ISSN:0971-1260
Vol-22-Issue-34-December -2019

Applications of Fungal Endophytes in agriculture and medicine field

Poorva Sharma*, Chetan Bhattarai

Lovely faculty of Technology and Sciences, School of Agriculture, Lovely Professional University, Jalandhar-Delhi GT Road, Phagwara-144411, Punjab, India

Submit correspondence to: Poorva Sharma at the address provided. E-mail: Sharma.poorva78@gmail.com, poorva.19600@lpu.co.in

Abstract

Usage of beneficial microorganisms, commonly named as endophytes, is a novel approach to control the antibiotic resistance of pathogenic microorganisms both in agriculture and medicine. In addition, rising cost of production of chemical based drugs and environmental pollution caused by chemical fertilizers and pesticides is another fact to incline towards natural alternatives. Endophytic fungi are important source of novel compounds to be exploited in the sector of agriculture and medicine. The current paper explains the applications of endophytic fungi and the activity of various compounds produced by these microorganisms in the sectors of agriculture and medicine.

Keywords: *Endophytes, Biological control, Sustainable agriculture, Biodegradation*

Introduction

Endophytes can be defined as those organisms that colonize the internal tissues of the plant reside during certain time of their life span without harming it. They can be isolated from woody tree to herbaceous plant, monocotyledonous to dicotyledonous plant.(Miche and Balandreau 2001). Fungal endophytes are found to inhabit almost all of the tissues of the plant like root, stems, branches, leaves, flowers, fruit, seed and bark (Crozier et al. 2006). The endophytic microorganism is in mutualistic association with the host plant where endophytes obtain nutrients and minerals sufficient enough form host plant for their survival. On the

 Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

other hand, the endophytic microorganisms produce various bioactive chemicals in order to help host plant to defend the abiotic and biotic stress while benefiting the host for their growth.Among thousand different plant species, each of them is host to at least one endophytic microbial population. Even several thousand microbial strains are possible for a given endophytic species (Strobel *et al*. 2003). The endophytic growth depends upon manifold components such as: host species, host development, environmental factors and density of inoculum (Dudeja *et al*. 2014).

Endophytic fungi are widely exploited in the medicinal and agricultural field (Figure 1) to obtain the bioactive compounds present within them (Zhao *et al*., 2011). The ability of bioactive compound to be used in wide range of fields has grabbed the attention for several years. Endophytic fungi are well known for their ability to produce various bioactive compounds possess multifarious bioactivities such as antimicrobial, insecticidal, cytotoxic, and anticancer activities. In some cases, the bioactive compounds produced by the fungi are also seen to be similar with those originated from their host plant. Because of the capability of these fungi to produce large number of plant growth-promoting chemicals, they are also recognized to ameliorate host plant growth and fertility of soil. Endophytic fungi could also be useful to the pharmaceutical industries by exploiting the active compound released by these microbes.

With rise of antibiotic resistance by pathogens, the necessity to search for new agents to antagonize the pathogenic microorganism by natural methods increased. The number of bioactive metabolites produced by endophytic fungi is found to be in greater number than other endophytic microorganisms. Moreover, about half of the of bioactive substances produced by the fungal endophytes were unknown earlier.. They are known to produce bioactive metabolites including steroids, terpenoids, diterpenes, isocumarins, quinones, lactones phenyl propanoids, lignans and aliphatic metabolites; extracellular enzymes

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

including cellulases, proteinase, esterases and lipases. Amines and amides, common endophytic metabolite, are seen to be toxic to insects without harming the mammals. A large number of plant are also reported to produce amines and amides which have the ability to solubilize phosphates present in insoluble form. They are also responsible for production of auxins, gibberellins, 1-aminocyclopropane-1- carboxylate (ACC) deaminase and cytokinins. Moreover, endophytic fungi have significant role to protect he host plant against the pathogens by promoting the host defense mechanism.

Role and Application of Fungal Endophytes

To escalate the plant production, 100 millions of tons of chemical fertilizer have been used annually. Most commonly used are potash, nitrogen and phosphate (Glick *et al.* 1999). The chemical fertilizers are associated with negative effects on the environment globally along with increasing the production cost of the food products. In order to enhance the growth and yield of plant, fungal endophytes can be used in sustainable agricultural practice; endophytes plays a role by consuming nutrients, consequently, conquering pathogens, and increase fitness of plant by conferring tolerance against stress (Vega *et al*. 2008). Secondary metabolites produced by endophytes help to minimize the damage by pathogen and promotes the defense of host against the pathogenic organisms by regulating the physiological response of plant (Gao *et al*. 2010).

Phytohormone production

Phytohormones are the chemicals that regulate the growth of plant. They are also having major roles in while plant faces biotic stress. Endophytes on other hand are also found to produce plant growth promoting hormones. There are various classes of phytohormones produced by the endophytes including Auxins, Gibberellins (GA), Indole Acetic Acid (IAA),

 Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Abscisic acid (ABA), salicylic acid (SA), jasmonic acid (JA) and so on (Table 1) (Waqas *et al*. 2014).

Auxins, an important class of phytohormones, have a significant role in development and growth of the plant. Auxins is also found to play major roles in vascular differentiation, root and shoot orientation in response to gravity and light, division of cells, stem and root elongation, apical dominance and so on (Frankenberger *et al.* 1995; Patten *et al.* 1996; Aloni *et al*. 2006; Cecchetti *et al*. 2008). Auxins are also found to be involved onteraction between host and parasite(Hamill 1993; Gutierrez *et al*. 2009). Khan et al., 2015b isolated the two fungal strains, *Fusarium tricinctum* and *Alternaria alternate* from the leaves of *Solanumnigrum* and these strains were found to produce IAA and also promote the growth of Dongjin rice plants.

Endophytic fungi producing gibberellins increases growth of plants plant and promotes biomass under stressed conditions, and could be exploited to reduce the harmful effects of abiotic stresse (Khan *et al*. 2015). The aquatic plant *Trapa japonica*, containing endophytic fungi*Galactomyces geotrichum* produced biologically active GAs (GA1, GA4, and GA7) and IAA (Waqas *et al*. 2014). Moreover, two different fungi *Phoma glomerata* and *Penicillium* sp., isolated from the roots of cucumber, are studied to secrete IAA and gibberellic acid (GA3) as well as GA1, GA4 and GA7. The growth parameters, plant biomass and absorption of minerals (K, Ca and Mg) increased significantly while toxicity caused by sodium was alleviated, on inoculating the microorganisms in cucumber plants during stress conditions (Waqas *et al*. 2012). Khan et al., 2012 observed the similar effects with *Paecilomyces formosus* an another endophytic strain isolated from cucumber. Rim et al., 2005 studied the effect of *Fusarium proliferatum, a* fungal strainisolated from roots of *Physalis alkekengi* var. *francheti*, and reported apromotion in growth of plant even double than *F. fujikuroi*, a wild strain. This growth promotion was a result of production of the

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

physiologically active Gibberellic acid (GA1, GA3, GA4, and GA7, as well as GA9, GA20 and GA24) (Rim *et al*. 2005).

