**ENDOPHYTIC FUNGI: FUTURISTIC TOOL FOR BIOREMEDIATION**

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**ABSTRACT**

Heavy metal of soil and water has become a difficult issue around the world. This issue has pulled in significant public consideration in light of the fact that increase of metal levels in soil and water poses a health risk to humans and animals. On the other hand, increased concentration of heavy metals is harmful to most plants; the plant's metabolism and growth were debilitated. There are various conventional methods that have been used for heavy metal removal. But these methods possess several disadvantages including high cost, high energy and incomplete removal of heavy metals. Microorganisms based bioremediation serves as an alternative solution and most promising option to treat heavy metals. Different microorganisms have the ability to reduce heavy metal stress from the plants. Endophytic fungi though not extensively studied yet are potent source in protecting plants against heavy metal toxicity. Endophytic fungi reside asymptomatically in internal tissues of all higher plants without showing any harmful effects on the ecology of their host. Benefits offered by endophytic fungi to their host plant comprises of enhanced plant growth, resistance to cold, heat, salt and temperature, production of important and valuable medicinal, pharmaceutical and therapeutical compounds. Endophytes ameliorate bioremediation efficiencies by reducing heavy metal toxicity of plants.

Keywords: Bioremediation, Heavy metals, Endophytic fungi.

**1.1 INTRODUCTION**

With rapid increase in the industrialization and urbanization, there is a great accumulation of heavy metals composing high risk to flora and fauna. This plays a crucial role in maintaining the integrity of good health of soil and making them free from contamination. A plethora of measures have been developed that are easy to use, sustainable and economically feasible. From the past, there are various physiochemical approaches used for remediation of soil contaminated with heavy metals. But they possess some disadvantages such as remediation of soil on a large scale is not possible because of higher cost and various side effects due to exposure of heavy metals. To overcome these problems, microbe based remediation has shown effective results as a low cost and environmental friendly technique in order to remove toxicants from contaminated soils (Aishwarya S et al., 2014). The use of microorganisms to decontaminate heavy metals from soil has been found to be cost effective and environmentally clean. Rhizospheric microbes improve the soil health, proving stability, leading to sustained plant growth and development under stressful conditions. Microbe based bioremediation involve the use of bacteria, fungi, and algae (Hassan et al., 2017).

**1.2 Heavy Metals**

With the development of various human activities in recent years, there is increase in both type and content of substantial heavy metals in the soil caused by various human activities resulting in the deterioration of environment. Major heavy metals that cause toxicity in soil includes mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr) and arsenic (As), zinc (Zn), copper (Cu), nickel (Ni), stannum (Sn), vanadium (V), and many more (Su et al., 2014). Since this can have serious consequences, it is imperative to better understand that can impose serious health hazards and can be transferred through the food chain. Once the soil experienxes heavy metal contamination, it is hard to be remediated.

**1.2.1. Heavy metal uptake by plants**

The primary recruitment stream of heavy metals in plants and animals are through water, food and air. Upon entry, they attach to specific cellular compartments resulting in the damage of various biological functions. In some cases, metals can easily attach to sulfhydryl groups of several enzymes to control the speed of metabolic reactions: the “new” metal-enzyme complex leads to the loss of the catalytic activity of the enzyme. The level of toxicity from heavy metals depends on several factors i.e., exposure time, concentration, and the health status of the flora and fauna exposed. Bioaccumulation is the process whereby the accumulation of toxic substances in living beings increases in concentration following a rise in the trophic level: the higher the trophic level, the stronger the concentration of heavy metals. Biomagnification is also expressed as the concentration increase of a pollutant in a biological organism over time (Aprile & Bellis, 2020). Hence, there has been an increased recognition that more attention needs to be paid to this area.

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BY Leaf (through polluted air)

* Entry via cuticle cracks.
* Entry via stomata.

