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Editorial

Biodiversity and Biotechnological Applications of Host-Specific Endophytic Fungi for Sustainable Agriculture and Allied Sectors

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The endophytic microbes are referred to those microorganisms, which colonizes the interior of the plant parts, *viz*: root, stem, or seeds without causing any harmful effect on host plant. Endophytic fungi influence the development of plant by producing plant growth hormones thus, at the same time improving nutrition by bidirectional transfer of nutrients and health of plant by protecting against pathogens. Endophytic fungal associations with plants confer protection against adverse environmental conditions such as tolerance to heavy metal, and increased drought resistance. Endophytes are ubiquitous and have been reported from different host plant studies, which are valued for their ability to synthesize various bioactive compounds and extracellular enzymes. The plant inoculated with endophytic fungi results in significant increase in biomass, improved commercial plant production. Endophytic fungi are of biotechnological interest due to their potential of being used as biological control agents, source of secondary metabolites, antimicrobial agents, antitumor compounds, antibiotics, immunosuppressant, production of natural antioxidant, antiviral compounds, insecticidal products, and antidiabetic agents.

The word endophyte means ''in the plant'' and mostly, endophytes originated from rhizosphere and phyllosphere. Microbial endophytes can be sorted from surface-disinfected plant tissue or extracted from internal plant tissue. Plant associated fungi may be sorted in different group on the basis of their survival and role such as mycorrhizal, pathogenic, epiphytic, endophytic, and saprotrophic fungi. A relatively small number of organisms, such as mycorrhizal fungi, endophytic, and pathogenic fungi cross the borderline of the rhizosphere and reach deeper into the roots of plant. Fungal endophytes colonize the tissues of host; transmission of endophytes vertically or horizontally. Endophytic microbes (Archaea, bacteria and eukarya) live in plant tissues without causing substantive harm to the host. They exist within the living tissues of most plant species in the form of symbiotic association to slightly pathogenic. These microbes have been isolated from a variety of plants including wheat, Rice, Mustard, Chilli, Sugarcane, Maize, Citrus, Chilli, Potato; Tomato, Soybean, Pea, Common Bean, Sunflower, Cotton, Chickpea , Pearl millet and Strawberry [1,2]. A large number of endophytic fungal species belonging to different genera including *Alternaria, Aspergillus, Chaetomium, Claviceps, Collectotrichum, Cryptococcus, Curvularia, Fusarium, Geomyces, Glomus, Leptospora, Microdochium, Neotyphodium, Paecilomyces, Penicillium, Phaeomoniella, Piriformospora, Rhizoctonia, Rhizopus, Rhodotorula, Talaromyces, Trichoderma, Wallemia* and *Xylaria* have been isolated from different host plants [2-7]. Microbial biotechnology has opened up new possibilities for microbial applications of beneficial endophytic microbes for agriculture, industry and medicine. An understanding of endophytic fungal diversity from diverse niches and its potential applications microbial in agriculture is important and useful for plant growth, protection and yield. The endophytic microbes attracted the attention of the scientific community due to their ability to promote plant growth and adaptation under the diverse extreme abiotic stresses [2]. Endophytic fungi with novel secondary metabolites and bioactive compounds production ability will be applicable in broad range of industrial, agricultural and medical processes.

Fungi that colonizes inside tissues in plant is largely influenced by the environmental circumstances surrounding the host plants such as the type and pH of soil, the content in soil, rainfall, salinity of soil and temperatures. The endophytic fungi may be isolated from different parts of plant such as roots, shoots, stem, leaves, flowers, bark, and meristem using different surface sterilization, serial dilution and spread plate techniques. For identification and characterization of fungal endophytes, both morphological and molecular technique using genomic DNA isolation, amplifications of ITS gene and sequencing of desired gene, BLAST analysis and finally phylogenetic profiling [8,9]. The endophytic fungi may be screened for their PGP attributes such as production of phytohormones indole-3-acetic acid, gibberellic acid and 1-aminocyclopropane-1-carboxylate (ACC) deaminase; Solubilization of phosphorus, potassium and zinc; production of ammonia, HCN, Fe-chelating compounds, hydrolytic enzymes production and biocontrol against different microbial pathogens and other industrially important bioactive compounds productions using different methods and protocol [10,11].