Moreover, endophytic fungus *Asprgillus fumigatus* TS1 and *Fusarium proliferatum* BRL1, isolated form roots of *Oxalis corniculata, was found to increase the growth of Waito-C, a mutant rice. Promotion of growth was associated with the production of various types of GAs and IAA (Bilal et al. 2018). Similarly, endophytic basidiomycetous Porostereum spadiceum* AGH786, capable of producing six different GAs, was found to promote the growth of soyabean and also was found decrease the of effect of NaCl stress (Hamayun *et al.* 2017). Furthermore, the fungal endophytes *Penicillium citrinum* LWL4 and *Aspergillus terreus* LWL5, enhanced the growth of sunflower (*Helianthus annuus* L). These fungi were also found to reduce the stem rot caused by *Sclerotium rolfsii* in great extent; the content of salicylic acid and jasmonic acid was seen to increase in presence of disease (Waqas *et al*. 2015).

Similarly, other phytohormones produced by endophytic fungi play major on plant defense against stress stimuli. Salicylic acid (SA) jasmonic acid abscisic acid (ABA), are seen to respond against abiotic and biotic stress, and were found to play a role as defense signaling agent. Jasmonic acid stimulates the production of defensive proteins and secondary bioactive metabolites (Brodersen *et al*., 2006; Balbi *et al*., 2008). Salicylic Acid induces the systemic resistance against fungi promoting plant growth and thus playing a role in biotic and abiotic stress. Endophytic fungi producing GA and IAA, *Phoma glomerata* LWL2 and *Penicillium* sp. LWL3, are seen to promote the shoot length of rice significantly during drought and salinity. (Waqas *et al*., 2012). An endophyte fungal strain *Galactomyces geotrichum*, isolated from *Trapa japonica*, inhabiting a Korean river is responsible for Induced Systemic Resistance (ISR) in soybeans and had a priming effect as indicated by production of significantly greater amounts of JA (Waqas *et al*., 2014).

 Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Similarly, endophytic fungus *Paecilomyces formosus* LWL was found to produce abscisic acid (ABA) and jasmonic acd (JA) in japonica rice under prolonged heat stress condition to protect the rice from heat (Waqas *et al.* 2015). The sunflower plants when inoculated with *Penicillium citrinum* and *Aspergillus terreus* was seen to alter SA and JA level of the plants, as compared to control plants which were infected or non-infected by pathogen *Sclerotiumrolfsii* (Waqas *et al*. 2017). Moreover, extracellular enzymes like cellulose, pectinase, xylanase, amylase and gelatinase were produced by three different endophytic fungus; *Alternaria alternate, Penicillum chrysogenum* and sterile hyphae, isolated form medicinal plant *Asclepias sinaica*. These endophytic fungal strain produced Indole Acetic Acid (IAA) and ammonia resulting in growth of root (Fouda *et al*. 2015). Endophytic fungi *Penicillium sp., Chrysosporium pseudomerdarium*, *Paecilomyces* sp., *Phoma glomerata*, *Aspergillus fumigates* and *Paecilomyces formosus* produced gibberallic acid and indole-3-acetic acid and also promoted chlorophyll contents, shoot length, and biomass of both wild and mutant- type rice (Waqas *et al*., 2014).

Biocontrol Agents

Farmers are using various measures to controlling pest, disease causing pathogen or any other invasive species in plants. One way to control those foreign agents is by the use of living organism or its metabolites. This is known as biological control or biocontrol. It is the natural method of controlling foreign bodies on the host plant by reducing the dependency of chemical pesticides as synthetic chemical pesticide and herbicide uses have shown to impart negative health consequences on the public health (USNRC 1993). The role of endophytic fungi in agricultural sector as biocontrol agent is one of the most studied fields of endophytes (Table 2). Endophytic fungi are widely used as insect repellent, insecticidal agent, plant

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

growth promoters and plant pathogen inhibitors (Selim *et al.* 2017). Endophytic fungi are reported to modify of plant disease. This modification may be from pathogen antagonism to pathogen facilitation; depending upon the type and group of endophyte and nature and type of pathogen found in the host plant. Pathogen antagonism is the most common measure found among the host plant (Busby et al. 2016). Various studies have reported the mitigation of pathogenic diseases after the inoculation of common endophytic fungus in the plants. Some of those endophytic fungi are *Fusariumverticillioides*, *Acremoniumzeae* (Poling *et al.* 2008).

Similarly, widely used medicinal plant, *Rawwolfia serpentine*, found of Assam is seen to host endophytic fungi *Nigrospora*, *Trichoderma* and *Curvularia* having antagonistic properties against *Phytophthora* spp. and *Fusarium oxysporum* (Doley and Jha 2010). *Similarly, endophytic fungi Aspergillus niger* and *A. flavus* isolated from *Cannabis sativa* is seen antagonist to plant pathogenic microorganisms, *Colletotrichum gloeosporioides* and *Curvularia lunata* (Gautam *et al.* 2013). Moreover, endophytic fungi are also found to inhibit and reduce the condition of various plant diseases. Witches Broom Disease in Cacao is caused by the basidiomycete fungus *Crinipellis perniciosa.* Endophytic fungi *Gliocladium catenulatum* was found to inhibit the pathological condition in cacao seedling by 70% (Rubini et al. 2005). An endophytic fungus *Phaeosphaeria nodorum,* isolated form leaves of plum (*Prunus domestica*), was reported to produce inhibitory volatiles preventing the growth of fungus *Monilinia fructicola*; causes blossom blight, brown rot and twig blight of stone fruits (Pimenta et al. 2012). Furthermore, endophytic fungal strain from cotton roots, CEF-818 (*Penicillium simplicissimum*), CEF-642 (*Talaromyces flavus.)*, CEF-714 (*Leptosphaeria sp.)* and CEF-193 (*Acremonium sp.*), were used to assess their effects against *V. dahliae* strain Vd080 which causes verticillium wilt in cotton. Results indicated that these endophytes both delay as well as reduced the symptoms of cotton wilt(Yuan et al. 2017). *Endophytic*

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

fungus Cryptosporiopsis quercina, isolated form medicinal plant *Tripterigeum wilfordiii demonstrated antifungal properties against Candida albican* (Strobel *et al*. 1999). Bioactive compounds Cryptocandin and Cryptocin, isolated form *Cryptosporiopsis quercina,* were found to be responsible for antifungal activity. Cryptocin acts as an antifungal agent against several pathogenic plant fungi.

Strategic management when involved in agricultural practices helps to reduce the dependence on excessive use of fungicides to maintain ecofriendly sustainable farming practice. Two endophytic fungi *Penicilliumcitrinum* and *Aspergillusterreus* are seen to enhance the growth of sunflower plant and reduce the adverse effect caused by stem rot(Waqas *et al*., 2017). The growth of plant was increased during the diseased condition by inoculating fungal endophytes on host plant by regulating host plant defense responses. Moreover, studies shows that endophytic fungi are also involved on control of nematode. They help to develop defense against the harmful nematodes in plants. Such endophytes help to improve sustainability in agricultural practices even though the actual mechanism is poorly understood (Schouten et al. 2016).