By Roots

Heavy metal entry in plants

Cu, Cd, Zn, Pb, Co, Cr, Ni, As

 **![C:\Users\Sunshine\AppData\Local\Microsoft\Windows\INetCache\IE\4NGAENSW\leaf_02[1].png]()**

* + 1. **Characteristics of Heavy Metal contamination in Soil:**

Heavy metal contamination has become increasingly common in the world being utilized in various industries possesses a serious threat to every country (Yang and Sun, 2009). Heavy metal contamination has a strong latency having unique characteristic of being colorless and odorless and gradually harm the environment. The heavy metal concentration in soil typically ranges from less than one to as high as 100,000 mg/kg (Long, Yang & Ni, 2002). Nevertheless, when it exceeds the environmental tolerance, heavy metals in the soil gets activated, when its concentration exceeds the environmental tolerance or changed environmental conditions. It was pointed out some time ago by Wood (1974) that heavy metal contamination acts as chemical Time Bombs (CTBs). Dilution and self-purification technique are not suitable for elimination of heavy metal (as in the case of air and water pollution). As the exsitu removal of heavy metal from soil is slow process, some contaminated soil takes one or two hundred years to be remediated (Wood, 1974).

From past to present, soil contamination cases are found to be caused by a variety of heavy metals. The complex contamination caused by a variety of heavy metals will always amplify the contamination by heavy metals separately. Yong Shang et al. (2008) showed that in terms of the influence on soil respiration, Cu+ Pb > Pb > Cu.

**1.2.3 Sources of Heavy metals**

Sources of Heavy metals

Anthropogenic

Natural

1. Weathering of rocks.
2. Erosion and volcanic activities.
3. Particles from vegetation.
4. Forest Fires.
5. Electronic waste and wood preservatives.
6. Stack emissions
7. Mining.
8. Use of fertilizers.
9. Sewage Sludge.
10. Fuel combustion.
11. Kitchen appliances.
12. Industrial effluents.

Heavy metals in soil can be due to natural and anthropogenic origin. The solidity of heavy metals is more than that of water. Because of natural cycling in the earth's crust, the soil usually contains low concentrations of heavy metals. Heavy metal concentration in unpolluted areas in soil depends on the composition of the Earth's crust. The fundamental significance of living organism depends upon the low concentrations for most heavy metals are desirable. The major cause for the increase of heavy metals concentration above the natural level is due to anthropogenic activities. Their plentiful domestic, industrial, agricultural and technological usages have led to their widespread distribution in the environment and raising worries because their possible impacts on human health and the environment. As, Cd, Cr, Pb, Hg, Ni, Zn and Cu are the most widely distributed heavy metals. Being non biodegradable in nature, they enter into food chain. Excessive intake of heavy metals into living organisms leads to many harmful consequences; including death. The access of heavy metals into humans is inhalation, ingestion and direct and indirect contact (Smiljanić et al., 2019).The heavy metals can be entered into the soil in different ways. Sources of heavy metals pollution include natural processes and anthropogenic activities (Alloway, 2013).

**1.2.3.1 Natural activities**

Weathering of rocks, lithospheres’ and pedogenic processes are responsible for addition of heavy metals in unpolluted areas which are regarded as trace and rarely toxic (Alloway,2013; Yannagi, 2011). The ten elements (O, Si, Al, Fe, Ca, Na, K, Mg, Ti, P) make up over 99% of the total crust content, and the other elements that constitute the earth's crust are called "trace elements", and their concentrations do not exceed 1,000 mg/kg (0,1%) (Yanagi, 2011; Hawkeswarth & Kemp, 2006; Wuana & Okieimen,2011). All soils naturally contain trace levels of metals. The presence of metals in soil is, therefore, not indicative of contamination.

**1.2.3.2 Anthropogenic sources**

The main reason for exceeding heavy metals in soil is human activities. Effluents from industrial areas, mine dumps, sanitary landfill, disposal of high metal wastes, wastes from agricultural activities, use of fertilizers and animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, runoff of terrestrial systems, industrial and domestic effluents, spillage of petrochemicals, accidental leaks, atmospheric deposition leads to the accumulation of heavy metals and metalloids. Heavy metals present in soil due to anthropogenic sources tend to be more versatile, hence bioavailable than pedogenic, or lithogenic ones (Alloway, 2013, Wuana & Okieimen, 2011; He et al., 2015). Organic pollutants can easily biodegradable rather than heavy; therefore represent a long-term threat to the environment, health, soil/water degradation, and ecosystem malfunctioning. Moreover, heavy metals enter food chains from polluted soil, water, and air, and consequently cause food contamination and various diseases, thus posing a threat to human and animal health (Mahurpawar, 2015).

