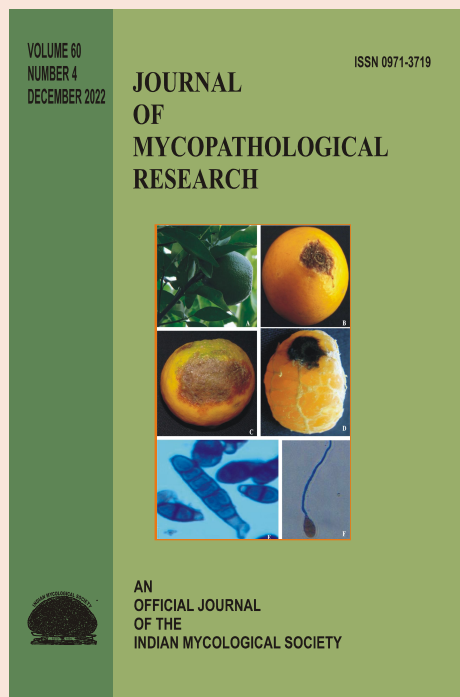


## REVIEW

# An exploration of unseen fungal world and analysis of their functional attributes in crop and human health

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## REVIEW

# An exploration of unseen fungal world and analysis of their functional attributes in crop and human health

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Fungal endophytes are a group of microbial entities that live in either apoplast or symplast region of healthy plant tissues without causing any detectable symptoms of disease to the concerned host. Since they derive nutrients and shelter from their host hence, in turn, provide protection to their host against various biotic and abiotic stresses. Because of country's diverse and distinctive plants diversity, coordinated efforts at front of endophytic diversity research and exploitation are required in light of their vast applicability in plant and human health and the environment. This article focuses on endophytic biodiversity, their role to protect plants against abiotic environmental stresses with special reference to drought, heat and dyes degradation. It will also cover the epigenetic modulations for cryptic bioactive compounds; endophytes mediated fabrication of metal nanoparticles (NPs), and mycomediated synthesis of carbon nano dots (CNDs) and their utilization in plant health promotion.

**Key words:** Carbon nano dots, dye degradation, epigenetic modulation, fungal endophytes, nanoparticles synthesis, stresses

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## INTRODUCTION

Endophytes are microorganisms that live for all or part of their life cycle within healthy plant tissues without creating any obvious indications of their presence. Endophytic microorganisms assist plants in variety of ways, they boost development and give a greater resistance to disease by generating antibiotics. Under stressful conditions, endophytes also generate uncommon secondary metabolites of plant value, as well as some lucrative pharmacological compounds of biotechnological interest. Endophytes are a diverse group of microbial adaptations that evolved in unique and secluded environments and their diversity and particular habits make them an attractive subject of research for novel metabolites (Bacon and White 2000, Tan and Zou 2001). Because of country's diverse and distinctive plants diversity, coordinated

efforts at front of endophytic diversity research and exploitation are required in light of their vast applicability in plant and human health and the environment (Nair and Padmavathy 2014). The vast diversity of fungi that associated with plants do not harm their hosts, but rather drive growth and disease resistance, as well as tolerance to harmful environmental effects. Plant-endophyte interactions boost plant health and have a significant role in low-input, high-productivity and sustainable agriculture (Mapelli *et al.* 2013, Aroca *et al.* 2013, Veneklaas *et al.* 2012, Li *et al.* 2012). Endophytes could be isolated from any plant investigated in the last many decades (Strobel and Daisy, 2003, Hardoim *et al.* 2015, Giauque *et al.* 2019). Many characteristics of endophytes, such as their widespread distribution, long-term presence in plants, non-pathogenic nature, ability to improve the biotic and abiotic stress tolerance of their plant hosts (Rodriguez *et al.* 2009), increase an access to soil nutrients, and increase plant yield (White *et al.* 2019), and these attributes project them as candidate with high promise for use in crop. Despite this, few of the endophytes's advantages have been converted in to practical agricultural applications.

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This review examines the potential barriers that could obstruct the use of endophytes in agricultural applications. It also aimed to highlight the endophytic fungal variety and their novel bioactive compounds in relation to plant and human health. It focuses on fungal endophytes mediated enhancement of abiotic stress tolerance of plants, dye decolorization and degradation. This review also discusses the epigenetic modulation for isolating cryptic metabolites, nanoparticles (NPs) synthesis and fungal endophyte's generated carbon nanodots (CNDs) potential in food adulterants detection and plant growth.

### **Diversity of fungal endophytes and their bioactive compounds**

Goveas *et al.* (2011) investigated the endophytic fungus of *Coscinium fenestratum*, a red listed, critically endangered medicinal plant. Using traditional methods, and identified 41 endophytic fungi belonging to sixteen different species isolated from 195 samples of healthy leaves and stems. The overall colonization rate of endophytic fungi was determined to be 21.02% in both the leaf and the stem. Leaf segments have more frequency of colonization than the stem. *Phomopsis jacquiniana* was determined to be the most common endophytic flora, with a colonization frequency of 4.6%. Fifty-three endophytes were identified from *Dendrobium devonianum* and *Dendrobium thyrsiflorum*'s stem and root, which had a significant impact on their hosts (Xing *et al.* 2011). *Fusarium* sp. colonized both the species of *Dendrobium* demonstrating the host specificity. Xing *et al.* (2010), investigated the diversity of fungal endophytes colonizing *Panax quinquefolium* (American ginseng). From different age groups of *P. quinquefolium*, 134 fungi were isolated by Xing and his colleagues. The infestation rates of these fungi differed depending on the age of the host and the tissues to which they colonized. The existence of endophytic fungi was investigated in 81 Thai medicinal plant species occurring in four geographical zones (Wiyakrutta *et al.* 2004).

The endophytic fungal occurrence was studied in 610 segments of four distinct plants, including *Boswellia ovalifoliolata*, *Pterocarpus santalinus*, *Shorea thumbuggaia* and *Syzygium alternifolium*. Based on their morphological and spore characteristics, 14 fungal species including *Fusarium oxysporum*, *Colletotrichum falcatum*, *Pestalotiopsis* sp., *Aspergillus fumigatus*, *A.*

*flavipes*, *Sterile mycelia*, *Penicillium senticosum*, *Gliocladium roseum*, *Phomopsis jacquiniana*, *P. archeri*, *Nigrospora sphaerica*, *Leptosphaeria* sp. and *Alternaria alternata* were isolated and identified. Some fungal endophytes emerging out from different tissues of plant on potato dextrose agar (PDA) are presented in Fig. 1.

*Colletotrichum falcatum* was revealed to be the core-group fungus among all isolates, with a colonization frequency of 12.5%. Sterile mycelia were seen throughout the host, with only a few exceptions. In the case of stem, endophytic colonization was lower than that of the leaf segments. For the first time, endophytes were isolated from the symptomless leaves, stems, fruits and roots of four ethnomedicinal angiospermic plants: *Digitalis lanata* (woolly foxglove), *D. purpurea* (purple foxglove), *Plantago ovata* (psyllium/isabgol) and *Dioscorea bulbifera* (air potato) (Ahmed *et al.* 2012). From these plants, a total of 132 microbial endophytes isolates were obtained. Tejesvi *et al.* (2007) studied at the genetic diversity of fungal endophytes in the root, bark and twigs of four medicinal plants: *Azadirachta indica*, *Holarrhena antidysenterica*, *Terminalia arjuna* and *Terminalia chebula*. Tejeswi *et al.* (2007) divided thirty *Pestalotiopsis* and two *Bartalinia robillardoides* isolates into four groups using RAPD analysis.