The different groups of microbes have been reported as endophytic such as archaea, bacteria and fungi. Among fungi, the members of different phyla such as Ascomycota, Basidiomycota, Mucoromycota and Oomycota have been reported as endophytic from most of crops studies. On review of different research on the biodiversity of endophytic fungi from different crops, it has been found that predominant genera included *Aspergillus, Fusarium, Penicillium* and *Piriformospora.* Along with predominant genera some host-specific fungal strains have been reported e.g. *Penicillium glabrum* isolated from barley (*Hordeum vulgare*); *Gibberella*

zeae, from maize (*Zea mays*); *Colletotrichum boninense, Colletotrichum capsici* and *Phoma herbarum* from soybean (*Glycine max*); *Diaporthe endophytica, Fusarium verticillioides* and *Metarhizium brunneum* from sugarcane (*Saccharum officinarum*); *Pleospora herbarum, Talaromyces flavus, Trichoderma atroviride* and *Trichoderma hamatum* from wheat (*Triticum aestivum*) [12-23].

Plants play an important role in selecting and enriching the types of microbes by the constituents of their root exudates. Thus, depending on the nature and concentrations of organic constituents of exudates, and the corresponding ability of the microbes to utilize these as sources of energy, the microbial community develops in the interaction as endophytic. Endophytes can actively or passively promote the growth of plant, through a variety of mechanisms, provide a variety of fitness to host, increased plant resistance to biotic and abiotic stresses. Fungal endophytes stimulate the growth of plant directly or indirectly by triggering solubilization of phosphorous, potassium and zinc, triggering host plant defence response against phytopathogens by various mechanisms such as niche exclusion and competition, direct antagonism of pathogens by antibiosis, parasitism or predation, altering plant hormonal levels such as auxin, abscisins, ethylene, gibberellins, and indole acetic acid (IAA), siderophore production, ACC deaminase production and supply essential vitamins to plants [24-26].

Biofertilizers are basically the microbes which bring about the enrichment of the nutrients of the soil by enhancement of the availability of the nutrients to the crops. Plant nutrients are one of the most essential components of the sustainable agriculture [27,28]. The production of the healthy crops so as to meet the demands of the world's expanding population mainly relies on the type of the fertilizers used to supplement all the nutrients to the plants but more reliability on the chemical fertilizers is damaging the environmental ecology as well as affecting the human health with great severity [29,30]. Thus, the use of the microbes as biofertilizers is considered as an alternative to chemical fertilizers so as to improve the fertility of the soil as well as increasing the productivity of the crops in sustainable farming. These microbes are considered to be the biopotential and a novel tool for providing substantial benefits to the agriculture. These microbes basically colonize the roots and stimulate the growth and these are referred to as the PGP Microbes. PGP microbes stimulate the growth by various direct as well as indirect mechanisms such as the production of various plant growth regulators, biological nitrogen fixation, phosphorus solubilization, production of the siderophores, HCN, various lytic enzymes. Extensive work on the biofertilizers is available which reveals that these microbes have capability of providing the required nutrients to the crops in amounts which are sufficient for the enhancement of yield of the crops [31,32]. A microbial consortium is two or more microbial groups living symbiotically. The consortium can be endosymbiotic or ectosymbiotic. The combination of multifarious PGP endophytic microbes for sustainable agriculture may be replacement of chemical fertilizer. There are many reports on developments of microbial consortium and microbes having multifarious PGP attribute which may be archaea, bacteria or fungi. These consortiums may be epiphytic, endophytic or rhizospheric [2,3,33,34].

Presently, bio-fortification approach is getting much attention to increase the availability of micronutrients especially Fe and Zn in the major food crops. Use of plant growth promoting endophytic fungi is becoming an effective approach to substitute synthetic fertilizers, pesticides, and supplements. The selected efficient plant growth promoting microbes mobilize the nutrients by various mechanisms such as acidification, chelation, exchange reactions, and release of organic acids [35,36]. Biofortification is the most sustainable, targeted and cost effective approach which circumvents these problems by improving the micronutrient content and nutritional quality of cereal crops themselves by increasing mineral levels and bioavailability in the edible parts more specifically in the endosperm [36-39].