**Heavy metals and their toxicities:**

|  |  |
| --- | --- |
| **HEAVY METAL** | **TOXICITIES** |
| ARSENIC | Skin manifestations, visceral cancers, vascular disease |
| CADMIUM | Kidney damage, renal disorder, human carcinogen |
| COPPER | Liver damage, Wilson disease, insomnia |
| MERCURY | Rheumatoid arthritis, and diseases of the kidneys, circulatory system, and nervous system |
| LEAD | Damage the fetal brain, diseases of the kidneys, circulatory system, and nervous system |
| NICKLE | Dermatitis, nausea, chronic asthma, coughing, human carcinogen |
| ZINC | Depression, lethargy, neurological signs and increased thirst |
| CHROMIUM | Headache, diarrhea, nausea, vomiting, carcinogenic |

**Technologies for remediation of heavy metal-contaminated soils (Wuana and Okieimen, 2011).**

|  |  |
| --- | --- |
| **Category** | **Remediation Technique** |
| 1. Isolation
 | 1. Capping.
2. Subsurface barriers.
3. Chemical Treatment.
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| 1. Toxicity /Mobility reduction
 | 1. Chemical treatment
2. permeable treatment walls
3. Biologicaltreatment bioaccumulation, phytoremediation(phytoextraction, phytostabilization,and rhizofiltration), bioleaching, biochemical processes
 |
| 1. Physical Separation Extraction
 | 1. Soil washing, pyrometallurgical extraction, in situ soil flushing, and electrokinetic treatment.
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Generally, microorganisms have the biochemical and ecological capacity to diminish the risk associated with metals, metalloids and radionuclide are either by chemical modification or by influencing chemical bioavailability. Nevertheless plant-associated endophytes can overcome these constraints, which can assist plants to accumulate a higher amount of metals without showing any negative impact on plants.

**1.3 Bioremediation**

For the expulsion of toxic pollutants, biological approaches are cost effective and environmentally friendly (Doble and Kumar, 2005). Some biological techniques used are bioremediation, phytoremediation, bioventing, bioleaching, bioaugmentation, biostimulation, etc. Among these techniques, bioremediation and phytoremediation are the most useful. These techniques also maintain soil physical status unlike physiochemical approaches as documented by Beskoski et al. (2011). Bioremediation is a biological method used for the remediation of heavy metals (Boopathy 2000). Heavy metals, pesticides and phenolics waste release in the environment due to natural or manmade practices are of global concern. Microbial based remediation is suitable because of its low cost and less laborious process. Bioremediation is a technique used to remove heavy metal pollutants from environment that uses microbial metabolism. Various techniques and procedures of bioremediation (e.g., phytoremediation enhanced by endophytic microorganisms, rhizoremediation) can be predominantly used to eliminate hazardous waste from the biosphere. The mechanisms of bioremediation depend on the mobility, solubility, degradability, and bioavailability of contaminants. Moreover, these factors have a great influence on degradation. As a result, recognition of natural microbial processes is indispensable for understanding the mechanisms of effective bioremediation (Stępniewska & Kuźniar, 2013).

Previously, physiochemical and conventional techniques were used for remediation purposes are soil incineration, landfill, excavation, soil washing, leaching, solidification, and soil flushing (Wuana and Okieimen 2011). However, these approaches exerts negative impact on soil’s chemical and physical structure. These methods have some drawbacks of being costly, receive more labor, damage soil-living microorganisms and cause various pollution related problems. But these approaches negatively affect the soil’s physical and chemical structure. Rather than complete degradation, these heavy metals can transform from one form to another. So there is a need of advanced methods which are cost effective and eco-friendly (Lambert et al., 2000; Ali et al., 2013). Thus, there must be a need for advanced which is cost effective and environmentally safe for cleaning of heavy metals form the contaminated soils. For instance, *Bacillus* spp. and *Pseudomonas aeruginosa* have been used to alleviate Zn and Cu stress (Kumar et al. 2011). Subsequently, plant-organism cooperations have picked up significance because of the capability of microorganisms to bioaccumulation of heavy metals (Hadi and Bano, 2010).