In Europe and United states, the *Echinacea* genus is one of the top ten selling medicinal herbs. The ability to create defensive chemicals and the variety of the medicinal community associated with healthy *E. purpurea* clones were investigated. Thirty-nine fungal endophytes were collected and identified using molecular methods, resulting in 15 different phylotypes closely linked to species of the genera *Ceratobasidium*, *Cladosporium*, *Colletotrichum*, *Fusarium*, *Glomerella* and *Mycocleptodiscus*. At two locations in Kathmandu, Nepal one mycelia sterilia and five viable taxa (*Alternaria*, *Fusarium*, *Epicoccum*, *Phoma* and *Cladosporium*) were isolated from twigs of *Buddleja asiatica* (Chetri *et al.* 2013). *Epicoccum*, *Phoma* and *Cladosporium* have all been discovered to be site-specific. The frequency of colonization, isolation and fungal diversity were all higher in site II than in site I. Novel endophytic fungus can be found in abundance in traditional medicinal plants. Out of 1160 endophytic fungi isolated from 29 chinese medicinal herbs, several species of

*Colletotrichum*, *Phoma*, *Phomopsis* genera of xylariales and sterile mycelia were the most common isolates (Huang *et al.* 2008).

Li *et al.* (2012) identified 130 endophytic fungi from 12 Chinese traditional medicinal plants gathered from Yuamou County and Dawei Mountain in Yunnan province, southwest China, some of which were found to be prospective sources of novel bioactive chemicals. As an endophyte, the fungus *Bartalinia robillardoides* (strain AMB-9) was isolated from the medicinal plant *Aegle marmelos*. A total of 292 morphologically diverse endophytic fungi were isolated from 29 traditional Chinese medicinal plants, demonstrating the enormous diversity of fungal endophytes of Chinese traditional medicinal plants (Huang *et al.* 2007). For optimal survival in nature, microbial populations and their host plants must work together. Fungal endophytes of *Schedonorus phoenix* (syn. *Lolium arundinaceum*), particularly *Neotyphodium coenophialum*, have been shown to inhibit arbuscular mycorrhizal (AM) fungi colonization of other plants by creating various allelochemicals.

Toofanee and Dulymamode (2002) studied the diversity and frequency of endophytic fungus associated with young and old leaves of fungal endophytes of the indigenous plant *Cordemoya integrifolia* found both inside and outside the Maccabhe Conservation Management Area (CMA). All 26 fertile fungal taxa and one sterile morphospecies were dominated by *Pestalotiopsis* sp. and *Penicillium* sp. Endophytes colonized older leaves, veins of leaves and petioles more than younger leaves and inter vein tissues. As a result, variations in endophytic communities isolated from various tissues and tissues of varying ages were discovered. Five endophytic fungi were isolated from the roots of *Capsicum annum*, *Cucumis sativus* and *Glycine max* and tested on dwarf mutant (Waito C) and normal rice (Dongjin-byeo) rice (Khan *et al.* 2012). Garcia *et al.* (2012) investigated the diversity of endophytic fungi found in *S. saponaria* L. leaves. This plant's bark roots and fruits have been employed in tonics, blood purifiers and cough remedies for centuries. Using light and scanning electron microscopy, they observed the colonization of host plants by endophytic fungus. It was discovered and identified *Cochliobolus*, *Alternaria*, *Curvularia*, *Phomopsis*, *Diaporthe* and *Phoma* species. In southern Thailand, 376 endophytic fungi were discovered

from the leaves and branches of five different *Garcinia* species: *Garcinia atroviridis*, *Garcinia dulcis*, *Garcinia mangostana*, *Garcinia nigrolineata* and *Garcinia scortechinii* (Phongpaichit *et al.* 2006).

*Withania somnifera* is an endophyte-rich medicinal plant. Khan *et al.* assessed the diversity of endophytic fungi in *W. somnifera* as well as their potential for producing new chemicals of therapeutic value. Thirty-three fungal strains from 24 species were isolated from a total of 643 segments (202 leaf, 391 stem, and 50 root samples) from 20 different plants, four of the fungal strains belonged to the Ascomycetes and 20 to the Deuteromycetes. *Aspergillus niger*, *Aspergillus terreus* and *Aspergillus alternata*, which showed organ specificity. Four plants and human health benefits of fungal endophytes 67 during the winter and summer seasons in Kerala, 210 segments of *Rauwolfia serpentina* were isolated from 10 different species, including *Aspergillus brevipes*, *Aspergillus* spp., *Aureobasidium* spp., *Curvularia lunata*, *Fusarium moniliforme*, *Colletotrichum acutatum*, *Colletotrichum gloeosporioides*, *Phyllosticta hyman* (Meenatchi *et al.* 2016).

Hyphomycetes was determined to be most common. The greatest diversity of endophytic fungus was discovered in leaf, followed by bark and stem. Endophytic colonization frequency and diversity were found to be higher in the winter than in the summer. A total of four genera of endophytic fungi were isolated and identified from the roots, stems, leaves and fruit of the medicinal plant *Brucea javanica* (Amin *et al.* 2015). *Trichoderma* sp. was found in the plant's roots and stems, whereas *Fusarium* sp. and *Penicillium* sp. in the fruits and *Aspergillus* sp. only to leaves. The ecological diversity of endophytes was highlighted by the existence of endophytic fungus isolated from the holoparasite plant *Balanophora japonica* (Balanophoraceae) collected from Kochi and Shikoku in western Japan (Ikeda *et al.* 2016). *Trichoderma-Hypocrea*, *Penicillium* and *Phialemonium* were the dominating endophytes in a total 23 fungal strains from inflorescence and tubers of three *B. japonica* plants growing on the host plant *Symplocos lancifolia* (Symplocaceae).

A total of 5089 endophytic fungal isolates were recovered from leaf, bark and stem of *Tectona grandis* Linn. f., collected from four geographical locations in winter, summer and monsoon seasons.

Based on morpho-taxonomic characters they were assigned to 45 distinct morphotypes. The sequences of the internal transcribed spacers (ITS) of the nrDNA of some morphotypes were identical, but morphological differences were strong enough to consider these morphotypes as separate species. Forty-three morphotypes were assigned to ascomycotina and two to basidiomycotina. Ascomycotina was the predominating group with 99.7% of total isolates followed by basidiomycotina with only 0.3% of total isolates. *Diaporthe* (*Phomopsis*) species dominated the communities independently on tissue type, location or season. More than 60% of the examined tissue pieces were colonized by members of this species complex. While these endophytes are ubiquitous others were tissue or location specific. Tissue type had the strongest effect on the species evenness of the endophytic assemblage followed by geographical location and season. However, Shannon-Wiener index ( $H'$ ) significantly ( $p < 0.001$ ) varied with all three factors i.e. season, location and tissue type. Leaves supported the highest diversity across all the seasons and locations. In conclusion, all the three factors together determined the structure of endophytic mycobiota assemblage of *T. grandis* (Singh *et al.* 2017). In my lab *Syzygium cumini*, *Azadirachta indica*, *Aegle marmelos*, *Eucalyptus citriodora*, *Nyctanthes arbor-tristis*, *Tinospora cordifolia*, *Madhuca indica*, *Adenocalymma alliaceum* and *Tectona grandis* were investigated for their fungal endophytes structural and chemical diversity. Hyphomycetes members secured first rank followed by coelomycetes, sterile genera and least to ascomycetes (Fig. 2). The good percentage of sterile mycelia may be the indication of novel species existence as they are not producing the identifiable spores.

