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Conceptual

Endophytic Fungi for Plant Growth Promotion and Adaptation under Abiotic Stress Conditions

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The endophytic fungi are colonizing the interior of the plant parts. Among diverse microbial groups, endophytic fungi may play a biological role with their host plant for different attributes. Endophytic fungal interactions with plants confer protection against to abiotic stresses of temperature, salinity, pH and water deficient. The plant infected with endophytic fungi results in significant increase in biomass, improved commercial plant production and thus are useful in agro-forestry and biotechnological agricultural applications. The signalling molecules such as flavonoids, isoflavonoids, and phenolic are released from the roots of plant attracting the fungus from rhizosphere to colonize inside the plant as an endophyte. Fungal endophytes colonize the tissues of host; transmission of endophytes follows two routes vertical transmission of endophytic fungi take place from mother plant to offspring, via seeds, often referred to as "true endophytes". Horizontal transmission occurs via soil or air-borne spores. To date, endophytes in forbs infect the leaves of their hosts through horizontal transmission.

Plant- microbe interaction resulted in adaptation, plant growth promotion, uptake of micronutrient and production of different groups of secondary metabolites and bioactive compounds with potential applications in agriculture, medicine, industry allied sectors [1-4]. Due to protection of plant against biotic and abiotic stresses the beneficial endophytic fungi are considered as an eco-friendly bioresources. The members of different phylum such as Ascomycota, Basidiomycota, Mucoromycota and Oomycota have been reported as plant growth promoters and protectants under the natural normal as well as abiotic stress conditions [5]. Among the fungal groups, arbuscular mycorrhizal (AM) fungi are known to promote activities which can improve agricultural developments. In exchange for the AM fungi providing all of these nutrients, the plant in turn provides the mycorrhizae with carbon and other nutrients [6-10]. A large number of endophytic fungal species belonging to different genera including *Acremonium, Alternaria, Aspergillus, Berkleasmium, Chaetomium, Cladosporium, Claviceps, Collectotrichum, Cryptococcus, Curvularia, Fusarium, Geomyces, Glomus, Leptospora, Metarhizium, Microdochium, Neotyphodium, Ophiognomonia, Paecilomyces, Penicillium, Phaeomoniella, Phyllosticta, Piriformospora, Rhizoctonia, Rhizopus, Rhodotorula, Talaromyces, Trichoderma, Wallemia* and *Xylaria* have been isolated from different host plants [1,6,10,11].

Endophytic fungi are agriculturally important as they can enhance plant growth; improve plant nutrition through different direct and indirect PGP attributes including solubilization of phosphorus, potassium and zinc; production of phytohormones (Indole acetic acids, gibberrellic acids and cytokinin), Fe-chelating compounds, hydrolytic enzymes, hydrogen cyanide, ammonia [6,10,12-15]. In endophytic relationships, growth promoting fungi reside within the apoplastic spaces in the host plants. Sustainable agriculture requires the use of strategies to increase or maintain the current rate of food production while reducing damage to the environment and human health. The use of microbial plant growth promoters is an alternative to conventional agricultural technologies. Endophytes start their journey as rhizospheric microbes or soil microbiomes by different mechanisms. Plants deal with a series of adverse environmental and biotic stresses like drought, cold, hyper salinity, or pathogenesis. Fungal endophytes help plants to adapt under the abiotic stress of temperature, pH, salinity and drought via indirect mechanisms e.g. through induced systemic resistance (ISR), bioremediation, biocontrol. The fungi present inside tissue have capability to protect plants from pathogens and insects.

The fungal endophytes have significant roles for living organisms and human health due to production of wide range of bioactive compounds. The endophytic fungi along with other plant growth promting microbes as single or in consortium could potentially be used as future commercial bioinoculants and biocontrol agents for crops growing under the normal as well as abiotic stress conditions for sustainable agriculture and environments. The significance of enzymes and other bioactive compounds produced by fungal endo-

phytes may be use for bioremediation of environmental pollutants such as polychlorinated hydrocarbons, and polyaromatic hydrocarbons for sustainable environments. For exploring the endophytes of biotechnological importance isolation of endophytes by laboratory techniques and scale up are the important steps. Recently, interest has been generated for the research of endophytic microbiomes in different plants for secondary metabolites for potential applications in industry, agricultures pharmaceuticals and allied sectors may be by advancements in genetic engineering, metagenomics, meta-transcriptomics, microbial fermentation, proteomics, and drug design techniques intelligent productivity of some potential candidates for discovering new drugs can be increased. Future research on endophytic fungi are of biotechnological interest due to their potential of being used as genetic vectors, biological control agents, source of secondary metabolites, antimicrobial agent, antitumor compounds, antibiotics, immunosuppressant, production of natural antioxidant, antiviral compounds, insecticidal products, and antidiabetic agents.

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Competing Interests

The authors declare no conflict of interest.

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