**1.3.1 Why Endophytic fungi?**

The word endophyte means, ‘endo’= within, ‘phyte’= plants. The term endophyte came into exixtence in 1866 by De Bary.  It is noteworthy that, of the nearly 300,000 plant species on our planet, each individual plant is considered to host at least one type of endophyte (Strobel and Daisy, [2003](https://annalsmicrobiology.biomedcentral.com/articles/10.1007/s13213-015-1153-7#ref-CR95)), creating an enormous biodiversity. However, only a few of plant-associated endophytic fungi have been studied, indicating that the opportunity to find interesting endophytes among myriad plants in different niches and ecosystems is great. Petrini ([1991](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3825493/#CR61)) viewed them as all organisms living in plant organisms that can colonize tissues without any macroscopically visible symptoms. These microorganisms reside inside both specific plant tissues and the root cortex or the xylem. They also systematically colonize the plant by the vascular or apoplast system (Stępniewska & Kuźniar, 2013).

**1.3.2 Colonization of plants by Endophytic fungi**

There is a continuous interaction between plants and microcosm of soil that help plants in terms of development, dealing with biotic and abiotic stresses, modulation of plant immune system, production of bioactives such as polyketides, coumarins, isocoumarins, quinones, anthrones etc. There are various reports suggesting that endophytic fungi have capability to aid in the defense of their host plants. Currently, the researchers have more focus on the application of endophytic fungi with the capability to produce valuable bioactive molecules, and to use them as biocontrol agents. Endophytic fungi belong to mitosporic and meiosporic microorganisms that live asymptomatically inside the healthy plant tissues beneath the epidermal cell layers via “quiescent infections” ([Bacon and White, 2000](https://www.frontiersin.org/articles/10.3389/fmicb.2016.00906/full#B4)). Plant responses upon endophytic fungi colonization are also good for the immune system of the plant. During long-term evolution, plants have acquired numerous beneficial strategies in response to endophytic fungi colonization. The interaction of endophytic fungi with plants modulates the relationship between plants and both biotic and abiotic stresses (Yan et al., 2019).

In plant-endophyte interaction, endophytic fungi release signals after perceiving stimuli by plants, which later activated the plants immune system. Plants generally have two branched innate immunity system which helps them to recognize signal from endophytes and help in cell communication. This primary signaling leads to the activation of two different pathways: one is that plants recognize the microbe-associated molecular patterns (MAMPs) via cell surface-localized pattern recognition receptors (PRRs), which lead to MAMP-triggered immunity (MTI); the other system is that plants recognize the molecules produced by microorganisms (termed effectors) via intracellular receptors and activate effector-triggered immunity (ETI) in response (Mendoza-Mendoza et al. [2018](https://link.springer.com/article/10.1007/s00253-019-09713-2#ref-CR68)).

 

 **Fig.1.: Endophytic fungus location inside plant tissue.**



Modulation of phyto hormone production

Plant growth promotion

Nutrient cycling

Heavy metal tolerance

Bioremediation

Anti-herbivory

Nitrogen Fixation

Antibiotic production

Endophytic Fungi

 **Fig.2: Different properties exhibited by endophytic fungi.**

**1.3.3 Endophytic Fungi in Bioremediation**

Our nature is a huge ecological niche for fungi and bacteria to act as decomposers of various dead materials. In the recent years, endophytic fungi have attained a high degree of metabolic versatility which results in degradation of hydrocarbons by the release of various enzymes. Many endophytic fungi have been found to be resistant to heavy metals and/or capable of degrading organic contaminates and endophyte based bioremediation has been documented as a promising tool for in-situ remediation of contaminated soils. The application of filamentous fungi can be a promising method or a valuable complement in situation of bacterial malfunction, in which bacterial cells fail to form the mycelia network to react with contaminants (Aishwarya S et al., 2014)..

Endophytes have become a potential resource to cope with these problems since they possess many systems that can break down complex compounds, degrade chemical pollutants, and effect biosorption of heavy metals (Xiao et al. 2010; Russell et al. 2011; Li et al. 2012c). The enzymatic reactions of various endophytic fungi have the capability to degrade small and large organic compounds by enzymatic reactions, decompose environmental contaminants, and improve the soil microenvironment (Krishnamurthy & Naik, 2017). They increase the ability of host plants to remove contaminants from soil, water, sediment, and air (H-Y Li et al., 2012). Endophytic fungi cause various morphological and physiological changes in host plant which in turn provide resistance to plants against metal contamination. This may be due to high surface to volume ratio, extracellular scavenging and intracellular precipitation (Barkey, Miller Summer, 2003; Kim et al., 2015). The difference in metal tolerance may be due to the presence of various strategies of resistance mechanism exhibited by the fungi (Iram et al. 2013). Fungal cell walls are typically composed of the polysaccharides chitin and cellulose and these constituents of the cell wall possess functional groups such as amino, carboxyl, hydroxyl and sulphate which have high metal binding capacities and are believed to have a significant potential for metal binding (Davis et al. 2003).