Furthermore, endophytic fungi are also associated in controlling insecticides. Endophytic fungus *Phomopsis oblonga* was the first endophyte reported to act against *Physocnemum brevilineum,* beetle present on elm tree *(Webber, 1981). E*rgot alkaloids and mycotoxins produced by endophytic fungus *P. oblonga* was found to reduce the spread of *Ceratocystis ulmi*, responsible for spreading Dutch elm disease, by regulating its vector *P. brevilineum.* Endophytic fungi *Bontia daphnoides,* which produced metabolites nodulisporic acids andnovel indole diterpines, was having potential insecticidal properties against bowl flay larva (Demain 2000). Endophytic fungi *Muscodor vitigenus*, producing an active ingredient naphthalene, isolated from liana plant (*Paullina paullinioides*) is used against the control of mothballs (Daisy *et al.* 2002). Endophytic fungal isolates from strawberry leaves

 Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

belonging to *Paecilomyces* genera were responsible to induce death of *Duponchelia fovealis,* a pest found in strawberries (Amatuzzi *et al.* 2017). Similarly, the borer insets in coffee seedlings were found to be controlled by *Beauveria bassiana*, also known as entomopathogen (Posada *et al.* 2006).

Phytostimulation and Plant Growth Promotion

The growth promotion of plants by microorganisms occurs by direct or indirect pathway (Glick, 1995). Endophytic fungal strains are seen to promote plant growth by producing growth promoting agents.

Phosphorus (P) is responsible for stimulating growth and promoting maturity of plant. As it is an essential nutrient for plant, deficiency leads to stunted growth, delay in maturity, and reduction in yield (Mallarino *et al*. 2002; Loria and Sawyer, 2005). Two isolates of Penicillium sp., isolated from *Camellia sinensis,* showed the solubilization of tri-calcium phosphate (Nath *et al*. 2012a). Similarly, endophytic fungi *Trichoderma peudokoningii* found in tomato roots in central Himalayan region, resulted in and auxins, HCN, ammonia and siderophores production as well as solubilization of phosphate. All this is activities are associated with plant growth promotion (Chadha *et al*. 2015).

Similarly, iron acts as a cofactor of various enzymes and is an essential nutrient for overall plant metabolism. Mostly iron is present in ferric hydroxide form in the soil limiting the utilization and growth of plant even with the presence of iron in soil. Siderophores are produced by microorganisms in iron deprived conditions. It helps in binding Fe^{3+} and uptake of iron into the plant tissues (Glick *et al*. 1999). Various endohytic microorganisms are seen to produce siderophores. Ferricrocin siderophore is associated to be released by endophytic fungi present in *Pinus sylvestris* L (Scots pine) and *Rhododendron tomentosum* Harmaja (Labrador tea) (Kajula *et al*. 2010). Moreover, *Camellia sinensis* plant grown in Assam, India is found to host for *Penicillium sclerotiorum*, *Aspergillus niger*, *P. chrysogenum* and

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Fusarium oxysporum. These endophytes are also found to be responsible in production of auxin; solubilization of phosphate, potassium and zine (Nath *et al*. 2012b). Likewise, endophytic fungi *Penicillium citrinum* and *Aspergillus terreus* promoted the growth of sunflower (*Helianthus annuus* L.) and enhanced resistance against the stem rot disease caused by pathogen *Sclerotium rolfsii* (Waqas *et al*., 2015).

Biodegradationand bioremediation

Biodegradation is a process of transformation of utilized nutrients by the use of bacteria, fungi or any other biological means back to ecosystem. Endophytic fungi are responsible for biodegradation of the litter produced by the host plant (Promputtha *et al*. 2010). Endophytic fungi responsible for decomposing cellulose, hemicellulose, lignin and other organic components have different ability (He *et al*. 2012).

Chitin forms the exoskeleton of insects as well as the structural component of fungal cell wall. Enzyme chitinases degrades the insoluble polymer of chitin. The carbon and nitrogen present within chitin are degraded by endophytic fungi and thus contributes the ecosystem (Kellner and Vandenbol, 2010). Chitinase enzyme and its isoform was found to be produced by endophytic fungi isolated from tree leaves of Western Ghats, India forest (Rajulu *et al*. 2011).Bioremediation is a technique of removal of waste materials with the use of microorganism form the environment. According to reported literatures, endophytic fungi as well as bacteria are shown to have strong potential of breaking complex molecules.

The decline in growth, yield and quality of crop is associated with cinnamic acid found in cropping soils. The degradation of cinnamic acid to styrene was carried out by endophytic fungus *Phomopsis liquidambari*. Enzymes such as laccase, hydroxylase and phenolic acid decarboxylase were involved during this process (Xie and Dai 2015). Endophytic fungi were found to have the properties of degrading the petroleum contaminants present in the soil

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

leading to promotion of growth of host plant (Krishnamurthy *et al.* 2017).Some of the serine hydrolase producing endophytic fungi were found to degrade the polyurethane, a plastic material found in various forms (Russel *et al.2011*). The phytoremediation of hydrocarbon concentrated soil is also performed by endophytic fungi. Endophytic fungi *Lewia* sp. helped in phytoremediation of hydrocarbon contaminated from both perlite and soil of *Festuca aruninaceae* (Krishnamurthy *et al.* 2017). Endophytic fungi are also helpful in degrading polyaromatic hydrocarbons (PAHs). The degradation of phenantherene was reported by *Ceratobasidium stevensii* isolated form plant *Euphorbiaceae* (Dai et al. 2010)and by *Phomopsi*s isolated form rice plant (Tian *et al.* 2007).

Fungal Endophytes as Source of Bioactive Compounds

The discovery of bioactive compounds form the microorganism has skyrocketed in last 50 years. More than 30,000 natural products have been discovered only after 1940 from microorganism among which over 10,000 were found to be biologically active (Fenical *et al.* 2006). The metabolic bio-products of endophytic microorganisms are found to be extremely useful for both the plant and animal. These novel compounds are used by the plants against foreign pathogen and these compounds are also used for the discovery of new drugs. Studies shows hundreds of bioactive natural products like steroids, alkaloids, terpenoids and flavonoids are produced by the endophytic microorganisms with various properties such as antioxidants, antibiotics, anticancer and immune-suppressants (Figure 2).

Anticancer

Endophytes are good candidates in drug discovery due to their property to produce novel compounds with antibiotic, antiviral and anticancer properties. Taxol, a diterpenoid compound, was initially isolatedfrom *Taxus brevifolia* (Stierle *et al.* 1993). This compound

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

later turned out to be the world's first billion dollar drug against cancer and most importantly facilitated the further research on endophytic microbes of plant for its potential use in medical field. Few years after, endophytic fungus *Taxomyces andreanae* isolated form inner bark of *Taxus brevifolia* plant was found to produce taxol. (Selim *et al.* 2012). Another endophytic fungi *Pestalotiopis microspore* found in *Taxus wallichiana* and plants were also found to produce taxol (Strobel *et al.* 1996).

