Chapter

Endophytes Potential Use in Crop Production

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Abstract

The endophytic microorganisms have the potential to improve the yield of agricultural crops. They can be used as biological control, plant growth promoter, or bioremediators. The action of endophytes in controlling phytopathogens, insects, and weeds that harm agriculture may be the result of microbial interactions with other organisms or the production of bioactive metabolites. Also, microorganisms can have the ability to favor plant growth and convert toxic compounds present in the soil. The presence of pollutants in the substrate reduces its quality for plant development, so bioremediation also impacts agricultural production. Therefore, prospecting endophytic microorganisms with agronomic potential may provide sustainable alternatives to increase crop yield.

Keywords: endophyte, agriculture, biological control, plant growth promoter, inoculant, bioremediator

1. Introduction

In order to apply sustainable solutions to problems related to food production, the biotechnological potential of endophytic microorganisms has been prospected in the agronomic area. The use of beneficial microorganisms in agricultural production aims for pest control, improvement of productivity and plant development, and/or recovery of ecological systems. Endophytes play a role in evolution of plant and in resistance of stresses through the production of bioactive metabolites, changes in enzyme metabolism, and gene expression related to resistance [1], and those beneficial effects of various endophytic genera may be the combined [2].

2. Biological control

Biological control of phytopathogens occurs when living microorganisms repress the development of the etiological agent in the plant [3]. Endophytes can act inducing resistance, promoting antibiosis and/or competition in consequence of the mutualistic relation with the plant [4]. These processes can occur independently, but the overlap of mechanisms may also happen [5], like is observed in the association of Beauveria bassiana and Metarhizium brunneum against the complex of Fusarium, the control occurs by competition and antibiosis [6].
The physiological definition of resistance is the delay or impediment of entry and/or subsequent activity of the pathogen in the plant [7]. Plants have numerous and efficient defense mechanisms naturally triggered when exposed to elicitors [8] that can be stimulated by the endophytes presence. The plant defense mechanisms are induced after the recognition of molecular patterns associated with pathogens/microbes (PAMPs/MAMPs), or plants’ molecular patterns associated with damage (DAMPs) and effectors, by proteins or by nucleotide-binding leucine-rich repeat (NB-LRR) [9]. Endophyte induces systemic resistance on plants providing an alert state, the priming [10, 11]. Priming plants exhibits faster and stronger responses against pathogen attacks because transcription factors and signaling proteins have already accumulated in cells. This defense induction is a consequence of molecular signaling during the establishment of plant-endophyte symbiosis [10]. An example of the host-induced resistance by endophytes is the frequent isolation of \textit{Curtobacterium flaccumfaciens} in plants without symptoms of citrus variegated chlorosis, suggesting that this endophyte has a role in the resistance of the citrus plant [12].

A reprogrammed genetic transcription occurs in plants associated with endophytes. The \textit{Epichloë festucae} symbiosis with ryegrass (\textit{Lolium perenne} var. Lolii) enhances gene expression of jasmonic acid (JA) precursors [13], and the expression of the systemic defense genes HvPr17b and HvHsp70 in barley is associated with the presence of the endophyte \textit{Piriformospora indica} [14]. Further, presence of endophytes may alter pathogenesis-related proteins (PR-proteins) concentration, as chitinase, peroxidase, glucanase and cellulase in cucumber inoculated with \textit{Trichoderma harzianum} [15], lignin and cellulose in \textit{Theobroma cacao} in symbiosis with \textit{Colletotrichum tropicale} [16], and PR2, PR6, PR15, and PR16 in rice with \textit{Bacillus subtilis} [17]. The resistance response induced by symbiosis of plant-endophyte is systemic. Studies have shown that gene expression or protein production related to host defense was evidenced in plant portions distant from those inoculated with \textit{Klebsiella pneumoniae} [18], \textit{Rhizobium etli} [19], and \textit{Pseudomonas fluorescens} [20].

The resistance induction is also related with the activity of defense enzymes, such as phenylalanine ammonia lyase, polyphenol oxidase, superoxide dismutase, peroxidase, ascorbate peroxidase, and guaiacol peroxidase. \textit{Pseudomonas fluorescens} induces resistance related to the activity of lipoxigenase, catalase, aminocyclopropane carboxylate oxidase, and phenylalanine ammonia lyase [20]. \textit{Pseudomonas fluorescens} is also capable to induce systemic resistance in plants by producing 2,4-diacetylphloroglucinol [21].