Endophytic fungi posses the biochemical and ecological capacity to decrease the risk associated with metals, metalloids and radionuclide’s either by chemical modification or by influencing chemical bioavailability. Furthermore the ability of fungi from extended mycelial networks makes them well suitable for bioremediation processes. The application of filamentous fungi can be a promising method or a valuable complement in situation of bacterial malfunction, in which bacterial cells fail to form the mycelia network to react with contaminants. The method is especially useful for circumstances, in which contaminants are physically inaccessible to unicellular organisms or pollution is too serious to maintain bacterial survival (Singh, Verma & Gaur, 2013). Compared to bacteria, most endophytic fungi exhibit a filamentous growth habit, which provides the ability to adopt both explorative or exploitative growth strategies and form linear organs of aggregated hyphae to protect fungal translocation (Deng & Cao, 2017). There are various research reports suggested that some endophytes could promote host plant growth in HM contaminated soils (Monnet et al. 2001; Sun et al. 2010; Zhang et al. 2010). However, the heterogeneity of endophytic fungi in Pb Zn contaminated ecosystems are almost unknown (Zhang et al. 2008; Guo et al. 2010; Xiao et al. 2010).

Microorganisms such as bacteria, fungi, algae and yeast

have been increasingly studied due to their metal sequestering

property (Wang and Chen 2009).

Based on previous studies, Pestalotiopsis microspora is

known to produce taxol, an anticancer drug (Strobel et al.

1996), however, there have been no reports on the use of

Pestalotiopsis species as heavy metal removal agents. Most

studies have been undertaken on filamentous fungal strains

and mostly members from the genera Aspergillus, Fusarium,

Humicola and Nannizzia have been reported to possess

resistance against heavy metals (Iram et al. 2013; Ezzouhri

et al. 2009; Valix et al. 2001). Recently, several studies have

reported a similar trend among endophytic fungi being able

to resist several heavy metals such as copper, zinc and

cadmium (Hong et al. 2010; Salvadori et al. 2013; Deng et

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al. 2014).

Choo et al., 2015 stated that endophytic fungi from the wetlands of Sarawak can grow at high heavy metal concentrations (up to 1000 ppm). This is the first report on heavy metal tolerance by *Pestalotiopsis* against a suite of heavy metals (Cu, Cr, Zn, and Pb) and has high potential to be screened as potential biosorbents. Phytoremediation has been proposed as a low cost, environmental friendly and effective method to remove toxicants from contaminated soils. However phytoremediation of heavy metal still has to deal with some important shortcomings such as phytotoxicity, slower than mechanical method and a limited mechanical uptake. Nevertheless plant-associated endophytes can overcome these constraints, which can assist plants to accumulate higher amount of metals without increasing phytotoxicity.

H.-Y. Li et al (2011) stated that endophytic fungi have a marked adaptation over heavy metals under constant metal stress followed by the exposure if a very long time. Half of the tested endophytic fungal isolates were tolerant to lead and zinc. However, the heavy metal can also be used as micronutrients by these growth stimulated endophytic fungi. Therefore, it might be beneficial to inoculate these stress-adapted fungi into plants for phytoremediation in heavy metal contaminated soils (Dodd & Thompson 1994; Zhang et al. 2008).

Li et al. (2010) reported that endophytic fungi can be used for phytoremediation or bioremediation at contaminated sites. The colonization of endophytic fungi were found in higher number area which is polluted by lead and zinc. Phoma, Alternaria and Peyronellaea were the most frequent endophytic fungi in Pb–Zn polluted area. They have showed increased tolerance to Pb2+ and/or Zn2+. Yang et al. (2012) described the screening for potential biosorbents in endophytic fungi isolated from the marine environment and reported promising results.

