**ENDOPHYTIC FUNGI: FUTURISTIC TOOL FOR BIOREMEDIATION**

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**ABSTRACT**

The global problem of heavy metal contamination of soil and water has gotten more complicated. Given that increased metal concentrations in soil and water constitute a health risk to both humans and animals, this topic has attracted a lot of public attention. The metabolism and growth of most plants were impaired by high concentrations of heavy metals, on the other hand. For the removal of heavy metals, several traditional techniques have been employed. However, these techniques have a number of drawbacks, including high costs, large energy requirements, and insufficient removal of heavy metals. Bioremediation based on microorganisms is the most effective and promising method for treating heavy metals. Different microorganisms have the capacity to lessen the stress caused by heavy metals on plants. Despite their limited research to far, endophytic fungi are an effective source for shielding plants from the toxicity of heavy metals. All higher plants have endophytic fungi that live in their internal tissues asymptomatically without having any negative consequences on the ecology of their host. Endophytic fungus provide their host plant with advantages such as improved plant development, tolerance to cold, heat, salt, and temperature, and generation of significant and valuable pharmacological, medicinal, and therapeutical substances. Endophytes increase the effectiveness of bioremediation by lowering the toxicity of plants to heavy metals.

Keywords: Bioremediation, Heavy metals, Endophytic fungi.

**1.1 INTRODUCTION**

There has been a significant concentration of heavy metals that pose a serious threat to flora and wildlife with the rapid growth of industrialisation and urbanisation. This is essential for preserving the purity of healthy soil and keeping it free from contaminants. Numerous strategies that are simple to implement, long-lasting, and practical from an economic standpoint have been devised. Different physiochemical techniques have been employed in the past to remediate soil that has been contaminated with heavy metals. However, they have significant drawbacks, such as the inability to remediate soil on a broad scale due to the higher expense and the variety of negative effects brought on by exposure to heavy metals. Microbe-based remediation has demonstrated successful outcomes as a low-cost and environmentally benign method to address these issues. Microbe-based remediation, a low-cost and environmentally benign method for removing toxicants from polluted soils, has shown efficient in resolving these issues (Aishwarya S et al., 2014). It has been discovered that using microorganisms to remove heavy metals from soil is both economical and environmentally safe. Rhizospheric bacteria enhance soil stability and health, enabling plants to grow and develop continuously despite adverse situations. Algae, fungi, and bacteria are used in microbe-based bioremediation (Hassan et al., 2017).

**1.2 Heavy Metals**

The environment has gotten worse as a result of the expansion of numerous human activities in recent years, which has led to an increase in both type and content of significant heavy metals in the soil. According to Su et al. (2014), the main heavy metals that are harmful in soil are mercury (Hg), cadmium (Cd), lead (Pb), chromium (Cr), and arsenic (As), as well as zinc (Zn), copper (Cu), nickel (Ni), stannum (Sn), and vanadium (V). It is crucial to comprehend that this can impose significant health risks and can be transmitted through the food chain because it may have major repercussions. It is challenging to remediate heavy metal pollution after it has occurred in the soil.

**1.2.1. Heavy metal uptake by plants**

Water, food, and air are the main sources of heavy metal recruitment in plants and animals. They bind to particular cellular compartments as soon as they enter, damaging a variety of biological processes. The loss of the enzyme's catalytic activity results from the "new" metal-enzyme complex, which can sometimes connect to the sulfhydryl groups of many enzymes to limit the rate of metabolic reactions. Heavy metal toxicity is dependent on a number of variables, including exposure duration, concentration, and the health of the exposed flora and fauna. The process of bioaccumulation is when the concentration of harmful compounds in living things rises as the trophic level does. to the process known as bioaccumulation, the concentration of harmful compounds in living things rises as the trophic level does. The higher the trophic level, the higher the concentration of heavy metals. According to Aprile and Bellis (2020), biomagnification is also defined as the gradual rise in a pollutant's concentration within a biological organism. Consequently, there has been a growing understanding that this sector need additional focus.