GangadeviandMuthumary2008 and *Liu et al*. 2009 isolated an endophytic fungi *Colletotrichum gloeosporioides*from the leaves of *Justicia gendarussa*was found to produce taxol, commonly used to cure breast cancer, ovarian cancer and lung cancer. Taxol also produced by *Lasiodiplodia theobromae*, endophytic fungi, isolated from *Morinda citrifolia* is reported to have cytotoxic activity breast cancer cell line of human (Pandi *et al.* 2011). Some other anticancer compounds produced by endophytic fungus are camptothecin, vincristine and podophyllotoxin (Redman*et al*. 2001). Similarly, many anticancer compounds are isolated from fungal species having different chemical activity against different cell lines. The extract of *Cordycepsmilitaris* was found to inhibit the growth of MCF-7 human breast cancer cells by response of dose upon time (Xu 2008). Fungal extract was able to reduce DNA methylation by suppressing methyltransferase transcripts and hence recovering tumor suppressing genes and inhibiting growth of tumor. Endophytic fungi isolated from *Juniperus communis*L. Horstmann has been reported to produce deoxy-podophyllotoxin (Kusari*et al.* 2009). Similarly, novel bioactive metabolite were isolated from endophytic fungus *Alternaria alternata*residing in Maytenus hookeri and were characterized by NMR as alternariol, (ii) alternariol monomethyl ether, (iii) 5-epialtenuene, (iv) altenuene, (v) uridine, (vi) adenosine, ACTG toxin-E, (viii) ergosta-4,6,8,22-tetraen-3-one.

In a study carried out by Banu and Kumar (2009), antimicrobial and antitumor activities were shown by endophytic fungi isolated form medicinal plant in yeast cell based assay.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Moreover, antimicrobial screening of isopropanol extract obtained from endophytic fungi against *Bacillus subtilis*, *Saccharomyces cerevisiae* and *Alternaria* sp. was performed in India. Similarly, a marine endophytic fungus *Aspergillus terreus* has been shown to produce compounds with anticancer activity (Suja *et al*. 2014). Another species of Aspergillus ,Aspergillus tubingensis, showed inhibitory response against tumour cell lines of MCF-7, MDA-MB-435, Hep3B, Huh7, SNB19 and U87 MG; monomeric naptho-g-pyrogens TMC 256 A1 was responsible for antitumour activity (Huang *et al.* 2011b). Similarly, endophytic fungi *Rhinocladiella* sp. present in T*ripterygium wilfordii.* produced novel cytochalasins which possess cellular toxicity resulting in antitumor activity (Wagenaar *et al*. 2000).

The endophyte having genus *Pestalotiopsis* shows higher number of antitumour activity. *Pestalotiopsis microspora*, was reported to produce Torreyanic acid having anticancer properties. Torreyanic acid was found to be cytotoxic in nature and capable of cell apoptosis (Li *et al.* 1996). *Pestalotiopsis microspore* found in inner bark of *Taxus sp*., is also seen to produce taxol (Strobel *et al.* 1996). Another strain of *Pestalotiopsi* has been identified to have maximum concentration of taxol. *Pestalotiopsi versicolor* produced 9560 times more taxol than *Taxomces andreanae* in culture broth (Kumaran *et al.* 2010).

Antimalarial Activity

Parasitic infections like malaria are one of the major concerns for developing nations. Every year two to three millions people are dying because of malarial infections. Natural products widely used to discover drugs against several diseases including malaria. Chloroquine and quinine are the most commonly used antimalarial drugs but are having reduced effectiveness as a result of resistance. Hence search for new anti -parasitic drugs is still equally important. Endophytic fungi, *Xylaria sp*., were found to produce two novel metabolites of benzoquinone along with other two known compounds. In vitro analysis showed that these compounds were antagonistic in nature to K1 strain of *Plasmodium*

 Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

falciparum, one of the causative agents of malaria (Tansuwan *et al.* 2007). Similarly, three different novel dihydroisocoumarin derivatives isolated from endophytic fungus *Geotrichum sp*. present in *Crassocephalum crepidioides* were found to be having antimalarial with anti-tuberculosis and antifungal properties (Kongsaeree *et al.* 2003). The extracts of endophytic fungi were isolated from *Psiduim guajava*, *Azadirachta indica, Newbouldia laevis* and *Agerantum conyziodes* form Nigeria. In vitro antiplasmodial test against *Plasmodium berghei* showed positive result indicating the presence of antiplasmodial along with immunomodulatory activities (Nonye *et al.* 2017). Fifty one endophytic fungi were isolated from *Garcinia* species and sixty-five crude extracts were isolated from those endophytes. The bioactivities of fungal extracts showed that 14.1% were having antimalarial activities (Phongpaichit *et al*. 2007).

Antimicrobial Activity.

Endophytes isolated from medicinal plants are widely known for their several antimicrobial activities (**Table 3**). They are seen to control and inhibit the pathogens in plants and animals. The bioactive compounds isolated form endophytes have wide spectrum of activity against pathogenic microbes. The bioactive assay of endophytic microbes like *Thielavia subthermophila, Dothideomycetes* sp., *Alternaria tenuissima, Alternariasp., Colletotrichum truncatum, Nigrospora oryzae, and Chaetomiumsp*., isolated from the medicinal plant, *Tylophora indica,* were found to inhibit the growth of *Sclerotinia sclerotiorum* and *Fusarium oxysporum* (Kumar *et al.* 2011). Similarly several other endophytic fungi like *Guignardia sp., Botryosphaeria sp., Fusicoccum sp, Muscodor sp, Aspergillus sp, Penicillium sp, Pestalotiopsis sp., Curvularia sp. and Phomopsis sp.* showed antibacterial, antimalarial, antiviral, and antioxidant activity (Phongpaichit *et al.* 2007). Cryptocandin produced by endophytic fungus *Cryptosporiopsis* cf. *quercina*, isolated form hard wood of *Tripterigeum wilfordi,* was seen to have antifungal actions against *Candida*

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

albicans, responsible for causing candidiasis in human (Strobel *et al.* 1999). Similarly, pestaloside, a bioactive compound isolated from endophytic fungus *P. microspore* present in *Torreya taxifoli* (Julie *et al.* 1995) and CR377 isolated from *Fusarium* sp. present in *Selaginellapallescens* were found to have antifungal properties (Sean *et al.* 2000). Jestoerone is an antifungal compound isolated from endophytic fungi *Pestalotiopsis jester* (Li *et al.* 2001).

Moreover, *Colletotrichum gloeosporioides,* an endophyte isolated from *Artemisia mongolica,* was reported to synthesize a bioactive compound Colletotric acid having antibacterial actions (Zou *et al.* 2000). Novel compound javanicin was synthesized by endophytic fungus *Chloridium* sp, isolated from *Neem* plant, showing antibacterial properties against *Pseudomonas* sp (Kharwar *et al.* 2009). Similarly, endophytic fungus *Cytonaema* sp. responsible for producing Cytonic acid A and B is seen to inhibit human cytomegalovirus (hCMV) protease (Guo *et al.* 2000). Diaportheone A and B are two benzopyranones extracted from the endophytic fungus *Diaporthe* sp. present in *Pandanus maryllifolius*leaves. Both, diaportheone A and B were seen to inhibit the growth of *Mycobacterium tuberculosis*H37Rv (M. E. Bungihan *et al.* 2011).

