Exploring the diverse application of Endophytes and their potential in Stress management in Plants.

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Abstract:

One of the agricultural loss that the farmers face is because of the inability of the crops to withstand unfavourable environmental condition. Use of chemicals, excess of pollution puts an additional tax to the agricultural loss. Endophytes are a promising group of micro organisms that shows ability to render a plethora of benefits to the plants which may help in boosting the agricultural sector. In addition to this Endophytes find its wide application in industrial, economical and pharmaceutical sectors as well. This review highlights the different properties of Endophytes and the benefits rendered to the host plant. Providing stress tolerance, Phytoremediation, Bioremediation, converting the wastes into useful substances, production of bio-fuels are some of the Endophytic properties. Reference of Endophytic isolates of Phomopsis sp., Alternaria sp., Fusarium sp. and many more have been cited in Table 1 with their properties. A hypothetical mechanism to illustrate the process of Bioremediation has been given in Fig. 1. This review gives scope of further work in understanding the genetic mechanism of the Endophytes in providing stress tolerance to the host plants.

Key Words: Endophytes, Bioactive substance, Bioprospecting, Biotechnological application, Phytoremediation and Stress tolerance.

1. Introduction

Endophytes form a unique group of micro organisms comprising of Fungi, Bacteria and Actinomycetes, which reside inside the plants without harming the host plant. For decades a lot of research work has taken place and a number of works is still going on to elucidate their behaviour inside the host plant and to exploit their resources for the benefit of the human kind. Endophytes originate from the microorganisms residing in the soil as free-living microbes either from the phyllo sphere [1] or the rhizosphere [2]. Different factors like biotic and the abiotic factors influences the endophytic community

structure within the host plant [3]. Endophytes are host specific and are symbiotically associated with the host plant. One of the great advantages of this association is the production of the secondary metabolites by the plants which is believed to be because of the specific endophytic community present in the host plant. The abundance of the endophytic microflora differs with the varying species of the plant [4]. Moreover, the distribution is also affected by the part of the plant and the age of the plant. Colonisation frequency and the species richness depends on the age of the tissue dominated by the endophytic microflora [5]. Whatever the differences may be, in all kinds of plant endophyte interaction, there is a two-way benefit being provided to both the partners. On one hand the Endophyte gains can be counted in terms of shelter and nutrients that it derives from the host plant. On the other hand, the plant gain can be counted in the form of growth promotion, increased tolerance to harsh environment and induced resistance to pests and diseases.

Endophytes isolated from different types of plant species includes various medicinal plants, economically important plants as well as mangroves. In all these studies fungal species, bacterial species and the actinomycetes have been isolated from the host plants as Endophytes. As per the data provided by Alvin *et al*, 2014 only 10-15 % of existing species of higher plants have been investigated for their medicinal benefits. Traditional knowledge related to the usage of the medicinal plants in the treatment of various diseases is very often kept secret. And therefore, the ethnobotanical knowledge has provided the basis for carrying out further investigation into the medicinal properties of these plants. In the recent past the biochemical assays of the secondary metabolites of the plant as well as the metabolites of the endophytic isolates have shown similarity in their properties. The endophytic derivatives have been found to be having anxiolytic properties, antimicrobial properties, ability to enhance plant growth etc [2]. There may be relation between the derivatives isolated from the plant and the endophytic species inhabiting the host plant. As the plants are affected by the environmental factors, hence any alteration in the environmental factor like temperature, humidity etc can have an impact on the bioactive substances produced by the endophytes. On the other hand, the biotic factors that can harm the plants have also been found to be affected by the presence of the endophytes [7]. Various environmental stress both biotic and abiotic ones have a detrimental effect on the overall growth and development of the plant. But it has been found in the studies that the presence of endophytes confers stress tolerance ability to the plants. This novel property can be utilised to provide stress tolerant varieties by genetic engineering which can boost the agricultural sectors globally. As Endophytes shows a varied trend in their properties hence to throw some light on it, the present review aims to bring out the diverse application of the endophytes in various sectors and understand the mechanism in rendering stress tolerance in plants. There is much scope in revealing the exact genetic mechanism that operates in the host plant due to the presence of the Endophytes. Furthermore extensive research is also required in finding the specific bioactive substance secreted by the specific endophytic species in the host plant.