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



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

Since heavy metals are used in many different industries around the world, they pose a severe hazard to every nation (Yang and Sun, 2009). The environment is gradually harmed by heavy metal contamination, which has a long latency and the distinct quality of being colourless and odourless. According to Long, Yang, and Ni (2002), the amount of heavy metals in soil can range from fewer than one to as much as 100,000 mg/kg. However, when its concentration exceeds the environmental tolerance or when the environmental conditions have altered, heavy metals in the soil become activated. Wood (1974) first made the observation that heavy metal pollution behaves like chemical Time Bombs (CTBs). Self-purification methods such as dilution are ineffective for removing heavy metals. As in the case of air and water pollution, dilution and self-purification techniques are not suitable for the removal of heavy metals. Some polluted soil requires one or two hundred years to be remedied since the ex situ removal of heavy metals from soil is a laborious process (Wood, 1974). Several different heavy metals have been implicated as the cause of soil contamination occurrences in the past and present. The pollution brought on by many heavy metals will always be amplified by the contamination brought on by the heavy metals independently. According to research by Yong Shang et al. (2008), Cu+ Pb > Pb > Cu has the greatest impact on soil respiration.

**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.

Both manmade and natural factors can contribute to soil-borne heavy metals. Heavy metals have more density than water. Low levels of heavy metals are typically present in the soil due to natural cycling in the earth's crust. The composition of the Earth's crust determines the concentration of heavy metals in soil in areas that are not contaminated. Low amounts of most heavy metals are ideal because they are essential to life as we know it. Anthropogenic activities are the main reason that the concentration of heavy metals has risen over the normal level. Their broad distribution in the environment as a result of their numerous residential, industrial, agricultural, and technical uses has caused concern due to their potential effects on human health and the environment. Among heavy metals, As, Cd, Cr, Pb, Hg, Ni, Zn, and Cu are the most prevalent. They enter the food chain since they are not biodegradable in nature. Excessive exposure to heavy metals in living things has various negative effects, including death. Inhalation, ingestion, direct contact, and indirect contact are the ways that heavy metals enter humans (Smiljani et al., 2019). There are numerous ways that heavy metals can get into the soil. Both manmade activities and natural processes can result in the contamination of heavy metals (Alloway, 2013).

**1.2.3.1 Natural activities**

Heavy metals, which are classified as trace and infrequently dangerous, are added to unpolluted places via weathering of rocks, lithospheres, and pedogenic processes (Alloway, 2013; Yannagi, 2011). Over 99% of the crust's total composition is made up of the ten elements O, Si, Al, Fe, Ca, Na, K, Mg, Ti, and P. The remaining elements are referred to as "trace elements" and have concentrations of no more than 1,000 mg/kg (0,1%) (Yanagi, 2011; Hawkeswarth & Kemp, 2006; Wuana & Okieimen, 2011). Metal traces are present in all soils by nature. Therefore, the presence of metals in soil does not necessarily indicate pollution.

**1.2.3.2 Anthropogenic sources**

Human activities are the main cause of excess heavy metals in soil. The buildup of heavy metals and metalloids is caused by wastewater from industrial areas, mine dumps, sanitary landfills, the disposal of high metal wastes, agricultural wastes, the use of fertilisers and animal manures, sewage sludge, pesticides, wastewater irrigation, residues from coal combustion, runoff from terrestrial systems, industrial and domestic effluents, spillage of petrochemicals, accidental leaks, and atmospheric deposition. Compared to pedogenic or lithogenic heavy metals, those found in soil from anthropogenic sources are typically more flexible and bioavailable (Alloway, 2013, Wuana & Okieimen, 2011; He et al., 2015). Organic pollutants provide a long-term hazard to the environment, human health, soil/water deterioration, and ecological dysfunction since they are easily biodegradable rather than weighty. In addition, heavy metals get into food chains and the spread of numerous diseases result from contaminated land, water, and air, endangering both 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. |
| 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. |

Microorganisms typically have the biochemical and ecological ability to reduce the danger associated with metals, metalloids, and radionuclides either by chemical alteration or by affecting chemical bioavailability. However, plant-associated endophytes can circumvent these limitations, allowing plants to accumulate greater amounts of metals without suffering any harmful effects.