### **Natural bioactive compounds from fungal endophytes**

Endophytic microorganisms have been discovered to release certain bioactive compounds without inflicting any visible damage to their host tissues (Ancheeva *et al.* 2020). Endophytic researches were mainly confined up to diversity, ecology, modes of infestation until the discovery taxol, an anticancer drug isolated from *Taxomyces andreanae*, a fungal endophyte of *Taxus wallichiana*. This discovery augmented the fungal endophyte's research especially addressing the

chemical diversity across the globe (Verma *et al.* 2009). Various endophytic microbes have been discovered to generate or exude bioactive compounds that help plants in resisting the infection. Kharwar *et al.* (2009) reported the production of javanicin, an antibacterial naphthaquinone from *Chloridium*, an endophyte of neem. In the field of pharmaceuticals and bioactive chemicals are used as antibacterial, anticancer, antidiabetic and antiviral agents (Rustamova *et al.* 2020). Antibacterial activities of some fungal crude extract against human pathogenic bacteria presented in Fig. 3.

Other important bioactive substances secreted by endophytic microbes include phenolics, alkaloids, terpenes and terpenoids, polyketones, flavonoids, peptides, quinols, steroids and toxic compounds that act as insecticides such as azadirachtin, all of which have been successfully investigated for the use in medicine, agriculture and industry (Zinniel *et al.* 2002, Meena *et al.* 2019). Many of these bioactive chemicals exhibited antimicrobial (antifungal, antibacterial and antiviral) properties, as well as antioxidant, antineoplastic, anti-leishmanial, cytotoxicity, antiproliferative and fuel-producing properties (Wang and Dai 2011, Rustamova *et al.* 2020). Pestalocide, cryptocandin, cryptocin, pestalopyrone, ecomycins and pseudomycins are antifungal chemicals produced by fungal endophytes (Yu *et al.* 2010). It has been discovered that terpenoids, phenolics, flavonoids, sugars, alkaloids, tannins, saponin and round worm antagonistic chemicals are all native to fungal endophytic species (Bogner *et al.* 2017, Vasundhara *et al.* 2019). Fungal endophytes produce bioactive chemicals that are used in drug development to treat a variety of illnesses. A few prominent host mimetic chemicals were identified from plant-associated fungal endophytes such as paclitaxel, podophyllotoxin, vincristin, vinblastin, camptothecin, hypericin, emodin, azadirachtin and deoxypodophyllotoxin (Kaul *et al.* 2012).

The generation of bioactive chemicals can be greatly aided by the well-known fungal genera *Penicillium*, *Fusarium*, *Aspergillus*, *Sclerotium*, *Myxormia*, *Alternaria*, *Colletotrichum*, *Cladosporium*, *Diaporthe* and *Curvularia* (Chepkirui and Stadler, 2017, Toghueo, 2020). Other endophytes are also known to produce bioactive chemicals with a substantial role in disease management, in addition to the fungal genera already mentioned

(Jia *et al.* 2016). Alkaloids, steroids, flavonoids, phenolics, benzopyranones, quinines, tannins, xanthenes, terpenoids and many more bioactive chemicals originating from fungi are categorized under broad functional groupings. Some bioactive compounds from endophytic fungi and their bioactivities are presented in Table 1.

### **Role of fungal endophytes in combating abiotic stresses to plants**

Several studies have demonstrated that the presence of endophytes promote resistance to abiotic stresses. Due to the growing consequences of global climate change, new agricultural techniques are currently required to maximize the productivity of crops in high temperatures. Plants like *Adiantum capillus-veneris*, *Helianthus annuus* and *Glycine max* and *Cucumis sativus* among others have shown the potential of endophytes to give heat tolerance. Treatment with the thermophilic *Thermomyces* sp. an endophytic fungus which supports high temperatures where cloud-point extraction (CpE) mechanism reduced the harmful effects of thermal stress on cucumber plants, retaining the highest quantum efficiency of photosystem II (Fontana *et al.* 2021), the photosynthetic rate and water use effectiveness.

Additionally, when cucumber plants were exposed to heat stress, CpE treatments resulted in a notable build up of total sugars, flavonoids, saponins, soluble proteins and the activity of antioxidant enzymes. On the other hand, compared to untreated cucumber plants, plants treated with *Thermomyces* sp. showed an improvement in root length. The plant can more effectively penetrate and take soil moisture and nutrients in water-scarce conditions because to this phenological response, which is a crucial adaptation characteristic in desert habitats (Ali *et al.* 2018).

To promote a high transpiration rate, plants under temperature stresses quickly increase stomatal conductance. Endophyte-treated plants still exhibit a sluggish stomatal opening and a low transpiration rate. Under stress conditions, the endophytic *Thermomyces* sp. increased the water use efficiency by maintaining the water content in the leaf. Additionally, as a physiologically adaptive strategy to conserve water before additional damage takes place as a result higher temperature challenges, thermophilic fungi prevent excessive

water losses from the plant through stomatal closure. The growth of primary and secondary metabolites is encouraged by these fungi (Ali *et al.* 2018). In many plant interactions, the increased accumulation of sugars and flavonoids in plant tissues functions as ROS scavengers and signalling molecules, promoting plant development and tolerance to abiotic and biotic stresses. *Cucumis sativus*, *Zea mays*, *Oryza sativa*, *S. lycopersicum*, *Triticum aestivum*, *Citrus reticulata* and *Saccharum officinarum* have all been observed to benefit from endophytes ability to regulate water stress-inducible genes (Fontana *et al.* 2021).

Endophytes reduce water stress by increasing the antioxidant enzymes, bioactive substances, chlorophyll content, carotenoid content and chlorophyll fluorescence. *Penicillium citrinum*, *Aureobasidium pullulans* and *Dothideomycetes* sp. endophytes altered all these parameters in *C. reticulata* plants and also encouraged plant growth (Sadeghi *et al.* 2020). Endophytes are reported to facilitate plant adaptation to drought tolerance through the production of phytohormones, ROS, exopolysaccharides, 1-aminocyclopropane-1-carboxylate deaminase, volatile compounds, changes in root morphology, the biosynthesis of anti-stress metabolites and the positive regulation of stress-responsive genes in host plants.

Additionally, it has been noted that grasses under water stress accumulate solutes in endophytic plants (Malinowski and Belesky, 2000). The use of CO<sub>2</sub> generated by endophytes to prolong photosynthesis is one of the hypotheses for tolerance to water stress mediated by endophytes in host plants. Due to stoma closure, this alleviates the lack of CO<sub>2</sub> in stressed plants. According to a study, 2.7% of the CO<sub>2</sub> that emitted by endophytes in *Populus deltoids*' roots was incorporated in to the host's photosynthesis (Bloemen *et al.* 2013).

Endophytes impart tolerance to heavy metal stresses in plant such as *Triticum aestivum* (Ikram *et al.* 2018, Malik *et al.* 2020), *Lycopersicum esculentum* (Zhu *et al.* 2018) and *Glycine max* (Bilal *et al.* 2020) among others. For example, the endophytic *P. roqueforti* fungus induced resistance in *T. aestivum* plant grows in soil contaminated with heavy metals, restricting heavy metal transfer from the soil to the plants and secreting indole acetic acid. In addition, these wheat plants inoculated with the endophytic fungus and watered with residual

water showed higher growth, nutrient absorption and low heavy metal concentrations in the shoot and roots. Endophytes help the host plant by improving its ability to absorb vital nutrients from contaminated soil (Bashan and de-Bashan, 2005). Additionally, these fungi can transform contaminants from contaminated soils (Khan and Doty, 2011) into a non-toxic form by degrading them. Endophytes can induce beneficial physiological changes in the host plant to endure stress circumstances by providing exogenous phytohormones. In addition to phytohormones, the biofertilization ability of endophytic fungus can boost the host plant's availability of nutrients by solubilizing them in heavy metal-contaminated soil (Khan *et al.* 2010).