The beneficial endophytic fungi may used for production of industrial products in mass quantities e.g. production of antimicrobial drugs, antibiotics, riboflavin, enzymes etc. Microbes are broadly used in large-scale industrial processes, not only in the making of a variety of metabolites, such as ethanol, butanol, lactic acid and riboflavin, but also in the biotransformation of numerous chemicals to enable the lessening of environmental pollution by various methods such as waste water management, bioremediation, mycoremediation, composting etc. Over the year, natural products from microorganisms, plants, or animals are playing a key role in the search for novel drug. The naturally derived products are non-toxic and inexpensive, have been exploited for human use. The biggest store house of bio-active compound is fungal endophyte. Bioactive compounds (phytonutrients) lower the risk of heart disease, cancer and other diseases; they include carotenoids and flavonoids (anthocyanins, phenolic acids, polyphenols). For last two decades, Fungal endophyte isolated from various plant sources have proven themselves as invaluable sources of natural products for agriculture, industry, biomedical development etc. and also produces extracellular hydrolases enzymes; such as pectinases, cellulases, lipases, amylases, laccases, xylanase, and proteases as one of the mechanism to resist against pathogenic organism and to gain nutrition from host. Enzymes are a sustainable alternative to the use of harsh chemicals. Enzymes work under neutral pH and moderate temperature. In the recent years, enzyme research using microbes has been very dynamic and hopeful. There are many reports on microbial diversity from extreme environments and its biotechnological applications in agriculture, medicine and industry [8,40-46]. Fungal endophytes producing extracellular enzymes have been reported from diverse cereal, woody and medicinal plants. The extracellular enzymes targets various macromolecules e.g. lignin, proteins, carbohydrates, sugar-based polymer to breakdown into simpler ones

Endophytic microbes colonizes the healthy tissues of plant inter or intracellularly. Fungi utilize a wide range of organic compounds for source of nutrition. The organic compounds include cellulose, pectin, lignin, chitin, starch, xenobiotic, hydrocarbons and pesticides. The research role of endophytic fungi has been reported worldwide and it has been concluded that fungal endophyte play important roles in the degradation of debris of plant. Endophyte produces certain enzymes cellulose, lipoidase, proteinase, phenoloxidase, pectinase etc. When the plant die and fall on ground, that

time fungal endophyte utilizes glucose, oligosaccharide, cellulose, lignin, keratin, pectin, lipids components of plant residues and decomposed rapidly [47,48]. Due to industrialization or anthropogenic activity a wide variety of pollutants petroleum hydrocarbons (PHC), polycyclic aromatic hydrocarbons (PAHs), halogenated hydrocarbons, pesticides, solvents, salt, and heavy metals have been introduced into the environment and cause environmental pollution [49]. PAHs are one of the environmental pollutants, carcinogenic or toxic to living organisms. New emerging technologies such as phytoremediation and bioremediation are gaining considerable amount of attention [50].

In conclusion, the population of human has doubled and to feed the population, the production of food has to be increased. The application of chemical fertilizers, fungicides, bactericides, and pesticides to increase yield of crops have certain negative impacts on earth's atmosphere thus causes air and ground water pollution. In agriculture to improve nutrient supply and conserve the management of field new alternative methods came into light. Organic farming is one of the strategies that aid in the longer shelf life of plant and causes no adverse effects to ecosystem. Organic farming generally depends on natural microflora of soil, PGP microbes such as endophytes, epiphytes, and rhizospheric. Involvement of fungal endophyte in element cycling has significant consequences for living organisms and human health. The endophytic microbes could potentially be used as future commercial biofertilizers, biocontrol agents, and can be used for different crops, thus promoted the sustainable agriculture. The significance of fungal endophytes producing enzymes on remediating environmental pollutants such as polychlorinated hydrocarbons, and polyaromatic hydrocarbons has been understood. Endophytic microorganisms, producing metabolites of plant origin can be of great significance. The endophytic microbes in spite of huge biotechnological applications are less explored as they are rich source of bioactive metabolites. Recently, interest has been generated for natural bioactive compounds from fungal endophyte, by taking advantage of genetic engineering, proteomics, microbial fermentation, metagenomics, meta-transcriptomics, and drug design techniques intelligent productivity of some potential candidates for discovering new drugs can be increased. Future research will need to take into account on development of genomic tools and metabolomics tools both allowing further studies on the life of endophytes inside the plant and plant-microbe interaction.

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