The vast majority of endophytes are biotrophic [22]. Therefore, it is important to consider that when colonization of the plant by biotrophic endophytes begins, the salicylic acid (SA) route activates defenses, so endophytes need to be able to suppress this defense by specific effectors. The expression of the Ca$^{2+}$/calmodulin kinase enzyme is capable to suppress the pathway of SA [23]. In addition, the possibility of recruiting gibberellic acid (GA) reduces the proportion of DELLA proteins, altering the salicylic acid and jasmonic acid (JA) signaling [24]. The suppression of the SA stimulates JA route precursors and genes, which increases resistance to chewing insects and necrotrophic fungi and promotes susceptibility to biotrophics [10, 22]. To ensure plant protection against biotrophic fungi and sucking insects, endophytes have the ability to biosynthesize compounds responsible for antibiosis; besides they can also control these organisms through mycoparasitism and competition.

The endophytes are able to biosynthesize secondary metabolites, which are important for plant colonization processes [2] and are toxic to insects, pathogens [10], and algae [25]. These compounds are classified as alkaloids (amines and amides; indole derivatives), steroids, terpenoids (sesquiterpenes, diterpenes,
monoterpenes), isocoumarin derivatives, quinones, flavonoids, phenylpropanoids and lignans, peptides, phenol and phenolic acids, aliphatic compounds, and chlorinated metabolites [25]. The antagonistic activity of endophytes associated with antibiosis is described for different cultures, like potato [26, 27] and turmeric rhizome [28].

Alkaloids are an important group of metabolites produced by endophytes; some characterized classes are ergot alkaloids, diterpene indole, pyrrolizidines, and peramine. These compounds have important biological activity (antitumor, antimicrobial), including the reduction of insect performance [10, 13]. The resistance of chickpeas (Cicer arietinum) colonized by endophytic Streptomyces spp. against Sclerotium rolfsii is attributed to the production of phenols and flavonoids by the endophyte [29]. Nematicide compounds such as 4-vinylphenol, methionine, piperine, and palmitic acid were evidenced to have high concentrations in soybean colonized by Bacillus simplex [30].

The need for nutritional factors, like carbon, nitrogen, and iron, may also promote biological control. Direct parasitism is a fungus-fungus antagonism, in which one directly attacks another and utilizes its nutrients [31]. This kind of control, independent of a systemic defense response, was observed with the colonization of previously endophyte-free leaves of Theobroma cacao that significantly decreases necrosis in the local of inoculation when challenged with Phytophthora sp. [32]. Endophyte colonization can directly control a phytopathogen even without inducing defense mechanisms such as PR-proteins, like evidenced by the control of Trichoderma stromaticum over Moniliophthora perniciosa [33]. A scanning electron microscope showed that the Trichoderma endophytes cause deformities in the mycelia of Pythium aphanidermatum and Rhizoctonia solani, such as hyphal fragmentation, perforation, lysis, and mycelial degeneration [28]. A strain of Trichoderma harzianum showed in vitro growth contact points that suggest mycoparasitic activity against Fusarium solani [34]. Endophytic and epiphytic fungi isolated from fruits of organic Olea europaea were able to inhibit mycelial growth, germination, and sporulation and cause pathogenic hyphae abnormalities of Colletotrichum acutatum, particularly at mycelial contact [35]. In addition, endophytic fungi from Pachystachys lutea, mainly Diaporthe sp. perform antagonistic activity against Colletotrichum spp. and Fusarium oxysporum, in which contact interactions of the endophyte with the pathogen predominated [36].

Competition and direct parasitism require endophyte-pathogen contact, but those microorganisms have very little to no direct contact with the plant. Because of this, contact mechanisms are not the most important biological control pathway [4].

3. Plant growth promoters

Endophytic bacteria promote plant growth directly or indirectly: directly, producing phytohormones or enzymes [37, 38] and indirectly, contributing to plant nutrient uptake through nitrogen fixation, phosphate solubilization, or iron transformation [39, 40]. For this, the inoculant competes with an adapted indigenous microbiota; therefore, for the colonization of plant, some bacterial characteristics are important, such as motility and polysaccharide production [41–44].