The function of these microbes in supplying tolerance to salt stress has been observed in plant cultures like *Zea mays* (Jan *et al.* 2019), *S. lycopersicum* (Abdelaziz *et al.* 2019), *O. sativa* (Jogawat *et al.* 2013), *T. aestivum* (Zhang *et al.* 2016), *Cucumis sativus* (Waqas *et al.* 2012) and *G. max* (Radhakrishnan *et al.* 2013, 2015), among others, the function of these microbes in supplying tolerance to salt stress has been observed. For example, the endophytic fungus *P. indica* boosted the development and yield of *S. lycopersicum* under salt stress conditions, causing a sequence of morphological and biochemical events which together contributed to reduce the impact of salt stress. This endophyte encouraged a rise in the chlorophyll and indole acetic acid content, enzymes such as catalase and superoxide dismutase, improved the root branching, the fresh and dry mass of plants and fruit output by 65% under salt stress. Additionally, compared to uncolonized plants, endophyte treated with tomato plants decreased lower amounts of proline and abscisic acid (ABA) (Abdelaziz *et al.* 2019). The ROS-sequestering enzymes appear to considerably boost the capacity to endure salt stress (Hosseini *et al.* 2017).

Abiotic stresses, such as oxidative stress, drought, flooding, salinity and heat stress are interconnected and lead to the production of ROS, which damage cells and ultimately lead to cell death when exposed for an extended period of time. An increase of ROS in plant cells cause oxidative stress, lipid peroxidation and the destruction of DNA and RNA. The ROS signal directly alters the redox balance of regulatory proteins, transcription and

translation, so that reviving plant responses which help in minimizing the deleterious effects of stress and regulate the metabolic concentration of ROS (Choudhury *et al.* 2017). It was hypothesized, endophytes initially release a moderate quantity of ROS, such as hydrogen peroxide, which activates the host's antioxidant enzymes (White and Torres, 2010). It promotes plant nutrient uptake (phosphorus, magnesium, potassium and calcium) and other endosymbiotic interactions of the host when ROS are continuously released in moderate levels (Overmyer *et al.* 2003). Plant tissues primarily assembled proline, methionine, flavonoids and the other phenolic substances to strengthen their resistance in the presence of ROS generated by endophytes (Herrera-Carillo *et al.* 2009). Effect of endophytes in rice plants under abiotic stresses condition has shown in Fig. 4.

The formation of ROS and antioxidants as well as the interaction between endophytes and host plants are likely processes by which hypersensitive reactions and acquired systemic resistance of the hosts can occur (Tanaka *et al.* 2006). Although, some fungal endophytes generate ROS in order to feed off of host cells and keep up their mutualistic relationships with plants, other fungal endophytes reduce ROS levels in order to lessen the impact of abiotic stresses on their hosts (Rodriguez and Redman, 2008).

#### **Dye degradation and decolorization by fungal endophytes**

Adsorption has been recognized as an efficient and low-cost procedure for the treatment of dyes combined with effluents generated by industry, among all the approaches for wastewater treatment. The use of fungal biomass to remove textile colours from wastewater is an appealing alternative since it might minimize the total cost of the treatment procedure (Saraf and Vaidya 2015). When live biomass is employed, this binding process can happen quickly and biosorption, on the other hand, may employ both live and dead biomass. Microbial isolates coming from dye-polluted soils, industrial effluents, or marine sources have largely been used to degrade dyes (Saratale *et al.* 2006, Abedin 2008, Gou *et al.* 2009). Kabbout and Taha (2014), investigated the biosorption of methylene blue by *Aspergillus fumigatus* dead fungal biomass and modified the conditions for boosting the absorption. By

biosorption, *Aspergillus niger* and *Rhizopus stolonifer* were able to remove colours such as congo red and bromophenol blue (Fu and Viraraghavan 2001, Zeroual *et al.* 2006). Bayramoglu and Arica (2007) investigated the removal of two benzidine dyes, direct red 128 and direct blue 1, from native and heat-treated *Trametes versicolor* fungal biomass using various parameters. The heat-treated and native biomass of *T. versicolor* had biosorption activity of 152.3 and 101.1 mg/g for direct blue 1 and 225.4 and 189.7 mg/g for direct removal. According to Iqbal and Saeed (2007), the absorption efficiency of RBBR by immobilised *Phanerochaete chrysosporium* biomass in loofa was much higher than that of free fungal biomass, with RBBR uptake efficiency being significantly higher.

When compared to free fungal biomass, the value of loofa sponge-immobilized biomass enhanced (18.6%). *Trichoderma asperellum* grown on lower resources can keep its dye-decolorizing effectiveness (Marcharchand and Ting, 2017). *Trichoderma asperellum* (Ta) has been cultivated on synthetic media at various concentrations, including 20%, 50%, 75% and 100% and has demonstrated the capacity to perform biosorption. This is also an excellent cost-effective technique for dye removal through fungal mass, this method can assist to reduce the expense of growing Ta biomass for dye removal activities isolated at lower concentrations (20%, 50% and 75%). Lower nutrient levels were shown to be beneficial in developing the biomass of Ta for colour removal activities (Marcharchand and Ting, 2017). Although, endophytes connected with plants have had far less research done on their biosorbent activity. Ting *et al.* (2016) isolated an endophytic *Diaporthe* sp. fungus from *Portulaca* weed and investigated its potential activity in triphenylmethane (TPM) dye biodegradation and biosorption.

*Diaporthe* sp. live cells had higher decolorizing efficiency against malachite green, crystal violet and methyl violet, with decolorizing efficiencies of 87.80%, 84.87% and 78.81%, respectively. Ting *et al.* (2016) also found that the decolorization efficiency of living cells is considerably superior to that of dead cells (18.82%, 39.88% and 48.32%, respectively). According to Aksu and Donmez (2005), certain fungi such as *Candida tropicalis* have the potential to remove colours such as

Remazol Black B and Remazol Blue through a bioaccumulation process. *Saccharomyces cerevisiae* may also bioaccumulate colours like Remazol Blue, Remazol Black B, and Remazol Red RB (Aksu, 2003). Taskin and Erdel (2010) have shown the ability of *Aspergillus niger*, a soil-borne fungus, to decolorize the textile dye Reactive Black 5 through bioaccumulation. Melati *et al.* (2021) reported that the two dark septate endophytic fungi (DSE) CPP and KSP successfully have decolorized the congo red (CR) synthetic dye up to 97% and 85%, respectively, after 14 days, with decolorization indices of 1.37 and 1.36. DSE growth does not alter much with or without the addition of CR dye. Both fungi generate lignolytic enzymes. DSE have the potential to be employed as decolorization agents for azo synthetic dyes. This is the first report on DSE for decolorization of azo synthetic dyes. Congo red dye decolorization by fungal endophyte presented in Fig. 5.

