest harbor rich diversity of plant species. Owing to its favorable climatic conditions these plants serves as the reservoir for obtaining novel endophytic microbes. Diminishing of these plant resources will also eliminate the associate endophytes. Hence research priority should be directed to study them before they are exploited or get extinct.

Antimicrobial metabolites from endophytic fungi

The developed world has seen an explosion in the incidence and reporting of multi-resistant drug infections by pathogenic microorganisms and emerging of new diseases. This has necessitated the needs for new and effective antimicrobial agents to control human health problems. Without new antibiotics, medicine will change beyond recognition as most of the currently used antibiotics are getting resistant. The failure to bring new antimicrobial agents to the market partly reflects a failure of discovery. This is because many of the reputed pharma companies have stop finding for antibiotics research and have diverted their attention to invest medicines for diseases like diabetes, anti-aging and heart. As a result, the search for new antibiotics is almost shrinking gradually. Microorganisms have been good sources of antibiotics since decades. Among microbes, endophytic fungi are known for their production of diverse biologically active metabolites. Many endophytic fungi produce antimicrobial metabolites in culture that are active againsthuman and plant pathogens.

In recent years, endophytic fungi colonizing medicinal plants are of special interest because of the fact that such microbes have produced similar metabolites as their respective host, sometime displaying more biological activity. There is a need to investigate fungal endophytes from medicinal plants because it has been hypothesized that these plants harbor some distinct and rare microbes that mimic the chemistry of their respective hosts and synthesize identical bioactive natural products or derivatives that are more bioactive than the one produced by the host. Strobel and Daisy (2003) have necessitated the need to study plants growing in unique environmental settings having ethno medicinal uses, extreme age or interesting endemic locations because they are expected to harbor novel endophytes that may produce unique metabolites having diversified applications. Wang *et al.* (2007) have demonstrated that the endophytes isolated from these plants are excellent producer of strong fungicidal and bactericidal metabolites. The production of antimicrobial metabolites from endophytic fungi around the world has been well document by Strobel and Daisy (2003). Endophytic *Phoma* sp., isolated from different medicinal plants has beenreported to be a promising source of antimicrobial compounds. A new alpha-tetralone derivative -3,6,7-trihydroxy-alpha-tetralone together with cercosporamide,beta-sitosterol and trichodermin was reported to beproduced by Phoma sp. endophytic in *Arisaema erubescens*. These isolated compounds exhibited antifungal and antibacterial activity against pathogenic fungi *Fusarium oxysporum, Rhizoctonia solani, Colletotrichum gloeosporioides* and *Magnaporthe oryzae* as well as against two plant pathogenic bacteria *Xanthomonas campestris* and *Xanthomonas oryzae* (Wang *et al*. 2012). Similarly, *Phoma* sp., endophyticin *Saurauia scaberrinae* is known to produce Phomodione, an usnicacid derivative. Phomodione was found to be effective at a minimum inhibitory concentration of 1.6 mg/mlagainst *Staphylococcus aureus* (Hoffman and Arnold, 2008).A terpenoid compound with known antibacterial activity was obtained from the ethyl acetate fraction of *Phomopsis* sp. an endophyte of *Plumeria acutifolia* Poiret plant (Nithya and Muthumary, 2011). Ethyl acetate extract of *Xylaria* sp. isolated from *Piper aduncum* also produced two new presilphiperfolane sesquiterpenes with antifungal activity (Silva *et al*. 2010). Liu *et al*. (2008) reported *Xylaria* sp.YX-28 from *Ginkgo biloba* producing 7-amino-4-methylcoumarin which showed antibacterial and antifungal activity against many pathogenic organisms.Another endophytic *Fusarium* sp. produced novel antifungal antibiotic Fusarielin A and three related compounds. The mangrove endophytic fungus, *Phomopsis* sp. ZSUH76 produced three new metabolites *Phomopsin* A, B, C and known cytosporone B and cytosporone C. The latter possessed antifungal activity against *Candida albicans* and *F. oxysporum*. A few works on antimicrobial metabolites have been undertaken from India. Raviraja *et al*. (2006) have evaluated antimicrobial activity of some endophytic fungi isolated from medicinal plants of the Western Ghats of India. Elavarasi *et al*. (2012) have reported endophytic fungus, *Fusarium* sp. from mangrove producing volatile antimicrobial metabolites1-Dodecanol, 2-methyl. Similar work on antimicrobial metabolites from endophytic fungi isolated from various plant species were also reported by us (Mohanta *et al*. 2008; Tayung and Jha, 2010; Tayung*et al*. 2012, Padhiand Tayong, 2013). Ethyl acetate extract obtained from an endophytic fungus, *Fusarium solani* isolated from bark of *Taxus baccata* showed both antibacterial and antifungal activity. The metabolites were identified as 1-tetradecene, 8-octadecanone,8-pentadecanone, octylcyclo-hexane and10-nonadecanone (Tayung *et al*. 2011). Recently, antimicrobial and antiquorum sensing metabolites identified as tyrosol was isolated from an endophytic fungus, *Colletotrichum coccodes* obtained from healthy leaf tissues of *Houttuynia cordata* (Talukdar *et al*. 2021). Similarly, endophytic fungi isolated from *Zanthoxy-lumoxyphyllum* a medicinal plant showed promising antimicrobial activity against selected clinically significant human pathogenic test organisms.(Fig.2) (Talukdar and Tayung, 2021). Such finding suggested that extensive and scientific investigation of medicinal plants for endophytic microbes might leads to the discovery of potent endophytic strains with antimicrobial activity that could be developed into new and effective antimicrobial agents.