*Pestalotiopsis* sp. showed the greater resistance potential towards copper when comparedto bacterium *Pantoea* sp*.* while the resistance level of bacteria against copper was only 200 ppm (Ozdemir et al., 2014). However, higher heavy metal resistanceof fungi towards chromium (up to 10,000 ppm) was accountedby Congeevaram et al. (2007). *Aspergillus* *niger* strains were proficiently able to resist lead up to7000 ppm (Faryal et al., 2007). Both studies isolated fungi from heavy metalcontaminated environments, suggesting that the stresses ofthe environment towards the microorganisms play a majorrole in causing the fungi to resist heavy metals and adapt inorder to survive. Endophytic fungi isolated by Choo et al. (2014) also capable ofresisting heavy metals up to high concentrations. *Pestalotiopsis* sp. showed the capability to tolerance against a suite of heavy metals i.e., Cu, Cr, Zn and Pb. Furtherstudies are also needed to understand the mechanisms thatenable our fungi to grow in heavy metal concentrations upto 1000 ppm.

*Aspergillus flavus*, *Aspergillus niger*, *Fusarium solani*, and *Penicillium chrysogenum*, resistant to heavy metals like Cr and Pb were isolated after screening soil samples from peri-urban agricultural areas. The results revealed that the majority of the isolates were resistant to Pb and Cr, and only few of them were able to grow. Among the isolated strains, *Aspergillus niger* was the most tolerant against Pb, with MIC of 600 mg/l, and *Aspergillus flavus* against Cr, with MIC of 400 mg/l, which makes them attractive potential candidates as bioremediation agents (Iram et al., 2013).

Polyester polyurethane (PUR) is a plastic widely used in industry and manufacturing of high-resilience foam seating, rigid foam insulation panels, microcellular foam [seals](https://en.wikipedia.org/wiki/Seal_%28mechanical%29) and [gaskets](https://en.wikipedia.org/wiki/Gasket), [spray foam](https://en.wikipedia.org/wiki/Spray_foam), durable elastomeric wheels and tires; that has been shown to be susceptible to biodegradation (Darby & Kalpan, 1968; Howard, 2002). The polymer is generated by the condensation of a polyisocyanate and a polyol. This results in a carbon polymer composed of a series of urethane linkages. Variations in the spacing between urethane linkages, as well as the nature of the substitutions, can change the properties of the resulting polymer from linear and rigid to branched and flexible. PUR appears milky white and completely opaque under liquid suspension. Like other polyurethanes, this product is synthesized commercially for the manufacture of textiles and textile coatings (Russel et al., 2011).

The degradation of PUR by both bacteria and fungi is due the enzymes released by them (Cosgrove et al;, 2007; Crabe et al., 1994, Pathirana & Seal, 1984; Rowe & Howard, 2002). Soil fungi comprise the majority of organisms screened for PUR degradation activity. Fungi of genera *Alternaria*, *Aspergillus*, *Phoma*, *Pennicilium*, *Plectosphaerella*, *Geomyces*, *Nectria*, and *Neonectria* were isolated with access to mixed nutrient sources from buried PUR samples. *Geomyces pannorum* was the most commonly isolated PUR-degrading organism (Cosgrove et al., 2007). Few organisms have been shown to degrade PUR as a sole carbon source. *Aspergillus niger* has some reported degradation activity; however, it was observed to be quite slow, with visible signs of degradation occurring only after 30 days (Fillip, 1979).

The broad spectrum activities of endophytic fungi suggest that they might be a promising source of biodiversity in which to test for activities important for bioremediation and to degrade polyester polyurethane (Russell et al., 2011).

There are two mechanism through which endophytic fungi transfers inside plant: one by vertical gene transfer and another by horizontal gene transfer. The propensity for horizontal gene transfer may contribute to the ability of a subset of endophytic fungi to degrade polyester polyurethane as a sole carbon substrate, or it may reflect a significant level of phenotypic diversity among the genus. *Pestalotiopsis microspora* have a propensity for horizontal gene transfer. Aspergillus niger and Pencillium sp have promising bioadsorptions capacity of Cr, Ni, Cd from single and multi-metal solutions and highlighted possible exploitation of the filamentous fungi of metal-polluted habitat (Ahmed, Ansari & Aqil, 2006). Endophytic fungus Microsphaeropsis sp. isolated from cadmium hyperaccumulator Solanum nigrum L. a high biomass yield when cultured invitro. Endophytic fungi *Microsphaeropsis* sp. LSE10 has been found to utilized as a biosorbent for the detoxification of cadmium (Xiao et al., 2010). (Chandrakar et al., 2014) indicates that the fungal population retrieved from heavy metal contaminated sites has the ability to resist the higher concentration of metals. A comparative level of metal resistance was also shown by filamentous fungi originated from unpolluted sites. The tolerance and resistance of the isolates depended much more on the fungus tested than on the site of its isolation. This variation may be explained by the development of tolerance and adaptation of the fungi to heavy metals. *Aspergillus* sp. and *Fusarium* sp. were the most resistant to all the metals tested, which make them promising candidates for further investigations regarding their ability to remove metals from the contaminated environment.