The model dye CI Direct Blue 201 was totally decolorized by *Aspergillus niger* MN990895, where live biomass showed 100% dye removal. *A. niger* biosorbed  $8.4 \pm 1.2\%$  of the dye applied. Extracellular crude enzymes were found to be more engaged in the decolorization of DB 201 dye ( $72.73 \pm 3.3\%$ ) than intracellular crude enzymes. Laccase was shown to be the major enzyme involved in the decolorization of DB 201 textile dyes, which was validated by the appearance of discrete protein bands about 75-100 kDa on SDS-PAGE. The FTIR spectra and seed germination experiments both revealed that *A. niger* was effective at degrading and detoxifying the DB 201 textile dye (Ekanayake and Manage, 2022).

Within 14 days, *Bjerkandera adusta* showed the best decolorization for the TPM dyes. In addition, when 4 g biomass was introduced to a 100-mL dyes solution with a concentration of 50 mg/L under shaking (150 rpm) conditions, the decolorization rate by living cells of isolate SWUSI4 reached above 90% after 24 h. Furthermore, decolorization mechanism study reveals that the isolate SWUSI4 was responsible for the decolorization, which was mostly induced by biomass absorption and/ or enzyme degradation. Based on fourier transform infrared (FTIR) investigations, dye biosorption was attributed to binding to hydroxyl, amino, phosphoryl alkane and ester-lipid groups.

The alteration of peaks in the ultraviolet-visible (UV-vis) spectra, as well as the identification of



manganese peroxidase and lignin peroxidase activities, all pointed to SWUS14's biodegradation potential. Finally, the toxicity of TPM dyes after treatment with SWUS14's was significantly reduced than before treatment, according to the phytotoxicity test. These findings suggest that an endophytic SWUS14 could be exploited as a possible TPM dye adsorption and degradation agent, allowing researchers to better understand the plant-endophyte symbiosis in bioremediation processes (Gao *et al.*, 2020).

### **Biosynthesis of nanoparticles using fungal endophytes**

Due to their capacity for metal tolerance, absorption and accumulation, fungal endophytes have gained increased attention in recent years when it comes to the biofabrication of metallic nanoparticles (Moghaddam *et al.* 2015). Fungi as compared to other microorganisms, are efficient synthesizers of any sort of metallic nanoparticle and can produce a number of benefits, including: (i) simple to isolate from soil or plants as opposed to actinomycetes and uncommon bacteria, which needed particular enrichment techniques to be isolated (Xiaowen *et al.* 2019), (ii) secrete huge quantity of extracellular enzymes and metabolites, which help to reduce metal ions in to nanoparticles, (iii) simple to scale-up because of their quick growth (Shah *et al.* 2015), (iv) majority of the fungi have a enormous range of growth for pH, temperature and NaCl which makes it easier to adjust the culture conditions to create homogeneous nanoparticles (Guilger-Casagrande and Lima, 2019).

According to Clarence *et al.* (2020), the endophytic *Fusarium solani*, which is employed in the production of gold nanoparticles, was isolated from the plant *Chenopodium fragrans*. Pink-ruby red colours, a high peak plasmon band and needled and flower-like structures with spindle shapes were observed in the morphology of the produced nanomaterials. The gold-made nanoparticles shown cytotoxic action against human breast cancer cells (MCF-7) and cervical cancer cells (HeLa) (IC50:  $1.3 \pm 0.5$  g/mL and  $0.8 \pm 0.5$  µg/mL), respectively.

Abdelhakim *et al.* (2020), reported zinc oxide nanoparticles by using the culture filtrate of the endophytic fungi *Alternaria tenuissima* isolated from

*Erythrophleum fordii*. The biosynthesized nanoparticles had a spherical form with a diameter that ranged from 15 to 45 nm. They also had strong antibacterial, anticancer and antioxidant properties. Bagur *et al.* (2019), isolated the endophyte *Exosporium rostrata* from the plant *Ocimum tenuiflorum*. This strain was used for the biosynthesis spherical silver nanoparticles with a size, range between 10 and 15 nm that demonstrated significant antimicrobial activity as well as other biological properties like anti-inflammatory and antioxidant activities. An antibacterial silver and gold nanoparticles (NPs) were successfully synthesized by the cell free filtrate of an endophytic fungus *Chaetomium globosum*. The pH and temperature gradient help in synthesis of appropriate size and mono-dispersed condition. Fungal CFF fabricated nanoparticles of various shape under varied physicochemical conditions. Silver nanoparticles showed significantly enhanced antibacterial activity against *Staphylococcus aureus* and *Klebsiella pneumoniae* compared with AgNO<sub>3</sub>. Two prominent CFF proteins showed homology with benzoate 4-monooxygenase cytochrome P450 and ubiquinol-cytochrome c reductase (Singh *et al.* 2018).

The endophytic fungus *Penicillium oxalicum*, which was isolated from *Tecomella undulata* was used in the myco-synthesis of iron nanoparticles. Different methods were used to characterize iron nanoparticles that were created. Iron nanoparticles had an absorption band at 300 nm, which was seen in the UV-Visible absorption spectrum. Iron nanoparticles FTIR spectra revealed absorption peaks ranged in the  $3430.70$  cm<sup>-1</sup>- $466.83$  cm<sup>-1</sup>. SEM images exhibited 140 nm spherical particles shape.

Particle width and height were measured using an AFM and were found to be 3.9 and 100 nm, respectively. Study of decolorization of methylene blue dye in the presence of H<sub>2</sub>O<sub>2</sub> was done using the iron nanoparticles that were formed. In a period of 6 hours, the dye was successfully decolorized up to 99.17%. The prospect of removing harmful textile effluents in a sustainable manner is provided by a myco-synthesized nanoparticle-mediated decolorization technique (Mathur *et al.* 2021).

The size of the AgNPs produced by fungi were determined by XRD examination to be 49.3 nm, and they were confirmed to be face-centered cubic

crystals. *Listeria monocytogenes* (130.29 mm), *Escherichia coli* (170.14 mm), *Shigella dysenteriae* (180.21 mm) and *Salmonella typhi* (140.13 mm) were the tested strains that these nanoparticles significantly inhibited. These synthesized AgNPs effectively scavenged free radicals from 2,2,2-diphenylhydrazyl. The current study demonstrated that *Talaromyces purpureogenus*, an endophytic fungus, can be utilized as a significant source of AgNPs by using biological, eco-friendly and non-toxic methods along with antibacterial and antioxidant properties which can further reduce the harvesting pressure faced by *Taxus baccata* (Sharma *et al.* 2022).

Govindappa *et al.* (2020) synthesized silver nanoparticles from *Cladosporium perangustum* fungal endophyte. In a qualitative analysis, the endophytic fungal water extract produced biologically significant phytochemicals and the GC-MS produced five different kinds of phytochemicals. When silver nitrate and *C. perangustum* water extract were combined, the colour turned dark brown. It was determined that typical silver nanoparticle form was spherical shaped ranging size 30-40 nm, by using UV-visible spectra at 420 nm. The synthesis of silver nanoparticles from *C. perangustum* extract has been presented in Fig. 6.

In comparison to ascorbic acid and butylated hydroxytoluene in all the four methods (DPPH, scavenging activity of H<sub>2</sub>O<sub>2</sub> and nitric oxide and reducing power), the CpAgNPs demonstrated substantial antioxidant activity. The CpAgNPs considerably decreased the MCF-7 cancer cell line's viability and increased the greatest level of caspase-3, caspase-7, caspase-8 and caspase-9 activities, which is thought to be a sign that the CpAgNPs trigger mitochondrial-mediated apoptosis. By using a different route, the CpAgNPs showed lethal effects on onion root tip cells that were actively developing. However, CpAgNPs also showed anti-hemolysis and heme-biocompatible activity on human blood RBCs, while failing to suppress the formation of green gram (Govindappa *et al.* 2020).