Antimicrobial metabolites from endolichenic fungi

Endolichenic fungi are organisms that live in close association with the alga in the thalli of lichen areanalogous to that of plant endophytes inhabiting the intercellularspaces of the hosts. Similar to fungal endophytes, all lichen species studied so far have been found to be colonized by endolichenic fungi (Arnold *et al.* 2009; Tripathi and

Joshi 2015; Suryanarayanan and Thirunavukkarasu, 2017). However, considering the myriad of lichen species in the planet, only a tiny fraction of them have been studied for endolichenic fungi. Studies carried out by Bates *et al.* (2012) showed that numerous fungi are present in lichen thalli. Additionally, like the endophytic fungi,they are reported to produce an array of secondary metabolites suchas alkaloids, quinones, furanones, pyrones, benzopyranoids,xanthones, terpenes, steroids, peptides andallycylic compounds (Paranagama *et al.* 2007; Yang *et al*. 2012; Li *et al.* 2015; Kellogg and Raja 2017). The metabolites obtained from endolichenic fungi have been demonstrated to produce various antibiotics and natural bioactive compounds with multiple applications (Wu *et al.,* 2011). However, relatively very few studies have been undertaken on endolichenic fungi, and the substances they produced have not been investigatedin detail for their bioactivity and therapeutic potentials.

In recent years several bioactive metabolites have been reported from endolichenic fungi. Some of these metabolites showed promising antibacterial, antifungal, cytotoxic and antioxidant activities (Kellogg and Raja, 2017; Suryanarayanan and Thirunavukkarasu, 2017).Endolichenic fungus identified as *Aspergillus niger* isolated from lichen thallus of *Rocella montagnei* showed antibacterial activity against wide range of bacterial pathogens (Logesh *et al*. 2012). Amburic acid obtained from an endolichenic fungus, *Pestalotiopsis* sp. isolated from lichen thalli of *Clavaroides* sp., has shown antibacterial activity (Deng *et al*. 2009). Similarly, metabolites isolated lichen thalli of *Usnea cavernosa* have showed antifungal activity against some clinically significant human pathogenic fungi (Paranagama *et al.* 2007). We also investigated several lichen species for endolichenic fungi and reported some promising metabolites with antimicrobial activity. Endolichenic fungi were studied from lichen thalli of *Parmelia* sp. A total of 19 distinct endolichenic fungi were obtained from surface sterilized fragments of *Parmelia* thalli. The dominant fungi belonged to genera *Phomopsis*, *Aspergillus, Penicillium* and mycelia sterilia. Some of the isolates showed significant antimicrobial activity against wide range of pathogenic microbes. We reported an undescribed substituted dihydroxanthene-1,9-dione, named funiculosone,obtained from the culture filtrates of *Talaromycesfuniculosus*. The fungus was isolated as endolichenic fungus from surface sterilized lichen fragments of *Diorygmahiero glyphicum*. The metabolites showed promising antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*. Funiculosone also showed anticandidal activity against *Candida albicans* with an IC50 35 ìg/mL (Padhi *et al*. 2019). Furthermore, metabolites aspergyllone isolated from culture filtrates of an endolichenic fungus *Aspergillus niger* obtained from lichen thallus *Parmotrem aravum* showed promising against a panel of human, plant, food borne and fish pathogens (Padhi *et al.*2020).Such finding indicated that endolichenic fungi harboring lichen thalli may be a good source of new and effective antimicrobial metabolites.