*Aspergillus flavus* (ASC1) and *Aspergillus niger* (ASB3) are capable of removing 50%-76 % of arsenic from different arsenic enriched medium, simultaneously also tolerant to different other heavy metals (Cd, Pb, Hg, Zn and Cr) (Mukherje et al., 2014). In near future, these two fungal strains will be effective in arsenic removal planning from arsenic-contaminated sites. According to Deng et al. (2014), endophytic fungi *Lasiodiplodia* sp. MXSF31, isolated from metal accumulating *Portulaca oleracea* showed resistance against Cd, Pb and Zn. The endophytic fungus showed high biosorption and bioaccumulation capacities of Cd, Pb and Zn from the metal-contaminated solutions and enhanced the metal extraction efficacy of rape in soils contaminated by multiple metals. Because of the broad host range, the endophytic nature, resistance to multiple metals and endophytic fungi from plants accumulating multiple metals should be valuable microorganism resources for bioremediation of water and soils contaminated by multiple heavy metals. Many metal resistant endophytes have been recovered from hyperaccumulating plants such as *Alyssum bertoloni*, *Alnus firma*, *Brassica napus*, *Nicotiana tabacum*, *Thlapsi caerulescens*, *T. goesingense* and *Solanum nigrum*. On the other hand, many metal resistant endophytes have also been isolated from non – hyperaccumulating plants such as *Arabis hirusta*, *Acacia decurrens*, and *Symplocos paniculata* (Li et al., 2012). The metal resistant endophytic fungi are *Microspaeropsis, Mucor*,  *Phoma*, *Alternaria*, *Peyronellaea, Steganosporium* and *Aspergillus*.

**1.4 Other Applications Exhibited By Endophytic Fungi**

**1.4.1 Endophytic fungi in agriculture**

There are various health effects related with the use of chemical fertilizers and pesticides, so interest has increased to find alternative green methods of fertilization and control of pests. Fungal endophytes have been reported for useful compounds such as phytohormones, antimicrobial compounds, and many agrochemical bioactive metabolites. Endophytic and rhizosphere fungi are understood to be aiding the host plant to overcome a range of biotic and abiotic stresses (nutrition depletion, droughts, etc.) hence, they remain to be reservoirs of the plethora of natural products with immense use. However, the plant peripheral tissues form chemically complex microcosm that forms a community of diverse microorganisms. *Epicoccum nigrum* is also known for its biocontrol potential against bacterial and fungal plant pathogens (Lugtenberg et al. 2016). *E. nigrum* has shown biocontrol activity against the bacterial pathogen *Pseudomonas savastanoi* pv. *savastanoi* (Psv) causing olive knot and reduced psv growth/biomass up to 96% (Berardo et al. 2018). Endophyte *Colletotrichum gloeosporioides* isolated from *Theobroma cacao* tissues showed antagonistic activity against black pod rot pathogen *Phytophthora palmivora* (causing black pod rot) *Moniliophthora roreri* (causing frosty pod rot), and *M. perniciosa* (causes witches broom) in in vitro and field studies (Chhipa and Deshmukh 2019). *Trichoderma sp*. has used as BCA against plant pathogenic fungi such as *Botrytis cinerea*, *Fusarium* spp., *Pythium* spp., and *Rhizoctonia* spp. (Park et al. 2019). The endophytic fungi *T. viride* exhibit antagonistic activity when overgrew on pathogenic mycelium (Talapatra et al., 2017). Endophytic fungi are agriculturally important as they can enhance plant growth; improve plant nutrition through different direct and indirect PGP attributes including solubilization of phosphorus, potassium and zinc; production of phytohormones (Indole acetic acids, gibberrellic acids and cytokinin), Fe-chelating compounds, hydrolytic enzymes, hydrogen cyanide, ammonia (Suman et al., 2016; Verma et al., 2017; Saxena et al., 2016; Yadav & Yadav, 2018. A large number of endophytic fungal species belonging to different genera including *Acremonium*, *Alternaria*, *Aspergillus*, *Berkleasmium*, *Chaetomium*, *Cladosporium*, *Claviceps*, *Collectotrichum*, *Cryptococcus*, *Curvularia*, *Fusarium*, *Geomyces*, *Glomus*, *Leptospora*, *Metarhizium*, *Microdochium*, *Neotyphodium*, *Ophiognomonia*, *Paecilomyces*, *Penicillium*, *Phaeomoniella*, *Phyllosticta*, *Piriformospora*, *Rhizoctonia*, *Rhizopus*, *Rhodotorula*, *Talaromyces*, *Trichoderma*, *Wallemia* and *Xylaria* have been isolated from different host plants (Yadav et al., 2018).