2. Endophytes and the Host Plant

Microorganisms play a very important role in our environment. They are not only important for the nitrogen fixation, cleaning up the environment, recycling of the mineral nutrients etc but they also help the organisms by interacting with them. The relationship between the microorganism and the other living organisms are of diverse nature where plants also share a very interesting relationship with the microorganisms. Endophytism is one such interesting relationship between the two. Several plants have been studied for the presence of the

endophytic microflora. The endophytes are believed to enter the host plant by various mechanisms. The most common way of entry into the host plant is believed to be the roots. Any wound or injury in the roots may cause the transmission of the specific endophytes into the host plant. Wounds also create favourable conditions for the endophytic bacteria by allowing leakage of plant exudates that provide nutrition to the endophytic bacteria [8]. The specificity of the endophyte has been believed to be the signalling molecules produced by the host plant. The fungus *Phomopsis sp*. is capable of producing some specific enzymes that facilitates its entry into the host plant. This shows that there is a correlation between the mode of entry of the endophytic fungi and the host plant [9]. Generally the interactions seem to be simple but according to some believers' endophytic interactions are frequently complex which involves more than two partners. Endophytic bacteria and fungi may interact not only with the host plant but also with the other organisms, including mycorrhizal fungi and metazoa [10]. Colonization takes place in the internal tissues and this property gives them an ecological advantage over the epiphytic species [11].

The endophytic species have been isolated from the different tissues and parts of the plant. The mechanism of colonization shows similarity for both the endophytic bacteria as well as endophytic fungi with respect to colonisation in roots [10] but may differ as well to some extent. For studying the endophytic growth pattern, inter and intra cellular nature, endophyte density in tissue and to identify the particular tissue where the endophytes reside, histological investigations are carried out [12]. After isolation, the identification of the endophytic isolates has been done both by undertaking classical approach and modern methods. Traditional methods or Classical methods of identification is based on colony morphology, spore shape and size, microscopy etc. In recent times Modern technique of identification is being done on a large scale so as it gives proper identification at the generic level of the species. Modern techniques of molecular biology using genomic DNA isolation, amplification of ITS genes and sequencing of desired genes are done for proper identification of the isolates [8].

3. Secondary Metabolites

Worldwide efforts are under way to isolate endophytes from a vast range of host plants and to study their natural products. A large number of compounds are produced by the plants as a result of secondary metabolism. These compounds do not aid in the normal growth and development of the plant but have been found to be of immense benefits. Though some of the secondary metabolites like Ergot Alkaloids and Indole-diterpene derivatives are toxic in nature [13] but in most of the cases the metabolites have been found to be of importance. The pharmacological effects of the medicinal plants are basically dependent on their phytochemical constituents [14]. Both in the traditional and the modern medicine the plant derivates find its place for its applications. It has been hypothesized that the secondary metabolites produced by the plants may be due to the physiological activity of the specific endophytic microflora present within the host plant [6]. Medicinal plants are rich in secondary compounds like flavonoids, anthraquinones, saponins, sterols, phenols and essential oils [7]. Endophytes have been experimentally shown to produce effective bioactive substances from their host plants [9]. One of the most common Endophytic Fungi *Alternaria sp*. isolated from the roots of marine semi mangrove plant has been reported to produce Xanthone which is a strong anti-oxidant and antimicrobial agents. This single fungal endophyte is found to act as an Antioxidant agent, Anti- HIV agent, Anti-tumor agent as well as Anti diabetic agent [15]. Endophytic bacteria isolated from the stems of *Cissus quadrangularis* indicated the presence of secondary metabolites having bioactive potential by

GC-MS analysis [16]. Phytochemical screening done on the endophytic fungal isolates of *Riccinus Communis* also revealed the presence of secondary metabolites that resemble those in the host plant extracts [17]. In several other medicinal plants like *Bryophyllum pinnatum* [18,19] endophytic isolates exhibited biopotential activities in the form of showing antimicrobial activities. Though in most of these studies the antimicrobial activities have been shown against some of the pathogens but the specific bioactive compounds in the extracts that may be present has not been worked out. Hence ascertaining the role of the specific endophytic species is very important to draw out their benefits. A list of the Endophytic fungi showing the anti-microbial activities along with the host plants is shown in Table 1.