Antioxidants

Reactive oxygen species and free radicals cause oxidation of biomolecules of human body resulting in inflammation, coronary heart diseases, artherosclerosis, tumors, ageing, and neurodegenerative diseases and so on. Antioxidants are responsible in scavenging free radicals and reactive oxygen species; thus helping to reduce the risk of many diseases. The bioactive natural compounds produced by the endophytic fungi having antimicrobial, anticancer, insecticidal, pesticidal and antagonistic characteristics are also found to be antioxidant in nature (Strobel *et al.* 2004). A study on 292 morphologically different endophytic fungi isolated form several medicinal plants indicated the strong antioxidant

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

activities by several fungal metabolites (Huang *et al.* 2007). Isopestacin, obtained from endophytic fungus *Pestalotiopsis microspore*, possessed antifungal as well as antioxidant properties. Isopestacin was found to inhibit superoxide and hydroxyl free radicals as when measured by electron spin resonance spectroscopy (Strobel *et al.* 2002). Aryl tetralin ligans, produce by endophytic fungus *Trametes hirsute* and used in synthesis of topoisomerase inhibitoes, was biologically active and had antioxidant properties along with anticancer properties (Puri *et al.* 2006).

Similarly, antioxidant properties of endophytic fungal extracts are also screened in-vitro condition. An endophytic fungus *Phomopsis* sp. GJJM07, isolated from medicinal plant *Mesua ferrea,* was found to have potential antioxidant activity when evaluated for free radical scavenging (DPPH) activity (Jayanthi *et al.* 2011). Moreover ,the endophytic fungal extracts of *Chaetomium* sp., *Aspergillus*sp., *Aspergillus peyronelii* and *Aspergillus niger* strainisolated from *Eugenia jambolana*, when screened for in vitro antioxidant activity showed antioxidant activity in the range of 50% to 80% (Yadav *et al*. 2014). *In-vitro antioxidant activity of endophytic fungus Aspergillus fumigates isolated from pigeon pea showed the presence of luteolin, an antioxidant compound, in EtOAc fraction of MD-R-1, major compound of endophytic fungi. Luteolin is also used in food industry as natural antioxidant (*Zhao et al*. 2014).*

Conclusion

In recent years, many researchers had done bioprospecting of endophtic microbes, great work has been done regarding endophytic activity of three different classes of microbes-actinomycetes,fungi and bacteria.All these endophytic microbes playing great role in agriculture and medicinal fields.They are producing various bioactive novel compounds so they are highly beneficial for crops and mankind.As they also have the growth promoting role

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

to enhance the crop productivity by releasing various hormones,bacteria play major role regarding this.Fungi has the role in antibiotics,bioremediation etc.Actinomycetes also have growth promoting activity.So overall we can conclude these are highly advantegous as do not cause any harmful effect so can be utilized in many prospects.So much more novel compounds must be exploited from these microbes, keeping in view future aspects as most of pathogens becoming resistant to medicines,fertilizers etc.

References

1. Amatuzzi, R. F., Cardoso, N., Poltronieri, A. S., Poitevin, C. G., Dalzoto, P., Zawadeneak, M. A., & Pimentel, I. C. (2018). Potential of endophytic fungi as biocontrol agents of Duponchelia fovealis (Zeller)(Lepidoptera: Crambidae). *Brazilian Journal of Biology*, *78*(3), 429-435.
2. Balbi, V., & Devoto, A. (2008). Jasmonate signalling network in Arabidopsis thaliana: crucial regulatory nodes and new physiological scenarios. *New Phytologist*, *177*(2), 301-318.
3. Bilal, L., Asaf, S., Hamayun, M., Gul, H., Iqbal, A., Ullah, I., ... & Hussain, A. (2018). Plant growth promoting endophytic fungi Asprgillus fumigatus TS1 and Fusarium proliferatum BRL1 produce gibberellins and regulates plant endogenous hormones. *Symbiosis*, *76*(2), 117-127.
4. Busby, P. E., Ridout, M., & Newcombe, G. (2016). Fungal endophytes: modifiers of plant disease. *Plant molecular biology*, *90*(6), 645-655.
5. Brodersen, P., Petersen, M., Bjørn Nielsen, H., Zhu, S., Newman, M. A., Shokat, K. M., ... & Mundy, J. (2006). Arabidopsis MAP kinase 4 regulates salicylic acid-and jasmonic acid/ethylene-dependent responses via EDS1 and PAD4. *The Plant Journal*, *47*(4), 532-546.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

6. Chadha, N., Prasad, R., & Varma, A. (2015). Plant promoting activities of fungal endophytes associated with tomato roots from central Himalaya, India and their interaction with Piriformospora indica. *Int J Pharm Bio Sci*, *6*(1), 333-343.
7. Crozier, J., Thomas, S. E., Aime, M. C., Evans, H. C., & Holmes, K. A. (2006). Molecular characterization of fungal endophytic morphospecies isolated from stems and pods of Theobroma cacao. *Plant Pathology*, *55*(6), 783-791.
8. Daisy, B. H., Strobel, G. A., Castillo, U., Ezra, D., Sears, J., Weaver, D. K., & Runyon, J. B. (2002). Naphthalene, an insect repellent, is produced by Muscodor vitigenus, a novel endophytic fungus. *Microbiology*, *148*(11), 3737-3741.
9. Doley, P., & Jha, D. K. (2010). Endophytic fungal assemblages from ethnomedicinal plant Rauvolfia serpentina (L) Benth. *Journal of Mycology and Plant Pathology*, *40*(1), 44.
10. Dudeja, S. S., & Giri, R. (2014). Beneficial properties, colonization, establishment and molecular diversity of endophytic bacteria in legumes and non legumes. *African journal of microbiology research*, *8*(15), 1562-1572.
11. Gao, F. K., Dai, C. C., & Liu, X. Z. (2010). Mechanisms of fungal endophytes in plant protection against pathogens. *African Journal of Microbiology Research*, *4*(13), 1346-1351.
12. Gautam, A. K., Kant, M., & Thakur, Y. (2013). Isolation of endophytic fungi from Cannabis sativa and study their antifungal potential. *Archives of phytopathology and plant protection*, *46*(6), 627-635.
13. Guo, B., Dai, J. R., Ng, S., Huang, Y., Leong, C., Ong, W., & Carté, B. K. (2000). Cytonic acids A and B: novel tridepside inhibitors of hCMV protease from the endophytic fungus Cytonaema species. *Journal of Natural Products*, *63*(5), 602-604.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