**1.4.2 Endophytic fungus producing secondary metabolites.**

Fungal endophytes being capable in the production of variety of active secondary metabolites including alkaloids, various amides and other nitrogen containing compounds (Rustamova et al., 2020).There are various secondary metabolites produced by endophytic fungus. Antibacterial compounds produces from endophytic fungi includes Periconicin A and B, Petacin, Phomol, Mullein, Brefeldin A, Uridine and Cerebrocoide from *Periconia* sp., *Penicillium microspore,* *Phomopsis* sp., *Aspergillus clavatus*, *Phomopsis* sp., and *Fusarium* sp. respectively (Guo et al, 2000; Kim et al., 2004; Strobel et al., 2002; Lung & Hsieh, 2011). Compounds alternariol and alternariol-(9)-methyl ether from the endophytic fungus *Pleospora tarda* has been reported for their best antiviral activities (Selim et al., 2018). Brefeldin A is a antifungal, antiviral, anticancerous compound activities, and also acts as a protein-transport inhibitor (Zabala et a., 2014) has been isolated from several fungal species including Curvularia, Alternaria, Phyllosticta, Penicillium, and Cercospora (Wang et al., 2002). Podophyllotoxin from Podophyllum emodi, is a potent antimitotic agent and tubulin polymerase inhibitor; used as a topical treatment for genital warts. Some of its semisynthetic derivatives, however, are effective anticancer drugs and include the topoisomerase II inhibitors etoposide, teniposide, and etoposide phosphate (Stahelin & Wartburg, 1991; Baldwin & Osherhoff, 2005). Aflaquinolone, a secondary metabolite and a derivative of dihydroquinolone , isolated from the endophytic *Aspergillus versicolor*, isolated from the leaves of the Egyptian water hyacinth *Eichhornia crassipes.* Aflaquinolone shows better antiproliferative property (Ebada et al. 2018). Fusarithioamide, Pestalotiones, koninginol B from *Fusarium chlamydiosporium*, *Petalotiopsis theae*, *Trichoderma koningiopsis* are responsible for antifungal, antibacterial, antioxidant, cytotoxic, antimicrobial, activities, respectively (Ibrahim et al., 2018; Guo et al.,2020; Shushuai et al., 2020 ).

**Conclusion**

Endophytic fungi are the hidden companions residing inside the plant tissues. Number of researchers stipulated that metal tolerance and alleviation capability of plant endophytic fungi on contaminated soil. Endophytic fungi physiologically and mechanically interconnected with their host out turning in their proper growth, convalescent bioactive productivity and increased carbon metabolism. Endophyte-assisted bioremediation method is the revolutionary tool for removal of bio-hazardous contaminants, metals and metalloid pollutants, cancer causing agents, industrial effluents, inorganic pesticides and herbicides, hydrocarbon based elements and chlorinated products from nature. To check heavy metal pollution, bioremediation is effective as it has less adverse effect and economical for environment. Endophyte assisted bioremediative techniques are more challenging, however more achievable approach to remove metal pollution. Preceding records suggested that endophytic fungi have the potentiality to fragment metals but this process takes much time for degrading the metal pollution in natural manner.

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