Table 1: List of the endophytic microflora isolated from the different host plants conferring antimicrobial properties

Sl. No.	**Host Plant**	**Endophyte Isolated**	**Nature of endophytic activity**	**References**
1	*Bryophyllum pinnatum*	*Alternaria alternata*	Exhibited antibacterial effect against *E. coli, Y. pestis and S. aureus.*	Sagar et al, 2017
		Aspergillus niger		
		Chaetomium spp.		
		Fusarium solani		
		Penicillium citrinum		
		Penicillium notatum		
2	*Oryza sativa*	*Streptomyces sp.*	Exhibited antifungal activity against *Rhizoctonia solani, Macrophomina phaseolina, Nigrospora oryzae, Phoma sorghina and Alternaria alternata*	Naik et al, 2006 [63]
		Chaetomiun globosum		
		Penicillium chrysogenum		
		Fusarium oxysporum		
		Cladosporium cladosporioides		
3	*Vitex negundo*	*Alternaria solani*	Exhibited anti-bacterial activity against *E.coli, S. typhimurium, B. cereus, B. subtilis, K. pneumoniae* and *S. aureus*	Desale et al, 2013 [64]
		Aspergillus flavus		
		Mucor hiemalis		
		Phomopsis sp.		
4	*Potentilla fulgens*	*Talaromyces flavus*	Exhibited antimicrobial activity against five human pathogens namely- *Bacillus cereus, Salmonella typhi, Escherichia coli, Staphylococcus aureus, and Candida albicans*. Exhibited antioxidant activity as well.	Bhagowaty et al, 2012[65]
5	*Osbeckia stellata*	*Mortierella hyalina*		
6	*Osbeckia chinensis*	*Paecilomyces variabilis*		
7	*Camellia caduca*	*Penicillium*		
8	*Schima*	*Penicillium*		

	khasiana			
9	*Calotropis procera*	*Aspergillus nidulans*	Extracts of the isolates exhibited significant antibacterial activity against the tested bacterial strains which includes *Pseudomonas aeruginosa, Serratiamar cescens, Shigella flexneri, Salmonella typhi, Escherichia coli,* Proteus mirabilis and *Klebsiella pneumoniae*.	Rani et al, 2017 [66]
		Curvularia hawaiiensis		
		Chaetomium arcuatum		
		Chaetomium atrobrunneum		
10	*Ricinus communis*	*Aspergillus fumigates*	Exhibited antibacterial activity against six strains of pathogenic bacteria such as *Bacillus subtilis, Enterococcous sp., Klebsiella pneumoniae, Escherichia coli, Salmonella typhimurium* and *Staphylococcus aureus*	Sandhu et al, 2014)
		Aspergillus japonicas		
		Aspergillus niger		
		Fusarium semitectum		
		Curvularia pallescens		
		Phoma hedericola		
		Alternaria tenuissima		
		Fusarium solani		
		Drechslera australien		
		Aspergillus repens		
11	*Ephedra aphylla*	*Pleospora tarda*	Exhibited antiviral activity with the ability of producing compounds such as- alternariol and alternariol-(9)-methyl ether.	Selim et al,2018
12	*Rauwolfia tetraphylla L*	*Curvularia sp.*	Exhibited antimicrobial activity against *Staphylococcus aureus, Bacillus cereus, Pseudomonas aeruginosa, Escherichia coli, Salmonella typhimurium* and *Candida albicans*	Alurappa et al, 2018
		Aspergillus sp.	Extract of *Aspergillus sp.* gave effective inhibition against tested organisms except *P. aeruginosa*	