### **Epigenetic modulations in fungal endophytes**

Epigenetic modulations (such as DNA methylation and Histone modification) allow plants to regulate gene expression without altering the DNA

sequence, allowing for a quicker and more flexible response to changing environmental conditions (Thiebaut *et al.* 2019). It has been proposed that fungus-mediated epigenetic alternations, such as plant DNA methylation, histone modifications and chromatin remodelling might have been responsible for beneficial effects caused by fungal endophytes in the host and non-host plants (Woodward *et al.* 2012). Hubbard *et al.* (2014) provided evidence in favour of this claim when they showed that the endophytic fungus SMCD 2206 enhanced drought-stressed wheat seedlings by DNA methylation, which was backed by methyl-sensitive amplified polymorphism.

Li *et al.* (2017), used a NAD<sup>+</sup> dependent histone deacetylase (HDAC) inhibitor called nicotinamide to modify the epigenetic state of the endophytic fungus *Eupenicillium* sp. LG41, which was isolated from the Chinese medicinal plant *Xanthium sibiricum*. Two new decalincontaining compounds, eupenicinols C and D (3 and 4), as well as two biosynthetically related known compounds, eujavanicol A (1) and eupenicinicol A (2), were produced more abundantly when the endophyte was epigenetically stimulated (2). Extensive spectroscopic study employing single-crystal X-ray diffraction, LC-HRMS, NMR, optical rotation and ECD calculation revealed the structures and stereochemistry of the novel compounds. According to LC-MS analysis, compounds 3 and 4 are in chemical equilibrium with two and three cis/trans isomers, respectively. Compound 4 showed significant cytotoxicity against the human acute monocytic leukaemia cell line and also displayed activity against *Staphylococcus aureus* with a MIC of 0.1 g/mL (THP-1). They have demonstrated that the HDAC inhibitor, nicotinamide increased the production of compounds 3 and 4 by endophytic *Eupenicillium* sp. LG41, making it easier to isolate them, elucidate their structures and assess their biological activity.

Nishad *et al.* (2021) studied the potency of BRD4770, a brand-new histone methyltransferase inhibitor, in order to manipulate the epigenetic status of silent BGC in endophytic fungi. They isolated *Diaporthe longicolla*, a fungal endophyte from *Saraca asoca*, was supplemented with different concentrations of BRD4770, in order to generate the bioactive compounds with improved antibacterial and antioxidant activities. The induced chemicals were identified as berberine (an

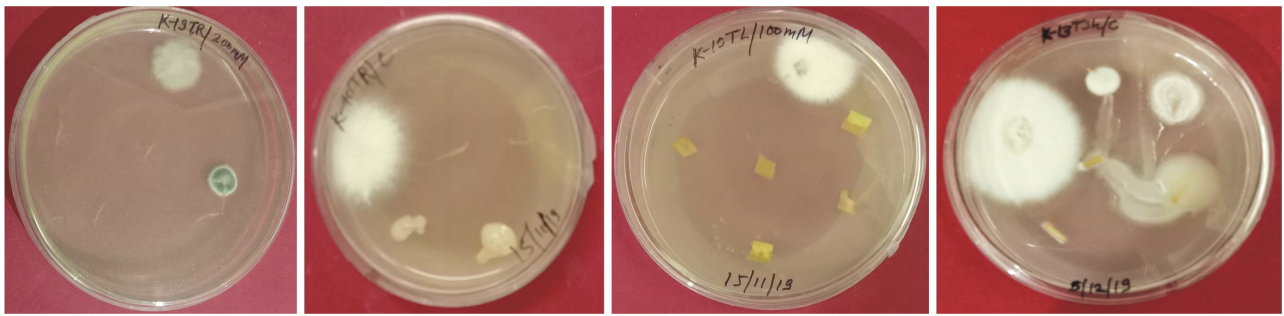


Fig.1 : Fungal endophytes emerging out from the surface sterilized fragments of plant in PDA medium

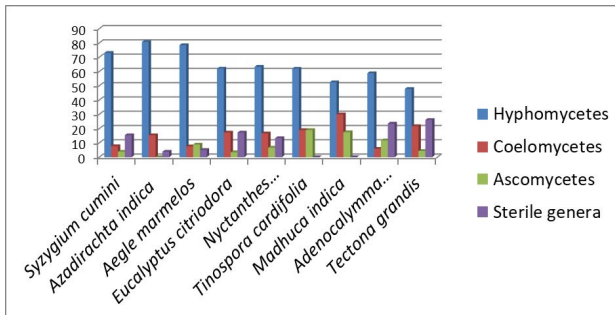


Fig. 2: Diversity of different endophytic fungal groups in different plants studied at BHU, Varanasi , India

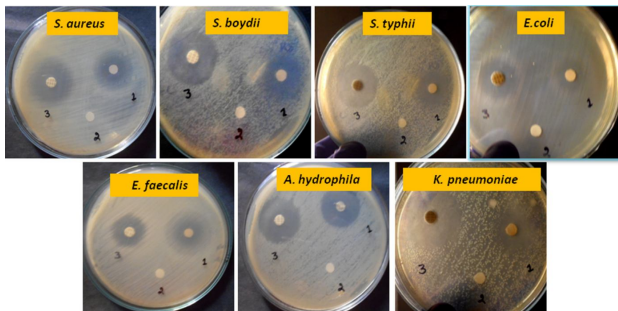


Fig. 3 : Antibacterial activity of fungus crude extract against human pathogens [disc 1- fungal crude extract, disc 2- methanol (negative control) and disc 3- chloramphenicol (positive control)] (Singh et al. (2021))

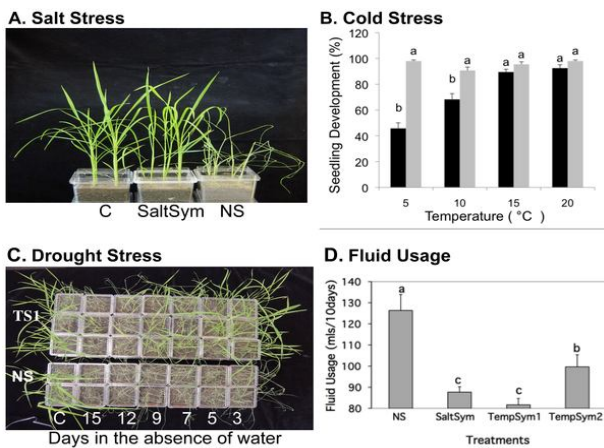


Fig. 4: Effects of salt, cold and drought stress and water usage in Symbiotic (S) and Non-symbiotic (NS) rice plants under laboratory conditions (Redman et al. 2011)

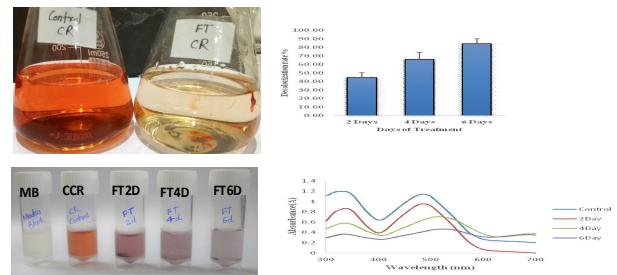


Fig. 5: Congo Red (CR) Dye Decolorization by endophytic fungi

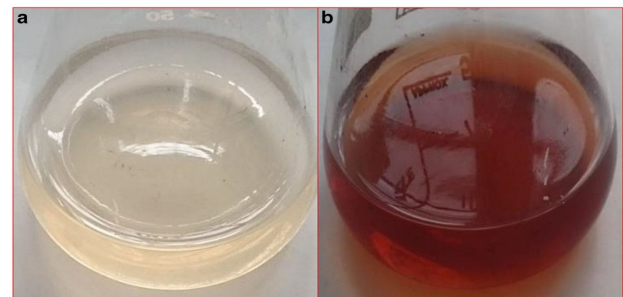


Fig. 6: Synthesis of silver nanoparticles from *C. perangustum* extract, (A) *C. perangustum* extract. (B) Colour change was observed after adding silver nitrate due to bioreduction (Govindappa et al. (2020))