**1.3 Bioremediation**

Biological methods are economical and environmentally responsible for the expulsion of harmful contaminants (Doble and Kumar, 2005). Bioremediation, phytoremediation, bioventing, bioleaching, bioaugmentation, and biostimulation are a few examples of biological processes employed. The most effective of these methods are bioremediation and phytoremediation. In contrast to physiochemical procedures, these strategies also maintain the soil's physical status, as Beskoski et al. (2011) have shown. A biological technique for heavy metal cleanup is called bioremediation (Boopathy 2000). Global worry surrounds the discharge of heavy metals, pesticides, and phenolic waste into the environment as a result of human or natural practices. The use of microbial-based remediation is appropriate due to its low cost and simplified procedure. Using microbial metabolism, the removal of heavy metal contaminants from the environment is known as bioremediation. a number of methods and processes. Hazardous waste can be mostly removed from the biosphere via a variety of bioremediation techniques and processes, such as phytoremediation improved by endophytic microbes and rhizoremediation. The mobility, solubility, degradability, and bioavailability of pollutants all affect how bioremediation works. Additionally, these elements have a significant impact on deterioration. As a result, understanding the mechanisms of efficient bioremediation depends on the detection of natural microbial processes (Stpniewska & Kuniar, 2013).

Physiochemical and traditional treatments such as soil burning, landfilling, excavation, soil washing, leaching, solidification, and soil flushing have already been utilised for remedial objectives (Wuana and Okieimen 2011). These methods, however, have a detrimental effect on the chemical and physical makeup of soil. These approaches have some limitations, including the fact that they are expensive, require more labour, harm soil-dwelling microorganisms, and result in a number of pollution-related issues. However, the physical and chemical composition of the soil is adversely impacted by these methods. These heavy metals have the ability to change from one form to another, as opposed to completely degrading. Therefore, there is a need for cutting-edge techniques that are both economical and environmentally benign (Lambert et al., 2000; Ali et al., 2013). Therefore, there must be a demand for modern heavy metal cleaning technology that is both economical and environmentally friendly. For instance, *Pseudomonas aeruginosa* and *Bacillus* spp. have been employed to reduce Zn and Cu stress (Kumar et al. 2011). The potential of microorganisms to bioaccumulate heavy metals has consequently increased the importance of plant-organism partnerships (Hadi and Bano, 2010).

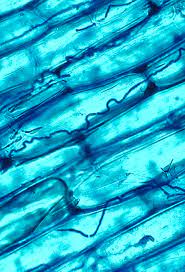
**1.3.1 Why Endophytic fungi?**

Endo- indicates inside, and phyte- means plants in the word endophyte. De Bary first used the term "endophyte" in 1866. The fact that each of the over 300,000 plant species on Earth is thought to have at least one form of endophyte contributes to the planet's immense biodiversity (Strobel and Daisy, 2003). The fact that so few plant-associated endophytic fungi have been examined suggests that there is a significant potential for discovering intriguing endophytes among the numerous plants in various niches and habitats. According to Petrini (1991), they are all organisms that may colonise tissues while exhibiting no macroscopic signs. Both specific plant tissues and the root cortex or xylem contain these bacteria. Additionally, they systematically take over the plant by the vascular or apoplast system (Stępniewska & Kuźniar, 2013).

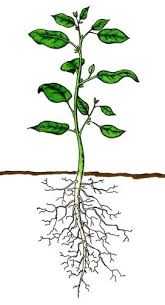
**1.3.2 Colonization of plants by endophytic fungi**

The interaction between plants and the soil's microcosm helps plants grow, deal with biotic and abiotic challenges, modulate their immune systems, and produce bioactives like polyketides, coumarins, isocoumarins, quinones, and anthrones, among other things. Several data indicate that endophytic fungi can support their host plants' defence mechanisms. The utilisation of endophytic fungi as biocontrol agents, which are capable of producing important bioactive compounds, is currently the focus of increasing research. Endophytic fungi are mitosporic and meiosporic microorganisms that are "quiescent infections" that exist asymptomatically within the healthy plant tissues beneath the epidermal cell layers. It's also beneficial for plants when endophytic fungus colonise them. Plant responses to endophytic fungal colonisation are also advantageous to the plant's immune system. Plants have evolved a variety of advantageous defence mechanisms against the invasion of endophytic fungus over the course of long-term evolution. According to Yan et al. (2019), endophytic fungi's interactions with plants modify how plants respond to biotic and abiotic stressors.