4. Bioprospecting and Biotechnological application of Endophytes

Endophytes have found its wide application in all the fields of biological applications. Its most important application is in the form of Biotechnological application. Phyto remediation,

Production of non- food crops for biomass and biofuel productions are some of the important applications of endophytes. They can be used as antibacterial and antifungal agents [19] which makes them a potent biocontrol agent. One of the major consequences with the use of chemicals for the agricultural field is pollution. So, if the plants can be infected with the specific endophytes then damage caused to the soil by the increased use of chemicals can be resolved. Many medicinal plants found to be infected with endophytes are able to produce the potent bioactive substances able to cure many diseases [18].

4.1 Growth Promotion in Plants

Various studies have shown the ability of the endophytic species to produce hormones capable of inducing growth in plants. This proves to be of great significance in the field of agronomy. Use of the specific microbial species or making the plant transgenic by inserting the genes of the specific endophytic species can reduce the dependence on the artificial growth promoters. This will thereby reduce soil pollution as well as water pollution to a great extent. In one of the experiment the endophytic bacteria isolated from Nepalese Sweet Potato exhibited IAA production ability along with having nitrogen fixing gene and acetylene reduction assay ability [20]. One of the Endophyte *Streptomyces sp.* belonging to Actinomycetes were found to produce IAA and also showed maximum amount of phosphate solubilization [7]. Thus this species can prove to be of significance if the specific genes can be identified and modified. In another study 25 endophytic bacterial species isolated from tropical legume crops exhibited the ability of producing growth promoting substances like gibberellic acid, Indole acetic acid and cytokinin [21]. Endophytic fungal isolates from *Theobrama cacao* and *Theobrama grandiflorum* trees exhibited the potential of growth promotion in plants [22]. In some species endophytic species have also shown the ability of Siderophore production. Siderophores are chemicals secreted under low iron stress thereby acting as ferric iron chelating agent [23]. Inoculating crop plants with such endophytic species can help in enhancing the growth of the plants, thereby increasing their production efficiency as well.

4.2 Endophytes in Bioremediation

The term bioremediation refers to the use of naturally occurring microbes or their genes to break down the environmental pollutants there by acting as cleaning agents. Among all the various applications of endophytes, the ability to degrade and clean the environment is again of importance. It is a dual process where the endophytes use the mineral elements for their growth and development and on the other hand the soil, water and air get rid of the harmful contaminants.