Plant growth promotion by endophytic fungi

Endophytic fungi may directly or indirectly contribute plant growth and health. They have been known to increase the seed germination rate, seed elongation, and solubilize nutrients for uptake. Fungal endophytes also contribute significantly to plant growth by producing phyto-hormones, such as auxin and cytokinin, as well as in other products such as phosphatases that solublized insoluble phosphorus and make it available to the plants (Tsavkelova *et al.* 2007). Many endophytic fungi have been reported to produce growth hormones like IAA and Gibberellin (Ismail *et al*. 2016) and also fix atmospheric nitrogen (Yang *et al*. 2015). Some endophytes have also been reported to solubilized phosphate and produce iron chelating metabolites called siderophroes (Potshangbam *et al*. 2017). Soil-borne plant pathogens continue to be a major threat to agricultural development and productivity worldwide. Several plant disease control methods have been implemented to protect crops against a wide range of phyto-pathogens but most of the approaches tend to have one or the other side effect associated with them. Many endophytic fungi have been reported to produce secondary metabolites which are inhibitory to phyto-pathogenic microbes. Therefore the recent development of screening technologies has revealed the great potential of fungal endophytes for producing novel biologically active compounds with promising medicinal or agricultural applications (Zhang *et al*. 2006; Aly *et al*. 2011; Wu *et al.* 2015).

There are many examples of secondary metabolites from endophytic fungi which are being used, or have promise to be used, against

Table 1: Endophytic fungi isolated from some selected plants species

Host plant	Isolated endophytic fungi	Reference
Azadirachta indica	*Acremonium* sp.	Tejesvi *et al*., 2006
Aegle marmelos	*Alternaria alternate* *Aspergillus niger*	Gond *et al.*, 2007
Butea monosperma	*Acremonium strictum* *Asteromella andrewsii*	Tejesvi *et al*., 2006
Cajanus cajan	*Fusarium solani, Fusarium oxysporum,* and *Fusarium proliferatum*	Zhao *et al*. 2012
Capsicum annuum	*Alternaria alternata*	Devari *et al.* 2014
Coffea arabica	*Aspergillus versicolor*	Sette *et al.*, 2006
Clerodendrum serratum	*Aspergillus* sp.	Banerjee *et al.*, 2009
Cinchona ledgeriana	*Penicillium, Fomitopsis* and *Arthrinium*	Maehara *et al*. 2013 and Maehara *et al.* 2011
Catharantus roseus	*Fusarium oxysporum, Talaromyces radicus,* and *Eutypella* spp	Palem *et al*., 2016
Centella asiatica	*Colletrotichum* sp. *Glomerella* sp.	Rakotoniriana *et al.,* 2008
Embelia ribes	*Aspergillus* sp. *Bipolaris spicifera* *Fusarium* sp. *Pestalotia* sp	Mokaya and Peter., 2016
Fritillaria cirrhosa	*Fusarium redolens*	Pan *et al*. 2015
Gerbera piloselloides	*Colletotrichum* sp. *Alternaria* sp. *Penicillium* sp. *Fusarium* sp.	Caruso *et al.*, 2020
Ginkgo biloba	*Fusarium oxysporum*	Cui *et al.* 2012
Houttuynia cordata	*Colletotrichum* sp., *Fusarium* sp. *Lasiodiplodia pseudotheo-bromae* *Xylariales* sp.	Aramsirirujiwet & Kitpreechavanich, 2016
Musa acuminate	*Colletotrichum gloeosporioidies C. Muase, Guignardia cocoicola*	Wipornpan*et al*., 2001
Leucas aspera	*Colletrotrichum* sp.	Banerjee *et al.*, 2009
Macleaya cordata	*Fusarium proliferatum*	Wang *et al.* 2014
Passiflora incarnata	*Altenaria alternata, Colletotrichum capsici, and Chryseobacterium taiwanense*	Seetharaman *et al.,* 2017
Solanum nigrum	*Fusarium* sp. *Alternaria* sp.	Khan *et al*., 2015
Terminalia arjuna	*Cladosporium sp.* *Chloridium sp.*	Tejesvi *et* al., 2006