14. Hamayun, M., Hussain, A., Khan, S. A., Kim, H. Y., Khan, A. L., Waqas, M., ... & Lee, I. J. (2017). Gibberellins producing endophytic fungus Porostereum spadiceum AGH786 rescues growth of salt affected soybean. *Frontiers in microbiology*, *8*, 686.
15. Huang, W. Y., Cai, Y. Z., Xing, J., Corke, H., & Sun, M. (2007). A potential antioxidant resource: endophytic fungi from medicinal plants. *Economic botany*, *61*(1), 14.
16. He, X., Han, G., Lin, Y., Tian, X., Xiang, C., Tian, Q., ... & He, Z. (2012). Diversity and decomposition potential of endophytes in leaves of a Cinnamomum camphora plantation in China. *Ecological research*, *27*(2), 273-284.
17. Huang, H. B., Xiao, Z. E., Feng, X. J., Huang, C. H., Zhu, X., Ju, J. H., ... & She, Z. G. (2011). Cytotoxic Naphtho-γ-pyrones from the Mangrove Endophytic Fungus Aspergillus tubingensis (GX1-5E). *Helvetica Chimica Acta*, *94*(9), 1732-1740.
18. Jayanthi, G., Kamalraj, S., Karthikeyan, K., & Muthumary, J. (2011). Antimicrobial and antioxidant activity of the endophytic fungus Phomopsis sp. GJJM07 isolated from Mesua ferrea. *Int J Curr Sci*, *1*, 85-90.
19. Kajula, M., Tejesvi, M. V., Kolehmainen, S., Mäkinen, A., Hokkanen, J., Mattila, S., & Pirttilä, A. M. (2010). The siderophore ferricrocin produced by specific foliar endophytic fungi in vitro. *Fungal biology*, *114*(2-3), 248-254.
20. Khan, A. L., Hamayun, M., Kang, S. M., Kim, Y. H., Jung, H. Y., Lee, J. H., & Lee, I. J. (2012). Endophytic fungal association via gibberellins and indole acetic acid can improve plant growth under abiotic stress: an example of Paecilomyces formosus LHL10. *BMC microbiology*, *12*(1), 3.
21. Khan, A. L., Hussain, J., Al-Harrasi, A., Al-Rawahi, A., & Lee, I. J. (2015). Endophytic fungi: resource for gibberellins and crop abiotic stress resistance. *Critical reviews in biotechnology*, *35*(1), 62-74.

 Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

22. Khan, A. R., Ullah, I., Waqas, M., Shahzad, R., Hong, S. J., Park, G. S., ... & Shin, J. H. (2015). Plant growth-promoting potential of endophytic fungi isolated from Solanum nigrum leaves. *World Journal of Microbiology and Biotechnology*, *31*(9), 1461-1466.
23. Kharwar, R. N., Verma, V. C., Kumar, A., Gond, S. K., Harper, J. K., Hess, W. M., ... & Strobel, G. A. (2009). Javanicin, an antibacterial naphthaquinone from an endophytic fungus of neem, Chloridium sp. *Current microbiology*, *58*(3), 233-238.
24. Kongsaeree, P., Prabpai, S., Sriubolmas, N., Vongvein, C., & Wiyakrutta, S. (2003). Antimalarial dihydroisocoumarins produced by Geotrichum sp., an endophytic fungus of Crassocephalum c repidioides. *Journal of natural products*, *66*(5), 709-711.
25. Krishnamurthy, Y. L., & Naik, B. S. (2017). Endophytic fungi bioremediation. In *Endophytes: Crop Productivity and Protection* (pp. 47-60). Springer, Cham.
26. Kumaran, R. S., Kim, H. J., & Hur, B. K. (2010). Taxol promising fungal endophyte, Pestalotiopsis species isolated from Taxus cuspidata. *Journal of bioscience and bioengineering*, *110*(5), 541-546.
27. Kumar, S., Kaushik, N., Edrada-Ebel, R., Ebel, R., & Proksch, P. (2011). Isolation, characterization, and bioactivity of endophytic fungi of Tylophora indica. *World Journal of Microbiology and Biotechnology*, *27*(3), 571-577.
28. Li, J. Y., & Strobel, G. A. (2001). Jesterone and hydroxy-jesterone antioomycete cyclohexenone epoxides from the endophytic fungus Pestalotiopsis jesteri. *Phytochemistry*, *57*(2), 261-265.
29. Mejía, L. C., Rojas, E. I., Maynard, Z., Van Bael, S., Arnold, A. E., Hebbar, P., ... & Herre, E. A. (2008). Endophytic fungi as biocontrol agents of Theobroma cacao pathogens. *Biological Control*, *46*(1), 4-14.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

30. Miché, L., & Balandreau, J. (2001). Effects of rice seed surface sterilization with hypochlorite on inoculated Burkholderia vietnamiensis. *Appl. Environ. Microbiol.*, *67*(7), 3046-3052.

31. Nath, R., Sharma, G. D., & Barooah, M. (2015). Plant growth promoting endophytic fungi isolated from tea (Camellia sinensis) shrubs of Assam, India. *Appl Ecol Environ Res*, *13*, 877-891.

32. Nonye, T. U., Peter, M. E., Blessing, O. U., Chika, C. A., Festus, B. O., & Charles, C. E. (2017). Evaluation of Antiplasmodial and Immunomodulatory activities of Extracts of Endophytic fungi Isolated from four Nigerian Medicinal Plants. *Planta Medica International Open*, *4*(S 01), Tu-PO.

33. Pandi, M., Kumaran, R. S., Choi, Y. K., Kim, H. J., & Muthumary, J. (2011). Isolation and detection of taxol, an anticancer drug produced from Lasiodiplodia theobromae, an endophytic fungus of the medicinal plant Morinda citrifolia. *African Journal of Biotechnology*, *10*(8), 1428-1435.

34. Phongpaichit, S., Nikom, J., Rungjindamai, N., Sakayaroj, J., Hutadilok-Towatana, N., Rukachaisirikul, V., & Kirtikara, K. (2007). Biological activities of extracts from endophytic fungi isolated from Garcinia plants. *FEMS Immunology & Medical Microbiology*, *51*(3), 517-525.

35. Poling, S. M., Wicklow, D. T., Rogers, K. D., & Gloer, J. B. (2008). Acremonium zeae, a protective endophyte of maize, produces dihydroresorcylide and 7-hydroxydihydroresorcylides. *Journal of agricultural and food chemistry*, *56*(9), 3006-3009.