The mechanism of Bioremediation can be shown as follows-

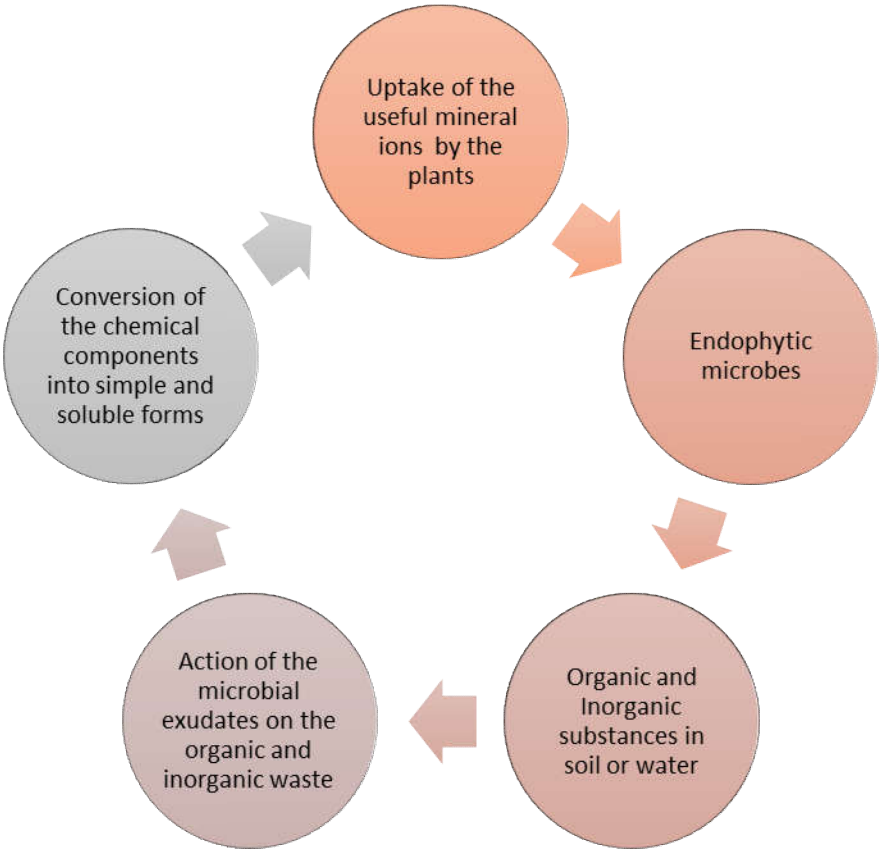

Fig. 1: Hypothetical mechanism to show the process of bioremediation by the endophytic microbes.

The figure depicted above is a hypothetical assumption on the benefits that the plants can derive out of the process. The endophytic microbial population is thus serving dual purpose. On one hand it is acting as a cleaning mechanism in the environment and on the other hand it is acting as a source of mineral ions to the plants. This feature is of much agronomic importance.

Various metal- ions were found to be degraded and solubilised with the use of the endophytes. Endophytic fungi grown in culture media supplemented with toxic metal concentration were found to have undergone bioremediation [24].Endophytic bacteria isolated from *Solanum nigrum* (25), Endophytic fungi isolated from *Agrostis stolonifera* (26) have been found to be effective as heavy metal bioremediation. Accumulation of toxic elements in soil is one of the main problems of industrialization. These element pose a serious threat to the Crops as well. Accumulation of Chromium is one such example. Endophytic microbes have been demonstrated to detoxify Chromium from the affected soil. *Rhizopus sp., Aspergillus fumigatus* and *Penicillium radicum* showed 95% detoxification of chromium extracellularly isolated from *Lactuca sativa* [27].

4.3 Endophytes in phytoremediation

Phytoremediation is equivalent to Bioremediation process which uses plants to remove or destroy the contaminants in the soil or water. Plants harbouring endophytes are an excellent source for phytoremediation. Various studies have shown the ability of the isolated

endophytes in dissolving or breaking down the contaminants into useful products. Phytoremediation along with cropping is considered a sustainable strategy for remediation of trace element contaminated fields without interrupting crop production. *Sedum alfredii* when cultivated with leguminous plant fava bean (*Vicia fava*) have been found to be effective in removing the trace elements like Cadmium and Lead from the soil [28]. This might have been possible because of the endophytic species in *Sedum alfredii* which also increased the productivity of the fava beans.

Phytoremediation have been also effective in removing heavy metals from the soil. Inoculation of *Alnus firma* with *Bacillus thuringiensis* helps in phytoremediation of soil contaminated with heavy metals [29]. Removal of polyaromatic hydrocarbon has also successful with phytoremediation. Inoculating plants with endophytic bacteria *Pseudomonas putida* prevents the plants from phytotoxic effects of naphthalene [30]. Another endophytic bacteria has been found to be an excellent source for the remediation of Bisphenol from contaminated ground water. The cultivable bacterial endophytic community of *Juncus acutus* is able to use organic contaminants as carbon sources, tolerates metals and is equipped with plant-growth promoting traits [31]. Therefore, inoculating plants with this bacterial strain can be a potent source of phytoremediation in wetlands.