When endophytic fungi interact with plants, they produce signals after sensing plant stimuli, which then cause the plants' immune systems to become active. Plants typically have a two-branch innate immune system that aids in cell communication and allows them to recognise signals from endophytes. Two distinct pathways are activated as a result of this primary signalling: one leads to MAMP-triggered immunity (MTI), where plants recognise the molecules produced by microorganisms (referred to as effectors) via intracellular receptors; the other leads to effector-triggered immunity (ETI), where plants recognise the molecules produced by microorganisms (referred to as MAMPs) via cell surface-localized pattern recognition receptors (PRRs).



**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**

For fungi and bacteria to operate as decomposers of varied dead materials, our nature is a vast ecological niche. Endophytic fungi have developed a high level of metabolic adaptability in recent years, which leads to the release of numerous enzymes that degrade hydrocarbons. Endophyte-based bioremediation has been described as a viable method for in-situ remediation of contaminated soils since several endophytic fungi have been discovered to be resistant to heavy metals and/or capable of decomposing organic contaminants. In cases of bacterial malfunction, where bacterial cells are unable to generate the mycelia network necessary to respond with pollutants, the use of filamentous fungi can be a promising strategy or an important complement (Aishwarya S et al., 2014).

Endophytes have emerged as a possible resource to address these issues since they have a variety of mechanisms that can degrade chemical contaminants, break down complex chemicals, and cause heavy metal biosorption (Xiao et al. 2010; Russell et al. 2011; Li et al. 2012c). Different endophytic fungi can degrade both small and big organic substances through enzymatic processes, break down environmental pollutants, and enhance the soil microenvironment (Krishnamurthy & Naik, 2017). According to H-Y Li et al. (2012), they improve host plants' capacity to remove pollutants from soil, water, sediment, and the air. Endophytic fungi alter the morphology and physiological processes of the host plant, which in turn gives the plant resistance to metal pollution. This may be due to high surface to volume ratio. According to Barkey, Miller Summer (2003) and Kim et al. (2015), this may be caused by a high surface to volume ratio, extracellular scavenging, and intracellular precipitation. The existence of different tactics of resistance mechanisms displayed by the fungi may account for the variation in metal tolerance (Iram et al. 2013). Chitin and cellulose, two polysaccharides that are typically found in fungi, contain functional groups like amino, carboxyl, hydroxyl, and sulphate that are highly capable of binding to metals and are thought to have a significant potential for doing so (Davis et al. 2003).

Endophytic fungi have the biochemical and ecological potential to reduce the risk posed by metals, metalloids, and radionuclides through chemical modification or by affecting chemical bioavailability. Fungi are also well suited for bioremediation procedures because they can form long mycelial networks. When bacteria fail to develop the mycelia network necessary to respond with pollutants due to malfunction, the use of filamentous fungi can be a promising solution or an important augmentation. The approach is particularly helpful in situations where unicellular organisms cannot physically access toxins or where pollution is too severe to support bacterial survival (Singh, Verma, & Gaur, 2013). In contrast to bacteria, the majority of endophytic fungus have a filamentous growth habit, which allows them to engage in either exploratory or to prevent fungal translocation, exploitative growth methods and linear organs of aggregated hyphae are formed (Deng & Cao, 2017). According to several research studies (Monnet et al. 2001; Sun et al. 2010; Zhang et al. 2010), certain endophytes may encourage host plant growth in HM-contaminated soils. However, according to Zhang et al. (2008), Guo et al. (2010), and Xiao et al. (2010), there is essentially no knowledge about the variability of endophytic fungi in Pb Zn polluted habitats.

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* 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 al. 2014).