(*contd. part table* 1)

	Gliocladiumdelequescens	
Ocimum sanctum	*Bacillus subtilis*	Chowdhary and Nutan, 2015
	Aspergillus niger	
	Alternaria alternata	
	Bipolaris maydis	
	Fusarium verticillioides	
Rauvolfia serpentine	*Colletotricumgloeosporioides, Penicillium sp.,*	Nath *et al*., 2015
	Aspergillus awamori	
Vitex negundo	*Fusarium* sp.	Banerjee *et al*., 2009
	Papulaspora sp.	Raviraja *et al*., 2006

Table 2: List of some selected plant species studied for endophytic fungi

Plant name	Family	Habit	Economic importance
Houttuynia cordata	Saururaceae	herb	Medicinal
Eryngium foetidum	Apiaceae	herb	Medicinal
Zanthoxylum oxyphyllum	*Rutaceae*	shrub	Essential oil, medicinal
Solanum rubrum	Solanaceae	shrub	Medicinal
Morinda pubescens	Rubiaceae	herb	Medicinal
Taxus baccata	Taxaceae	tree	Anticancer
Ipomoea carnea	Convolvulaceae	shrub	Medicinal/invasive
Rhynchostylis retusa	Orchidaceae	epiphytic	Medicinal
Shorea robusta	Dipterocarpaceae	tree	Timber/medicinal
Cassia alata	Fabaceae	shrub	Medicinal/invasive
Oryza sativa	Poaceae	herb	Food
Parmelia sp. (Lichen)	Parmeliaceae	epiphytic	Medicinal
Parmotrema ravum (Lichen)	Parmeliaceae	epiphytic	Medicinal

pathogens and pests of horticultural and agricultural plants. Endophytic fungi have also been reported to improve the uptake of macronutrients, such as phosphorus, nitrogen, potassium and magnesium, or micronutrients, such as zinc, iron, and copper, from the soil and organic matter and increase the supply of these nutrients to the plant host (Rana *et al*. 2020).Garcia *et al*. (2015) reported that inoculation of endophytic fungal isolate, *Trichoderma asperellum* significantly reduced the use of phosphorus fertilisation in onion (*Allium cepa*). Similar results were obtained by Baron *et al*. (2018) where inoculated maize (*Zea mays*) with *Aspergillus sydowii*, and the plants that interacted with the fungus accumulated significantly higher amounts of P in their tissues even when receiving lower fertilisation doses. Production of IAA and GA by endophytic fungi *Phoma glomerata* and *Penicillium* sp. isolated from cucumber plant (Waqau *et al*. 2012). Khan *et al*. (2008) reported gibberellin production by *Penicillium citrinum* IR-3-3, a fungus isolated as endophyte from dune plants. In our study also we have isolated many endophytic fungi from various plant species that showed plant growth promoting activities. In one the study endophytic fungi

Fig. 1 : Endophytic fungi growing out from the surface sterilized fragments in PDA medium(Source: Talukdar and Tayung, 2021)

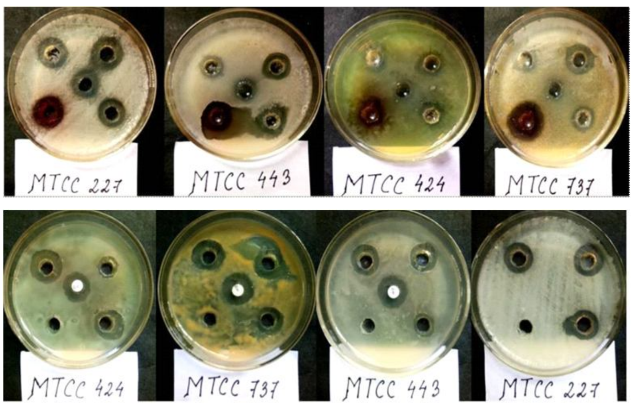

Fig. 2 : Antimicrobial activities of some endophytic fungi against some test pathogens (source: Talukdar and Tayung, 2021)