4.4 Organic tools for Hydrocarbon production

Endophytes have been also regarded as a potent candidate for the production of hydrocarbons and their derivatives. Studies reveal that the endophytic relationship with plants may possess metabolic processes that convert cellulose and other carbon sources into myco-diesel hydrocarbons and their derivatives. An endophytic fungus, *Gliocladiun roseum* produced a series of volatile hydrocarbons and hydrocarbon derivatives [32]. Another fungal isolate *Nigrograna mackinnonii* exhibits the ability to produce a series of volatile natural products, including terpenes and odd chain polyenes [33]. Production of hydrocarbon compounds by endophytic fungi *Gliocladium* species grown on cellulose also contributes to the various forms of endophytes capable of producing hydrocarbons [34]. *Myrothecium inunduatum* isolated as an endophyte from a Euphorbeacean herb, *Acalypha indica* in NE India exhibited a mixture of volatile organic compounds (VOCs) including many terpenes, organic acids, ketones, and alcohols [35]. All these findings clearly throw light on the abundance of the endophytic microbes as potent sources for the production of the biofuels.

4.5 Endophytes in Pharmaceutical Industries

The Bioactive substances produced by the endophytic microflora are promising resources as therapeutic agents. Many endophytic species have been identified as the possible sources for their useful products but still their large-scale exploitation is a challenge. However, a lot of work is going on in the field of genome sequencing of these endophytic isolates to derive benefits out of them. Endophytic actinomycetes *Streptomycetes* isolated from medicinal plants exhibited antitumor and antimicrobial activity [36]. Endophytes isolated from eight different anticancer plants demonstrated antiproliferative effects [37]. Endophytic fungi isolated from *Rauwolfia tetraphylla* L. exhibited antimicrobial activity. Phytochemical compounds screening of the endophytic extracts revealed the presence of alkaloids, terpenoids and tannin compounds [38]. A number of medicinal plants have been studied and

endophytic microflora isolated from them have been tested for their antifungal, antibacterial and properties of medicinal importance. Chandra S (2012) has also mentioned the endophytic fungi as a novel source of anticancer lead molecules [39]. Plants like *Riccinus communis*, *Bryophyllum pinnatum*, *Andrographis paniculata*, *Ocimum sanctum* which are used in traditional medicine if exploited for their endophytic diversity can be of immense importance in the field of modern medicine.

A number of endophytes have been isolated from these plants and their endophytic microflora exhibited the presence of bioactive substances as well as the ability to act as antimicrobial agents [17,18,19,40]. *Cissus quadrangularis* plant belonging to Vitaceae family also known 'Asthisamharaka' is used in setting bone fractures in traditional medicines. Phytochemical screening disclosed the presence of alkaloids, flavonoids, saponins, terpenoids, steroids, tannins, amino acids and proteins [41]. The endophytic microflora of this pant also exhibits antimicrobial activity which may be due to the bioactive substances produced by the plant. Genomic sequencing of the endophytic species will help in proper identification of the isolates, phytochemical screening of the endophytic exudates helps in knowing the nature of the chemical component which then can be used for the biotechnological application.

In the recent past few years, scientists have recognized various biotechnological applications of microorganisms which are useful not only for the plants but are of economic importance to humans as well. In this aspect endophytic microbes can perform various tasks such as plant growth promotion, biocontrol agents and also inducing a range of novel compounds that could be potential candidates for use in pharmaceutical and agriculture industries. Endophytic microbes have also been documented to help in bioremediation by removing soil contaminants and increasing soil fertility through nutrient cycling. Secondary metabolites produced by these microorganisms have shown so much potential that they are being manipulated, both physiochemically and genetically, to multiply yields of desired compounds [42].

4.6 Industrial application of Endophytes

Endophytic microorganisms exist within the living tissues of most plant species and are diverse in nature. Endophytes have been documented to be useful in all sorts of industrial applications. From pharmaceutical industries to the textile and agricultural sector, in every discipline they have been found to be effective. *Muscodor* an endophytic fungal genus, produces bioactive volatile organic compounds that has enormous potential in industrial sector. This mixture of gases consists primarily of various alcohols, acids, esters, ketones and lipids [32]. Endophytes have been documented to be an excellent source for removing textile industrial wastes. Bacterial augmentation helped in enhancing the process of remediation effectively [14].. Endophyte-infected grasses have been shown to reduce bird populations at airports through the production of secondary metabolites [45]. Industrially useful enzymes like Amylase and Protease production have been observed in the endophyte isolated from the plant *Eremophilia longifolia* [46]. Further more due to the ability to produce many volatile compounds by the endophytes, they can be used in aroma industries as well as in treating waste water as documented in some of the research work [43, 44].