36. Posada, F., & Vega, F. E. (2006). Inoculation and colonization of coffee seedlings (Coffea arabica L.) with the fungal entomopathogen Beauveria bassiana (Ascomycota: Hypocreales). *Mycoscience*, *47*(5), 284-289.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

37. Promputtha, I., Hyde, K. D., McKenzie, E. H., Peberdy, J. F., & Lumyong, S. (2010). Can leaf degrading enzymes provide evidence that endophytic fungi becoming saprobes?. *Fungal Diversity*, *41*(1), 89-99.
38. Puri, S. C., Nazir, A., Chawla, R., Arora, R., Riyaz-ul-Hasan, S., Amna, T., ... & Sharma, A. (2006). The endophytic fungus Trametes hirsuta as a novel alternative source of podophyllotoxin and related aryl tetralin lignans. *Journal of biotechnology*, *122*(4), 494-510.
39. Rajulu, M. B. G., Thirunavukkarasu, N., Suryanarayanan, T. S., Ravishankar, J. P., El Gueddari, N. E., & Moerschbacher, B. M. (2011). Chitinolytic enzymes from endophytic fungi. *Fungal Diversity*, *47*(1), 43-53.
40. Rim, S. O., Lee, J. H., Choi, W. Y., Hwang, S. K., Seok, J. S., Lee, I. J., ... & Kim, J. G. (2005). Fusarium proliferatum KGL0401 as a new gibberellin-producing fungus. *Journal of microbiology and biotechnology*, *15*(4), 809-814.
41. Rubini, M. R., Silva-Ribeiro, R. T., Pomella, A. W., Maki, C. S., Araújo, W. L., Dos Santos, D. R., & Azevedo, J. L. (2005). Diversity of endophytic fungal community of cacao (Theobroma cacao L.) and biological control of Crinipellis perniciosa, causal agent of Witches' Broom Disease. *International Journal of Biological Sciences*, *1*(1), 24.
42. Russell, J. R., Huang, J., Anand, P., Kucera, K., Sandoval, A. G., Dantzler, K. W., ... & Marks, D. H. (2011). Biodegradation of polyester polyurethane by endophytic fungi. *Appl. Environ. Microbiol.*, *77*(17), 6076-6084.
43. Selim, K. A., Nagia, M. M., & Ghwas, D. E. E. (2017). Endophytic fungi are multifunctional biosynthesizers: ecological role and chemical diversity. *Endophytic fungi: diversity, characterization and biocontrol, 39*.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

44. Stierle, A., Strobel, G., & Stierle, D. (1993). Taxol and taxane production by Taxomyces andreanae, an endophytic fungus of Pacific yew. *Science*, *260*(5105), 214-216.

45. Strobel, G. A. (2003). Endophytes as sources of bioactive products. *Microbes and infection*, *5*(6), 535-544.

46. Strobel, G., Ford, E., Worapong, J., Harper, J. K., Arif, A. M., Grant, D. M., ... & Chau, R. M. W. (2002). Isopestacin, an isobenzofuranone from Pestalotiopsis microspora, possessing antifungal and antioxidant activities. *Phytochemistry*, *60*(2), 179-183.

47. Strobel, G., Daisy, B., Castillo, U., & Harper, J. (2004). Natural products from endophytic microorganisms. *Journal of Natural products*, *67*(2), 257-268.

48. Suja, M., Vasuki, S., & Sajitha, N. (2014). Anticancer activity of compounds isolated from marine endophytic fungus Aspergillus terreus. *World J Pharm Pharm Sci*, *3*, 661-672.

49. Tansuwan, S., Pornpakakul, S., Roengsumran, S., Petsom, A., Muangsin, N., Sihanonta, P., & Chaichit, N. (2007). Antimalarial benzoquinones from an endophytic fungus, Xylaria sp. *Journal of natural products*, *70*(10), 1620-1623.

50. Tian, L. S., Dai, C. C., Zhao, Y. T., Zhao, M., Yong, Y. H., & Wang, X. X. (2007). The degradation of phenanthrene by endophytic fungi Phomopsis sp. single and co-cultured with rice. *CHINA ENVIRONMENTAL SCIENCE-CHINESE EDITION-*, *27*(6), 757.

51. Vega, F. E., Posada, F., Aime, M. C., Pava-Ripoll, M., Infante, F., & Rehner, S. A. (2008). Entomopathogenic fungal endophytes.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

52. Wagenaar, M. M., Corwin, J., Strobel, G., & Clardy, J. (2000). Three new cytochalasins produced by an endophytic fungus in the genus Rhinocladiella. *Journal of Natural Products*, *63*(12), 1692-1695.

53. Waqas, M., Khan, A. L., Hamayun, M., Shahzad, R., Kang, S. M., Kim, J. G., & Lee, I. J. (2015). Endophytic fungi promote plant growth and mitigate the adverse effects of stem rot: an example of Penicillium citrinum and Aspergillus terreus. *Journal of plant interactions*, *10*(1), 280-287.

54. Waqas, M., Khan, A. L., & Lee, I. J. (2014). Bioactive chemical constituents produced by endophytes and effects on rice plant growth. *Journal of plant interactions*, *9*(1), 478-487.

55. Waqas, M., Khan, A. L., Shahzad, R., Ullah, I., Khan, A. R., & Lee, I. J. (2015). Mutualistic fungal endophytes produce phytohormones and organic acids that promote japonica rice plant growth under prolonged heat stress. *Journal of Zhejiang University-SCIENCE B*, *16*(12), 1011-1018.

56. Waqas, M., Khan, A. L., Hamayun, M., Shahzad, R., Kang, S. M., Kim, J. G., & Lee, I. J. (2015). Endophytic fungi promote plant growth and mitigate the adverse effects of stem rot: an example of Penicillium citrinum and Aspergillus terreus. *Journal of plant interactions*, *10*(1), 280-287.

57. Webber, J. (1981). A natural biological control of Dutch elm disease. *Nature, 292*(5822), 449.

58. Wrigley, S. K., Hayes, M. A., Thomas, R., Chrystal, E. J., Nicholson, N., & Demain, A. L. (2000). Microbial natural products: a past with a future. In *Biodiversity* (pp. 3-16).

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

59. Xie, X. G., & Dai, C. C. (2015). Biodegradation of a model allelochemical cinnamic acid by a novel endophytic fungus Phomopsis liquidambari. *International Biodeterioration & Biodegradation*, *104*, 498-507.

60. Yadav, M., Yadav, A., & Yadav, J. P. (2014). In vitro antioxidant activity and total phenolic content of endophytic fungi isolated from Eugenia jambolana Lam. *Asian Pacific journal of tropical medicine*, *7*, S256-S261.

61. Yuan, Y., Feng, H., Wang, L., Li, Z., Shi, Y., Zhao, L., ... & Zhu, H. (2017). Potential of endophytic fungi isolated from cotton roots for biological control against verticillium wilt disease. *PLoS One*, *12*(1), e0170557.

62. Zhao, J., Shan, T., Mou, Y., & Zhou, L. (2011). Plant-derived bioactive compounds produced by endophytic fungi. *Mini reviews in medicinal chemistry*, *11*(2), 159-168.

63. Zhao, J., Ma, D., Luo, M., Wang, W., Zhao, C., Zu, Y., ... & Wink, M. (2014). In vitro antioxidant activities and antioxidant enzyme activities in HepG2 cells and main active compounds of endophytic fungus from pigeon pea [Cajanus cajan (L.) Millsp.]. *Food research international*, *56*, 243-251.