According to Choo et al. (2015), endophytic fungi from Sarawakian wetlands can thrive in environments with high levels of heavy metals (up to 1000 ppm). This is the first report on Pestalotiopsis's tolerance to a group of heavy metals (Cu, Cr, Zn, and Pb), and it has a high chance of being used to screen possible biosorbents. A cheap, environmentally responsible, and efficient way to remove toxicants from polluted soils has been suggested: phytoremediation. However, there are still some significant drawbacks in phytoremediation of heavy metals, such as phytotoxicity, a slower technique than mechanical, and a constrained mechanical uptake. However, plant-associated endophytes can get around these restrictions, allowing plants to accumulate more metals without experiencing an increase in phytotoxicity.

Endophytic fungi exhibit a noticeable resistance to heavy metals under persistent metal stress and long-term exposure, according to H.-Y. Li et al. (2011). A majority of the endophytic fungal isolates tested were lead and zinc resistant. However, these growth-stimulating endophytic fungus can also utilise the heavy metal as micronutrients. In order to facilitate phytoremediation in soils contaminated with heavy metals, it may be advantageous to inoculate these stress-adapted fungus into plants (Dodd & Thompson 1994; Zhang et al. 2008).

Endophytic fungus can be used for phytoremediation or bioremediation at contaminated locations (Li et al., 2010). Endophytic fungi were more commonly colonised in areas that were contaminated with lead and zinc. The most prevalent endophytic fungus in the Pb-Zn polluted area were *Phoma*, *Alternaria*, and *Peyronellaea.* Pb2+ and/or Zn2+ tolerance has risen in them. In endophytic fungi isolated from the marine environment, Yang et al. (2012) discussed the screening for possible biosorbents and reported encouraging results.

When compared to the bacterium *Pantoea* sp., *Pestalotiopsis* sp. shown stronger copper resistance capability; nonetheless, the resistance level of bacteria to copper was only 200 ppm (Ozdemir et al., 2014). Congeevaram et al. (2007) accounted for the greater heavy metal tolerance of fungi to chromium (up to 10,000 ppm). Lead concentrations up to 7000 ppm were successfully resisted by *Aspergillus niger* strains (Faryal et al., 2007). Both investigations isolated fungi from habitats contaminated with heavy metals, indicating that environmental pressures on microorganisms play a significant influence in the fungi's ability to resist heavy metals and adapt in order to survive. Choo et al. (2014) isolated endophytic fungi that can withstand high doses of heavy metals. The ability of *Pestalotiopsis* sp. to tolerate a group of heavy metals, including Cu, Cr, Zn, and Pb, was demonstrated. Understanding the mechanisms that allow endophytic fungi to flourish in environments with heavy metal concentrations of up to 1000 ppm will require more research.

*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 that is commonly used in manufacturing high-resilience foam seating, rigid foam insulation panels, microcellular foam seals and gaskets, spray foam, and durable elastomeric wheels and tyres; however, research has shown that PUR is biodegradable (Darby & Kalpan, 1968; Howard, 2002). A polyisocyanate and a polyol are condensed to create the polymer. As a result, a carbon polymer made up of many urethane connections is produced. The characteristics of the resultant polymer can differ from linear and rigid to branching and flexible depending on the type of the substitutions and variations in the distance between urethane links. Under liquid suspension, PUR is entirely opaque and milky white in appearance. This substance is synthesised commercially for the production of, like other polyurethanes, this product is synthesized commercially for the manufacture of textiles and textile coatings (Russel et al., 2011).

Both bacteria and fungi can degrade PUR because of the enzymes they produce (Cosgrove et al., 2007; Crabe et al., 1994; Pathirana & Seal, 1984; Rowe & Howard, 2002). The majority of the species tested for PUR degrading activity are soil fungus. With access to a variety of nutritional sources, fungi from the genera *Alternaria*, *Aspergillus*, *Phoma*, *Penicillium*, *Plectosphaerella*, *Geomyces*, *Nectria*, and *Neonectria* were isolated from buried PUR samples. The most often isolated PUR-degrading organism was *Geomyces pannorum* (Cosgrove et al., 2007). Only a few number of species have been found to breakdown PUR as the only carbon source. Although Aspergillus niger has been seen to degrade, it was found to be rather slowly, with noticeable indications appearing after just 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).