4.7 Production of anti-oxidants and anti-microbial agents

Several studies have established the fact that microbe invaded plants are a good source for a plethora of bioactive substances. Endophytes associated with various medicinal plants can become a good source for the pharmaceutical industries to produce substances of medicinal importance. According to the studies some fungal endophytic secondary metabolites have anti-fungal, anti- microbial, anti-viral, anti-oxidant and anti- cancer properties. Endophytic fungi like *Aspergillus fumigatus*, *Aspergillus niger*, *Alternaria tenuissima* etc. isolated from *Riccinus communis* were effective against many bacterial strains like *Bacillus subtilis*, *Enterococcus sp*. *E.coli* etc. [17]. Endophytic fungi having the ability to produce resveratrol have been found to be exhibiting antioxidant, antifungal and anti-staphylococcal activities in vitro[47]. In another work endophytic fungi isolated from *Ficus religiosa* L. and the extracts obtained from the isolated fungi were evaluated for their potential as anti-oxidant and anti-diabetic agents. Phenols, flavonoids, alkaloids, steroids, terpenes and terpenoids were found to be presented after doing phytochemical screening [48]. Antiviral activities have been found from the endophytic strains from Pleospora tarda extract [49].

5. Endophytes and stress tolerance mechanism in plants

The normal growth and development in the plants may be affected at times by the different factors externally or internally. This affects the rate of production of the agricultural crops which leads to a huge loss. Every year either due to drought or due to flood a large number of crops are damaged due to natural calamities. Apart from these other biotic and abiotic factors affects the plants. Stress factors in plants are mostly the external factors which may include factors like temperature, pH, light, mineral ion concentration etc. Endophytes rendering stress tolerance mechanism in the host plant has been reported by several workers. The molecular mechanisms for increasing stress tolerance in plants by endophytes include induction of plant stress genes as well as biomolecules like reactive oxygen species scavengers [50].

Thermotolerance of endophytic fungal isolates was reported from the plant species growing in Thar Desert, Rajasthan, India [51] where *Aspergillus species* and *Chaetomiun species* exhibited thermal tolerance to the temperature as high as 45^0C. Seedlings treated with endophytes grown under drought stress also exhibited better survival rate. These fungal species could be used for making transgenic plants tolerant to thermal fluctuations and thus can be useful in alleviating thermal stress in agriculturally important crops. The type of habitat also determine the nature of tolerance. It has been documented that in endophytes from Xeric areas are drought tolerant and the ones from coastal areas are tolerant to the concentrations of salt. Rodriguez et al (2008) had clearly demonstrated that the native grass species from coastal and geothermal habitats require symbiotic fungal endophytes to tolerate salt and heat respectively [52]. Endophytes have also been reported by them are to render drought tolerance, heat tolerance and salt tolerance to the plants regardless of their habitat.

The effect of fungal endophyte *Neotyphodium spp*. was studied on *Lolium perenne*. The endophyte infected plants exhibited increased plant growth under the conditions of drought [53]. Bacterial endophytes have been also found to be suitable as inoculants not only for plant growth promotion and biocontrol but also for enhancing stress tolerance in Styrian oil pumpkins [54]. An endophytic fungus *Piriformospora indica* has been found to confer

drought resistance in *Arabidopsis* seedlings, which is associated with the expression of some diverse set of stress related genes [55]. However, the exact identification of the specific genes conferring the heat and drought tolerance in all the studied plants is much required so as to exploit them for making the transgenic plants which could be grown in the abiotic stress conditions. In another work involving an endophytic fungus infected to pot-grown wheat, it was found that the plants exhibited tolerance to both heat and drought stress [56]. However, the identification of the fungal endophyte enabling the plant to tolerate the stress needs to be established.