64. Zou, W. X., Meng, J. C., Lu, H., Chen, G. X., Shi, G. X., Zhang, T. Y., & Tan, R. X. (2000). Metabolites of Colletotrichum gloeosporioides, an endophytic fungus in Artemisia mongolica. *Journal of Natural Products*, *63*(11), 1529-1530.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Table 1: Phytohormones produced by endophytic fungi

Endophyte	Host plant	Phytohormones	References
Fusarium tricinctum and *Alternaria alternate*	*Solanumnigrum*	IAA	Khan et al. 2015b
Galactomyces geotrichum	*Trapa japonica*	GAs (GA1, GA4, and GA7) and IAA	Waqas et al. 2014.
Fusarium proliferatum	*Physalis alkekengi*	GA1, GA3, GA4, and GA7, as well as GA9, GA20 and GA24	Rim et al. 2005
Asprgillus fumigatus TS1 and *Fusarium proliferatum* BRL1	*Oxalis corniculata*	GAs and IAA	Bilal et al.2018
Penicillium citrinum LWL4 and *Aspergillus terreus* LWL5	-	Salicylic acid and jasmonic acid	Waqas et al. 2015
Alternaria alternate, *Penicillum*	*Asclepias*	IAA	Fouda et al.

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

chrysogenum	*sinaica*		2015

Endophyte	**Host plant**	**Action**	**References**

Table 2: Endophytic fungi as biocontrol agent

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Penicillium copticola	*Cannabis sativa*	Inhibition of growth of *Botrytis cinerea* and *Trichothecium roseum*	Kusari et al. 2013
Penicillium simplicissimum, *Leptosphaeria* sp., *Talaromyces flavus*. and *Acremonium* sp.	Cotton	Incidence and index of verticillium wilt was lowered	Yuan et al. 2017
Gliocladium catenulatum	Cacao plant (*Theobroma cacao L.*)	Inhibition of pathological severity by *Moniliophtora perniciosa*	Rubini et al. 2005
Phaeosphaeria nodorum	Plum (*Prunus domestica*)	Inhibition of growth and reduction in width of *Monilinia fructicola*	Pimenta et al. 2012
Nigrospora, *Trichoderma* and	*Rawwolfia serpentine*	Antagonism against *Phytophthoa spp. and Fusarium*	Li et al. 2000, Doley and Jha 2010
Phomopsis oblonga	Elm Tree	Antagonism against *Physocnemm brevilineum*	Webber 1981
Penicillium citrinum and Aspergillus terreus	-	enhance the growth of sunflower plant and reduce the adverse effect caused by stem rot	Waqas et al. 2017).
Aspergillus niger and A. flavus	*Cannabis sativa*	Inhibit plant pathogenic microorganisms, *Colletotrichum gloeosporioides* and *Curvularia lunata*	Gautam et al. 2013

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Table 3: Endophytic fungi as antimicrobial agent

Endophyte	**Host plant**	**Bioactive compound**	**Action**	**References**
Cryptosporiopsis cf. *quercina*	*Tripterigeum wilfordi*	Cryptocandin	Antifungal actions against *Candida albicans*	Strobel et al. 1999
P. microspore	*Torreya taxifoli*	Pestaloside	Antifungal properties	Julie et al. 1995
Pestalotiopsis jester	-	Jestoerone	Antifungal properties	Li et al. 2001
Colletotrichum gloeosporioides	*Artemisia mongolica,*	Colletotric acid	Antibacterial properties	Zou et al. 2000
Chloridium sp.	Neem plant	Javanicin	Antibacterial properties	Kharwar et al. 2009
Cytonaema sp	-	Cytonic acid A and B	Inhibition of human cytomegalovirus (hCMV) protease	Guo et al. 2000
Diaporthe sp.	*Pandanus maryllifolius*	Diaportheone A and B	Inhibition of the growth of *Mycobacterium tuberculosis*H37Rv	Bungihan M E et al. 2011).

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

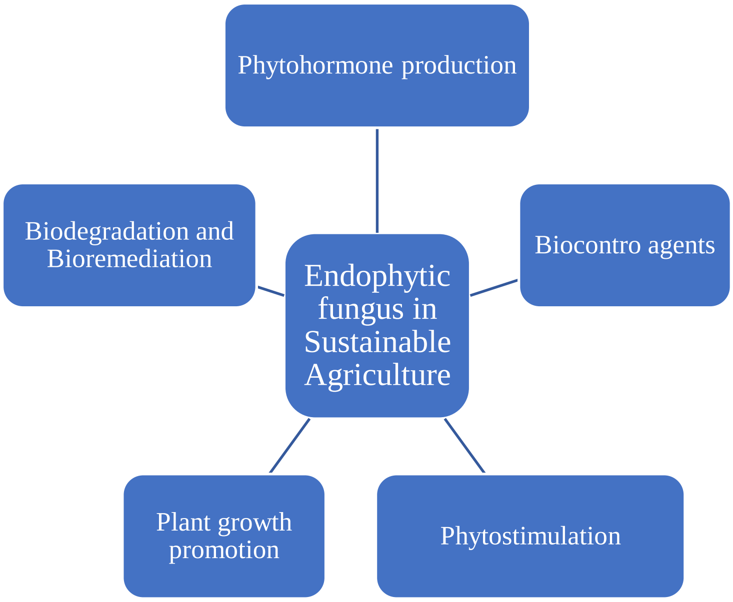

Figure 1 : Role of endophytic fungus in sustainable agricultural practices

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

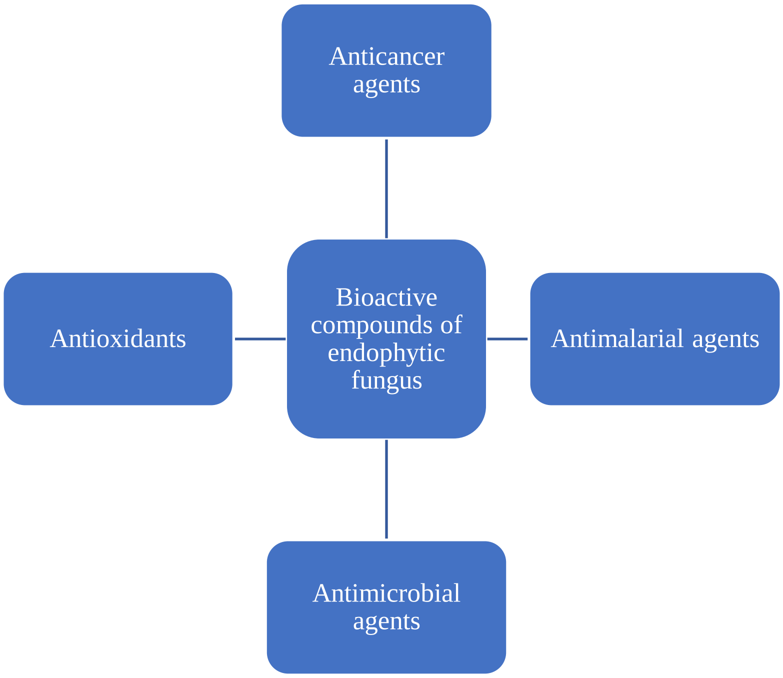

Figure 2 : Role of bioactive compounds form endophytic fungus

Copyright ⓒ 2019Authors

ISSN:0971-1260
Vol-22-Issue-34-December -2019

Copyright ⓒ 2019Authors