Endophytic fungi can move within plants via two different mechanisms: vertical gene transfer and horizontal gene transfer. The propensity for horizontal gene transfer may indicate a high degree of phenotypic variety within the genus or it may be a factor in the ability of some endophytic fungi to breakdown polyester polyurethane as the only carbon substrate. In *Pestalotiopsis microspora*, horizontal gene transfer occurs often. According to Ahmed, Ansari, and Aqil (2006), *Aspergillus niger* and *Pencillium* sp. exhibit remarkable bioadsorption capacities for Cr, Ni, and Cd from single and multi-metal solutions. This has emphasised the potential for using filamentous fungi from metal-polluted habitat. When grown in vitro, the endophytic fungus *Microsphaeropsis* sp. from the cadmium hyperaccumulator *Solanum nigrum* L. produces a large amount of biomass. According to research by Xiao et al. (2010), endophytic fungi LSE10 can be used as a biosorbent for the detoxification of cadmium. According to (Chandrakar et al., 2014), the fungal population that was taken from heavy metal-contaminated locations is able to withstand greater metal concentrations. Also demonstrating a comparative amount of metal resistance were filamentous fungi that originated from unpolluted areas. The test fungus determined the isolates' tolerance and resistance considerably more so than the isolation site. The fungi's tolerance and adaption to heavy metals may be the cause of this variance. Due to their high metal resistance to all examined metals, *Aspergillus* sp. and *Fusarium* sp. are intriguing candidates for additional research into their capacity to eliminate metals.

According to Mukherje et al. (2014), *Aspergillus flavus* (ASC1) and *Aspergillus niger* (ASB3) are capable of removing 50%-76% of arsenic from various arsenic-enriched mediums while also being tolerant to several other heavy metals (Cd, Pb, Hg, Zn, and Cr). These two fungi strains will be useful for planning the cleanup of arsenic from areas that have been contaminated with it in the near future. Endophytic fungus *Lasiodiplodia* sp. MXSF31, isolated from metal-accumulating *Portulaca oleracea*, shown resistance to Cd, Pb, and Zn, according to Deng et al. (2014). The endophytic fungus demonstrated strong Cd, Pb, and Zn biosorption and bioaccumulation capacities from the metal-contaminated solutions and improved the efficiency of rapeseed in metal extraction from soils polluted by various metals. A valuable source of microorganisms for bioremediation of water and soil affected by numerous heavy metals should be fungus from plants accumulating multiple metals. From hyperaccumulating plants such *Alyssum bertoloni*, *Alnus firma*, *Brassica napus*, *Nicotiana tabacum*, *Thlapsi caerulescens*, *T. goesingense*, and *Solanum nigrum*, numerous metal-resistant endophytes have been discovered. However, numerous metal-resistant endophytes have also been found in plants that do not hyperaccumulate metals, including *Symplocos paniculata*, *Acacia decurrens*, and *Arabis hirusta* (Li et al., 2012). *Microspaeropsis*, *Mucor*, *Phoma*, *Alternaria*, *Peyronellaea,* *Steganosporium*, and *Aspergillus* are the metal-resistant endophytic fungus.

**1.4 Other Applications Exhibited By Endophytic Fungi**

**1.4.1 Endophytic fungi in agriculture**

Finding more interest in environmentally friendly alternatives to artificial fertilisers and pesticides is due to the numerous negative health impacts associated with their use. There have been reports of fungal endophytes producing beneficial substances including phytohormones, antimicrobials, and other agrochemical bioactive metabolites. Since it is known that endophytic and rhizosphere fungi help the host plant withstand a variety of biotic and abiotic challenges (nutrient depletion, droughts, etc.), they continue to be important natural resource reservoirs. The peripheral tissues of the plant, however, provide a chemically intricate microcosm that supports a wide array of microbes. The ability of *Epicoccum nigrum* to biocontrol bacterial and fungal plant diseases is also well documented (Lugtenberg et al. 2016).