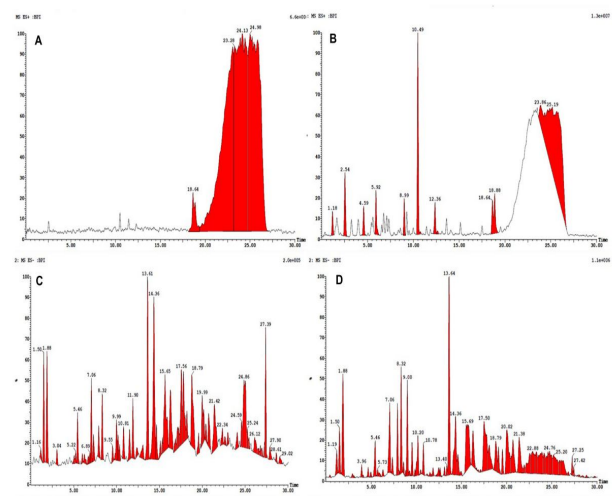


Fig. 7: HPLC-ESI-MS/MS base peak chromatogram (BPC) of metabolite (A) non-treated (positive), (B) treated with 100 nM BRD4770 (positive), (C) non-treated (negative), and (D) treated with 100 nM BRD4770 (negative). (Nishad et al. 2021).

**Table 1:** Bioactive compounds isolated from endophytic fungi and their bioactivities

Endophytic fungi	Source	Bioactive compounds	Bioactivities
<i>Chloridium</i> sp.	<i>Azadirachta indica</i>	Javanicin	Antimicrobial
<i>F. equiseti</i>	<i>Vitis</i> sp.	Resveratrol	Antioxidant
<i>C. gloeosporioides</i>	<i>P. nigrum</i>	Piperine	Anticancer, Antimicrobial, Antidepressant, Antiinflammatory, Antioxidant
<i>Diaporthe</i> sp.	<i>T. baccata</i>	Trichalasin (E,F and H)	Anticancer, Antioxidant
<i>Aspergillus terreus</i>	<i>Achyranthes aspera</i>	Terrein, 4,5-Dihydroxy-3-(1-propenyl)-2-cyclopenten-1-one	Anticancer, Antimicrobial
<i>Phomopsis</i> sp. and <i>Diaporthe</i> sp.	<i>Cinchona ledgeriana</i>	Quinidine	Antipyretic and antimalarial
<i>Phomopsis</i> sp. and <i>Diaporthe</i> sp.	<i>Cinchona ledgeriana</i>	Quinine	Antipyretic and antimalarial
<i>Phoma glomerata</i>	<i>Salvia miltiorrhiza</i>	Salvianolic acid C	Cardiovascular/ cerebrovascular
<i>Phialocephala fortinii</i>	<i>Podophyllum peltatum</i>	Podophyllotoxin	Anticancer antiviral, antioxidant, antibacterial and anti-rheumatic activities
<i>Phomopsis</i> sp. and <i>Diaporthe</i> sp.	<i>Cinchona ledgeriana</i>	Cinchonidine	Antipyretic and antimalarial
<i>Phomopsis</i> sp. and <i>Diaporthe</i> sp.	<i>Cinchona ledgeriana</i>	Cinchonine	Antipyretic and antimalarial
<i>Sordariomycetes</i> sp.	<i>Eucommia ulmoides</i>	Chlorogenic acid	Antimicrobial and antitumor
<i>Thielavia subthermophila</i>	<i>Hypericum perforatum</i>	Emodin	Antimicrobial, anti-inflammatory and antioxidant
<i>Trichoderma atroviride</i>	<i>Salvia miltiorrhiza</i>	Tanshinone I	Antibacterial and anti-inflammatory
<i>Trichoderma atroviride</i>	<i>Salvia miltiorrhiza</i>	Tanshinone II A	Antibacterial and anti-inflammatory
<i>Fusarium redolens</i> , <i>F. oxysporum</i> , <i>Alternaria brassicicola</i>	<i>Taxus baccata</i> , <i>Catharanthus roseus</i> , <i>T. arjuna</i>	Taxol	Anticancer
<i>P. microspora</i>	<i>Taxodium mucronatum</i>	7-epi-10-deacetylaxol	Anticancer
<i>F. oxysporum</i>	<i>Catharanthus roseus</i>	Vincristine and Vinblastine	Anticancer
<i>Phomopsis glabrae</i>	<i>Pongamia pinnata</i>	Depsipeptide	Anticancer
<i>Phomopsis</i> sp.	<i>Nyctanthes arbortristis</i>	Altersolanol	Anticancer
<i>Bipolaris setariae</i>	<i>Parthenium hysterophorus</i>	Ophiobolin A	Anticancer
<i>Phoma macrostoma</i>	<i>Glycyrrhiza glabra</i>	Macrophin	Anticancer
<i>Phoma macrostoma</i>	<i>Glycyrrhiza glabra</i>	Rosellisin	Anticancer
<i>Ascomycetes</i>	<i>M. elengi (Bakul)</i>	Ergoflavin	Anticancer, Anti-inflammatory
<i>Aspergillus aculeatus</i>	<i>Rosa damascene</i>	Secalonic acid derivative, F-7	Anticancer
<i>Alternaria</i> sp.	<i>Vitex negundo</i>	Alternariol methyl ether	Antimicrobial
<i>Aspergillus terreus</i>	<i>Achyranthus aspera</i>	Terrein, 4,5-Dihydroxy-3-(1-propenyl)-2-cyclopenten-1-one	Anticancer, Antimicrobial

antibiotic), caffeine and theobromine (antioxidant) with the help of GC-MS and LC-ESI-MS/MS as shown in Fig.7.

Ramesha *et al.* (2021) studied six well-known modifiers for epigenetic modulation in the endophytic fungus *Nigrospora sphaerica*, including two DNMT inhibitors (5-azacytidine and hydralazine hydrochloride), a sirtuin activator (quercetin) and three HDAC inhibitors (SAHA, sodium butyrate and valproic acid). They came to conclusion that HDAC therapies produced more cryptic metabolites than DNMT treatments.