In addition to heat and drought, endophyte infected plants have also been found to tolerate salt and heavy metal tolerance. Various research work throws light on the ability of the endophytic microflora enabling the host plants either in natural conditions or in invitro to exhibit this property. One of the endophytic fungi belonging to Basidiomycete *Piriformospora indica* has been shown to increase resistance in the host plant against various abiotic and biotic stress. The effect of this fungi in barley was studied with special focus on anti-oxidants [57]. It was found that the infected plant significantly elevated the amount of ascorbic acid and increased the activity of antioxidant enzymes in barley roots under salt stress conditions. This clearly shows that antioxidants may play a significant role in making the plants tolerant to salt stress. It has been hypothesised that the bacterial endophytes from the phyllo sphere of the halophytes may play a significant role in conferring high tolerance to excessive salinity in the plants unable to tolerate salt stress [58]. Endophytic bacteria belonging to *Bacillus* species has been found to confer this property in the host plant. In another work conducted on the roots of Elephant grass, the endophytic bacterial strains isolated belonging to four different genera, exhibited plant growth promoting activities as well as salt stress tolerance ability. The bacterial strains also exhibited the ability to solubilize insoluble phosphate, fix nitrogen, produce indole acetic acid [59]. Apart from endophytic bacteria, endophytic fungi also have been isolated from the halophytes. The isolates were assigned to Ascomycetes based on ITS sequencing [60]. However, their direct role in conferring salt tolerance to the host plant need to be established.

Mineral tolerance in the endophytic infected plants have also been found to be beneficial in terms of biotechnological application. Minerals are an important requirement for the normal growth and development for the plants. Mineral deficiency and mineral toxicity, both may affect the physiological activities in the plant, thereby effecting the normal growth and development of the plant. The effect of *Neotyphodium spp*. in *Festuca spp*. was studied for cadmium tolerance. The results from all Cd treatments showed higher biomass production and higher potential to accumulate Cd in roots and shoots of endophyte-infected plants than endophyte-free plants. Cadmium accumulation by plants indicated that the grasses were capable of Cd hyperaccumulation [61]. Endophyte infected plants have also been found to perform better in phosphorus deficient soil in comparison to non-infected plants [62].

6. Future challenges (Discussion) and Conclusion

For sustainable management in agriculture the challenges faced by the stakeholders must be addressed and dealt in a scientific manner. The main challenges faced by the farmers are the abiotic and the biotic factors which hamper the crop production, sometimes to a great extent. Not only the crops are affected but by excessive flooding and drought the soil quality is also affected. One of the most modern approach to deal with the problem is to produce hybrids or transgenic plants which can grow in stressful conditions as well as can also protect themselves from the biotic factors. Inoculating cereal crops like Oryza sativa with its bacterial isolates can protect the plant from the attack of insects and pests. Thus these isolates can behave as biocontrol agents [63]. Another plant Vitex negandu can be used for phytoremediation as its isolates exhibit antibacterial activities [64]. Use of natural products definitely helps in conservation of natural resources and thereby help in biodiversity conservation. Similarly other plants like Camellia sp., Calotropis sp., Osbeckia sp., etc. can also be made transgenic by inoculating with their specific endophytic isolates and then can be used for antimicrobial activities [65, 66]. Endophytes have been found to exhibit a plethora of benefits in all aspects. In most of the studies the nature and type of endophytes residing in the host plant have also been identified. However, their exact mechanisms need to be explored in most of the cases. In addition to this extensive work is required in isolating the endophyte specific to the host plant, identifying the bioactive substance secreted by the endophyte in the host plant and understanding the genetic mechanism involved in understanding the expression of the specific endophytic species in the host plant. Studies related to endophytic diversities are available but there is ample scope for doing research in other aspects of the endophytes as well. There is a much need to bring out the role of endophytes in conserving the bioresources by applying newer technologies. This not only will help in conserving the nature but will also bring benefits for the human kind.

Conflict of Interest:

The authors declare no conflict of interest.

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