According to Berardo et al. (2018), *E. nigrum* demonstrated biocontrol action against the bacterial pathogen *Pseudomonas savastanoi* pv. savastanoi (Psv), which causes olive knots, and significantly decreased psv growth and biomass. *Theobroma cacao* tissues included the endophyte *Colletotrichum gloeosporioides*, which exhibited antagonistic action towards the pathogen that causes black pod rot. In field and in vitro research, *Phytophthora palmivora* (which produces black pod rot), *Moniliophthora roreri* (which causes frosty pod rot), and M. perniciosa (which causes witches broom) have all been identified as the culprits. According to Park et al. (2019), *Trichoderma* sp. has been utilised as a BCA against plant pathogenic fungi like *Botrytis cinerea*, *Fusarium* spp., *Pythium* spp., and *Rhizoctonia* spp. When overgrown on pathogenic mycelium, the endophytic fungus *T. viride* display antagonistic activity (Talapatra et al., 2017). Agriculture needs endophytic fungi because they can improve plant nutrition by solubilizing phosphorus, potassium, and zinc and by producing phytohormones like Indole acetic acids, gibberellic acids, and cytokinin as well as Fe-chelating compounds, hydrolytic enzymes, hydrogen cyanide, and ammonia, endophytic fungi are crucial to agriculture. (Yadav & Yadav, 2018; Suman et al., 2016; Verma et al., 2017; Saxena et al., 2016). Numerous endophytic fungal species from various genera, such as *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.**

Alkaloids, different amides, and other nitrogen-containing chemicals are just a few of the active secondary metabolites that fungi endophytes are capable of producing (Rustamova et al., 2020). The secondary metabolites generated by endophytic fungi are diverse. Periconicin A and B, Petacin, Phomol, Mullein, Brefeldin A, Uridine, and Cerebrocoide, produced by Periconia sp., Penicillium microspore, Phomopsis sp., Aspergillus clavatus, Phomopsis sp., and Fusarium sp., respectively, are antibacterial compounds (Guo et al., 2000; Kim et al. The endophytic fungus *Pleospora tarda* produces the compounds alternariol and alternariol-(9)-methyl ether, which have been found to have the strongest antiviral effects (Selim et al., 2018). Brefeldin A has antifungal, antiviral, anticancerous, and protein-transport inhibitory properties (Zabala et al. 2014) has been isolated from several fungal species including Curvularia, Alternaria, Phyllosticta, Penicillium, and Cercospora (Wang et al., 2002). The tubulin polymerase inhibitor and powerful antimitotic podophyllotoxin from *Podophyllum emodi* is used topically to treat genital warts. However, several of its semi-synthetic derivatives, such as the topoisomerase II inhibitors etoposide, teniposide, and etoposide phosphate, are efficient anticancer medications (Stahelin & Wartburg, 1991; Baldwin & Osherhoff, 2005). The endophytic *Aspergillus versicolor*, which was isolated from the leaves of the Egyptian water hyacinth *Eichhornia crassipes*, produced aflaquinolone, a secondary metabolite and a derivative of dihydroquinolone. According to Ebada et al. (2018), aflaquinolone has superior antiproliferative properties. The antifungal, antibacterial, antioxidant, cytotoxic, and antimicrobial effects are caused by fusarithioamide, pestalotiones, koninginol B from *Fusarium chlamydiosporium*, *Petalotiopsis theae*, and *Trichoderma koningiopsis,* respectively (Ibrahim et al., 2018; Guo et al., 2020; Shushuai et al., 2020).

**Conclusion**

The hidden companions living inside the plant tissues are called endophytic fungi. Many researches agreed that plant endophytic fungi on contaminated soil had the potential to tolerate metals and alleviate their effects. Endophytic fungi benefit from their host by outgrowing it in terms of correct growth, recovering bioactive productivity, and accelerated carbon metabolism. Bio-hazardous contaminants, metals and metalloid pollutants, agents that cause cancer, industrial effluents, inorganic pesticides and herbicides, hydrocarbon-based components, and chlorinated products can all be removed from the environment utilising the innovative endophyte-assisted bioremediation technology. Bioremediation is successful at reducing heavy metal pollution because it is environmentally friendly and has fewer negative effects. The removal of metal pollution using endophyte-assisted bioremediative approaches is more difficult but also more feasible. Previous studies suggested that endophytic fungi may have the capacity to fragment metals but this process takes much time for degrading the metal pollution in natural manner.

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