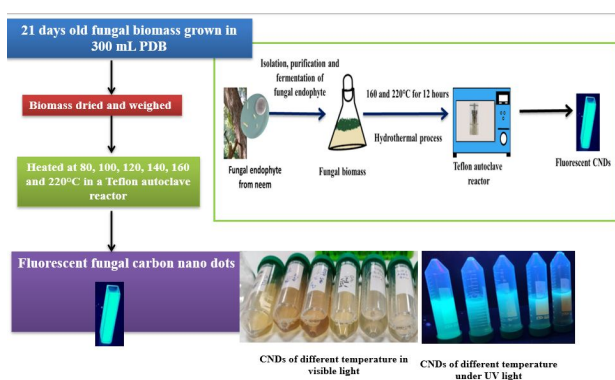


Fig. 8: Synthesis of carbon nano dots (CNDs) from fungal biomass

The two main compounds from the grape skin and turmeric extracts are resveratrol and curcumin, respectively. These compounds have been used to treat the endophytic fungus *Colletotrichum gloeosporioides* of *Syzygium cumini* for gene or gene cluster alternation. As compared to the untreated control, the fungal cultures treated with extracts of turmeric and grape skin produced higher amount of crude metabolites 174.32% and 272.48%, respectively. In comparison to untreated crude, the treated crude considerably suppressed the growth of human pathogenic bacterium *Aeromonas hydrophila* IMS/GN11. Grape skin-treated cultures and turmeric treated both the crude compounds shown a considerable DPPH free radical scavenging activity (86.46% inhibition and 11.80% inhibition, respectively), while the control culture (1.92% inhibition). In comparison to the control, the modified crude chemical demonstrated increased antioxidant and antibacterial properties. After investigation of crude compounds by HPLC, it was discovered that grape skin-treated cultures and turmeric extract both expressed, 20 and 40 cryptic compounds in the crude extract, respectively (Sharma *et al.* 2017).

### ***Mycomediated carbon quantum dots synthesis and their effect in plant health***

#### ***Carbon quantum dots***

Carbon quantum dots (CQDs) or Carbon nano dots (CNDs) or Carbon dots (CDs), a new member of the carbon family, are gaining attraction as a potential luminous material replacement. Carbon nano dots (CNDs) are spherical particles with a carbon core that are less than 10 nm and belong to the previously mentioned nanomaterials family. CNDs are first discovered in 2004 during the purification of single walled carbon nanotubes. Green CNDs made from renewable materials have received a lot of attention in comparison to chemically manufactured CNDs because of their unique characteristics including such as cost effectiveness, non-toxic nature, tunable luminescence, enhanced water solubility, and excellent biocompatibility. Optical properties of CNDs are determined by a surface item with a carbon core that is less than 10 nm. The sensing behaviour of CNDs determines their optical characteristics. Their structure can be either crystalline or amorphous. Surface defects or conjugated-bond band gap changes can both explain the fluorescence of carbon quantum dots. Top down and bottom up methods can be used to make nanodots. They are almost often modified afterward (Tajik *et al.* 2020; Mai *et al.* 2020; Devi *et al.* 2019; Jiang *et al.* 2020; Janus *et al.*, 2019; 2020a). It's primarily made up of such an amorphous carbon matrix with a sp<sup>2</sup> conjugated nanocrystalline core contained inside it. The unique features and applications of CNDs make them intriguing. The fluorescence of CNDs is their greatest distinguishing feature, which allows them to be used for bioimaging and biosensing (Janus *et al.*, 2020b), nanomedicine (Li *et al.* 2018; Yang *et al.*, 2013), gene delivery applications (Das *et al.*, 2016).

#### ***Synthesis of CNDs from different source***

Carbon nano dots were created from neem leaf (*Azadirachta indica*) extracts using a one-pot hydrothermal treatment method (Yadav *et al.*, 2018) as shown in Fig. 8. Carbon nano dots (CNDs) made from rapeseed pollen has a high yield, strong biocompatibility, good water solubility, low cost, and simple synthesis. However, CNDs were reported from various food items, grasses,

plant leaves, and many fruit juices, watermelon or pomelo peels (Luo *et al.*, 2013).

### **Carbon quantum dots from fungus, mushrooms**

For the first time, CQDs or CNDs were successfully synthesized from fungal fibres using a biosynthetic and hydrothermal technique. The high quantum yield CQDs produced, had good biocompatibility, water solubility, and photostability that could be employed for cellular imaging of cancer cells and detecting intracellular TC without additional modification (Shi *et al.* 2019). These findings showed that CQDs generated from fungal fibres could be employed as an environmentally benign material in the future for biological and environmental applications. Following a hydrothermal method, a new carbon quantum dots was made from the oriental mushroom *Ganoderma lucidum*. Different analytical techniques were used to determine the presence of hydroxyl functional group on the surface of the carbon among other things (Kumari *et al.* 2018).

As a fluorophore agent, fluorescent carbon quantum dots generated from edible mushroom species like *Agaricus bisporus*, *Pleurotus ostreatus*, and *Suillus luteus* that were used to image live cells. Carbon quantum dots were created using a simple and low-cost approach that involved microwave irradiating a dried mushroom sample in a hydrogen peroxide solution under optimal conditions of microwave energy, solution type, microwave treatment duration, mushroom amount (Sargin *et al.* 2021).

The enokitake mushroom was used to make the carbon dots with a quantum yield of 11%. CQDs in solution demonstrated high selectivity and sensitivity to the heavy metal Cr<sup>6+</sup> ion. In the presence of diluted sulphuric acid, highly luminous CQDs were produced from enokitake mushrooms using a one-step hydrothermal process (Pacquiao *et al.*, 2018).

### **Effects of CQDs in plant system**

Various advancements have been made in the application of carbon quantum dots in agriculture, with an emphasis on crop interactions. Unless they were treated at greater concentrations, carbon quantum dots had a favourable effect on crop plants, including their growth and resilience to

abiotic and biotic stressors in most tests (Qu *et al.* 2012; Song *et al.* 2013). CQDs or CNDs, when used at the right concentration, can help crop plants to grow faster by speeding up photosynthesis, nutrition absorption and *Azotobacter* based nitrogen fixation and led to higher shoot and root length (Wang *et al.*, 2018). CQDs can improve crop resistance to abiotic/biotic stresses because of their inherent free radical scavenging activities and influence on the antioxidant defence system along with the disease resistance gene expression. CQDs also have broad range of antimicrobial effect against bacteria and fungus (Zhao *et al.* 2015; Das *et al.* 2014). Despite the fact, CQDs have made significant development in the field of nanotechnology and the additional work is needed to apply CQDs in the agriculture sector at large scale.

### **CONCLUSION AND FUTURE PROSPECTIVE**

Endophytic fungi are reliable and remarkable source with a high level of biodiversity and special natural amalgams that produce a number of compounds that are currently of global interest to scientists. The fungal extract exhibited their potential as a source of biocontrol agents, antioxidants, anti-inflammatory and antibacterial compounds that might be employed in development of compounds against a variety of plant and human diseases. This review focused mostly on the interactions between plants and endophytes as well as the advancement of research on endophytic fungi for plant and human benefits. However, in the near future, there will be much focus on relationship between endophytic fungi and their host plant, how endophytes affect plant metabolites production and vice-versa, the action mechanisms of fungal endophytes's metabolites, strategies for effectively promoting production of these bioactive compounds, as well as their potential applications in various fields. From a molecular and biochemical point of view as well as an ecological and monetary one, the production of bioactive compounds by fungal endophytes, especially those unique to their host plants, is significant.

For the current scientific community, the ability of endophytic fungi to produce metabolites compounds with promising antibacterial, antifungal, antioxidant and anti-cancer activities, dye decolorization, carbon nano dot synthesis,

epigenetic modulations and features that promote plant growth have proven to be a boom in order to address the ever-increasing problems of humans. As discussed in review, endophytic fungi are advantageous because they produce host mimetic, novel and potent bioactive metabolites for application in medicines, industry and agriculture. Exploration of endophytic fungi from various ecological niches may result in the discovery of powerful endophytes including the novel species with a variety of usages. To ensure a continuous and sustained gain of bioactive pro-drugs against the current and upcoming diseases, it is advantageous for us to better understand the structural and functional diversity of less studied plant endophytic fungi.

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