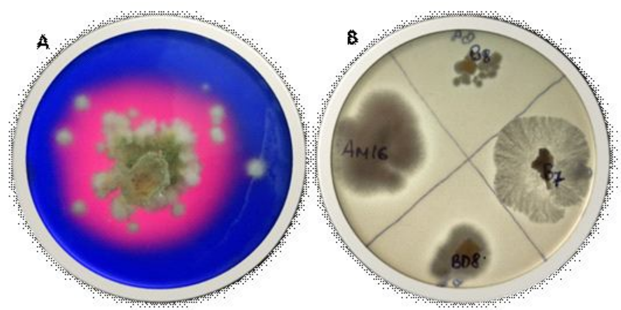

Fig. 3 : Siderophore (A) and phosphate solubilizing (B) activity of endophytic fungi isolated from seeds of indigenous rice cultivars (Source: Roy et al., 2021)

associated with seeds of some indigenous rice varieties of North East, India were determined for IAA activity *in-vitro* and antifungal activity against rice pathogen, *Magnaporthe grisea*. Among

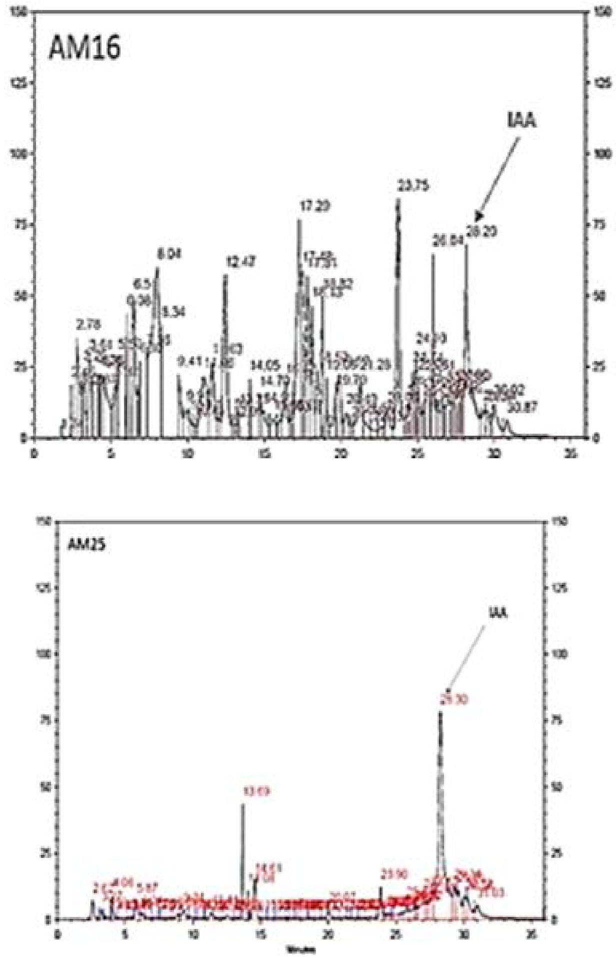

Fig. 4 : HPLC chromatogram showing presence of IAA in the crude metabolites obtained from endophytic fungi (Source: Roy et al., 2021)

several isolates, colonization frequency of *Fusarium* was found to behighest and was isolated from seeds of almost all the varieties.The isolates ofshowed good IAA production in the medium amended with tryptophan and displayed antifungal activity against *Magnaporthe grisea* (Roy *et al*. 2021). Some of the fungal isolates also showed siderophore and phosphate solubilizing activity in-vitro (Figs. 3 & 4). Endophytic fungi isolated from seeds of *Cassia alata* were also investigated from plant growth promotion traits. High colonization of *Fusarium* species were observed in the seeds collected from different sampling sites. All of the isolates good showed IAA activity *in-vitro* (Data unpublished). Such results exemplify that endophytic fungi inhabiting plant species may be exploited for sustainable agriculture to improve plant growth and health and increase productivity.

Conclusions and future perspectives

At present the world is facing many problems and among them global food crisis, emerging of new diseases and antibiotic resistance pathogenic microbes are major concern. To solve these growing human problems in sustainable method, there is need to discover new therapeutic agents to combat drug resistant microbes and explore bioinoculants to be used in agriculture so as to improve plant growth and health. Endophytic fungi have been reported to produce numerous secondary metabolites with biological activities. The ability of endophytic fungi to produce metabolites with promising antimicrobial activity and plant growth promotion traits has proven to be boon for the present scientific community to solve the ever growing human problems. As stated in the review endophytic fungi are beneficial because they provide new and effective bioactive metabolites for applications in agriculture and medicines. Considering the myriads plant species on the planet, exploration of endophytic fungi from different ecological niches may lead to the discovery of potent endophytes with multiple applications.

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