Ethylene and indole-3-acetic acid (IAA) are phytohormones that are involved in almost all aspects of plant growth and development, from seed germination to shoot growth, and they control the response of the plant to stress [45, 46]. Plant growth is promoted by reducing ethylene levels and increasing IAA. Biotic and abiotic stresses result in increased ethylene production in plants, leading to
inhibition of root elongation, lateral root development, and root hair formation. Plant-associated microorganisms can increase root growth and budding of plants by reducing ethylene levels [47]. The endophytic bacteria can produce an enzyme called 1-aminocyclopropane-1-carboxylate (ACC) deaminase, which hydrolyzes ACC, an ethylene immediate precursor, relieving stress and improving the growth of plants under disturbed conditions [42, 48, 49]. An inoculum from Burkholderia phytofirmans with the gene responsible for producing mutated ACC deaminase was unable to promote root growth of canola. The reintroduction of the ACC deaminase gene restored the microorganism's ability to promote plant growth, highlighting the importance of the enzyme in promoting host plant growth [48]. On the other hand, the IAA is an auxin, a growth hormone that promotes differential cell elongation and functions as the plant growth regulator. Besides being produced by plants, IAA may also be produced by root-associated bacteria, such as Enterobacter spp., Pseudomonas spp., and Azospirillum spp. [50].

Endophytic bacteria can benefit the host by producing cytokines and gibberellins. Corn endophytic bacteria, Azospirillum lipoferum, produce gibberellin, which is important in relieving plant stress [51]. Similarly, extracts of two endophytic bacteria from Gynura procumbens, Pseudomonas resinovorans, and Paenibacillus polymyxa presented cytokines [52].

Nitrogen is the most important nutrient for plant growth and productivity. Although abundant in the atmosphere, it is not available to plants. For this, it requires to be transformed by a biological nitrogen fixation (BNF) process in which \( N_2 \) is converted to \( NH_3 \) by bacteria expressing nitrogenase, such as Burkholderia spp., Azotobacter sp., Gluconacetobacter diazotrophicus, Herbaspirillum sp., Azospirillum brasilense, and Paenibacillus sp. [53–55]. Nitrogen-fixing endophytes outperform rhizosphere microorganisms in this process allowing plants to thrive even in nitrogen-limited soil environments, promoting plant health and growth [56]. Endophytic nitrogen-fixing bacteria can also increase the buildup and the nitrogen fixation rate in plants residing in soils with nitrogen limitation.

Phosphorus is an important micronutrient for the enzymatic reactions of plant physiological processes [57]. Although present in large quantities, most of the soil phosphorus is insoluble and therefore unavailable to the plant. In addition, almost 75% of phosphorus applied as fertilizer forms complexes in the soil, which prevents its absorption by the vegetable [58]. The endophytic bacteria can increase soil phosphorus availability to plants by solubilizing precipitated phosphates through mechanisms of acidification, chelation, ion exchange, and the production of organic acids [59]. They can also increase the availability of phosphorus in the soil by secreting acid phosphatase, which can mineralize organic phosphorus [60]. Furthermore, endophytic bacteria can prevent phosphate adsorption and fixation under phosphate-limiting conditions and assimilate solubilized phosphorus [61]. Studies show that endophytic populations of cactus, strawberry, sunflower, soybean, and other legumes have the ability to solubilize phosphate [62–64]. A study examined the role of phosphate-solubilizing endophytic bacteria in cactus cultivation and observed that inoculated plants grew well without added nutrients and that their growth was comparable to fertilized plants. This indicates that endophytic bacteria provide the limiting nutrient to seedlings [65].

Iron is a component of proteins that control physiological processes such as respiration and transpiration [66]. Generally, it occurs in the ferric insoluble form, unavailable to the plants. The endophytic bacteria produce iron chelators called siderophores that may bind to insoluble ferric ions allowing this nutrient uptake by plants [66–68]. The action of bacterial-produced siderophores has already been correlated with the growth of cultivars such as corn, including shoot and root biomass [69], and on tomato development in hydroponic crops [70].
The ability to promote plant growth by endophytic bacteria may be influenced by host genotype [71]. However, many endophytic bacteria can have a wide range of hosts, such as *B. phytofirmans*, which promote growth of *Arabidopsis thaliana*, grapes, corn, potatoes, grass, tomatoes, and wheat [72–74]. Similarly, the bacterial genotype also influences the capacity and potential of stimulatory effects over host plants. For example, the individual ability of different *B. phytofirmans* strains to promote growth of a single potato cultivar [75] and the plant colonization by different *Salmonella enterica* isolates were observed [76]. Therefore, colonization and growth promotion of plants by endophytic bacteria are active processes controlled by genetic factors of both partners.

4. Bioremediators

The prompt development of agriculture has made it possible to increase the food supply all over the world. However, the intensification of agricultural activities brought serious environmental impacts, which not only affect food security but also have impacts on socioeconomic aspects. These impacts comprise contribution to air pollution, impacts on land, waste of water, loss of biological and ecological diversity, and perturbation of global biogeochemical cycles. The pollutants generated by agricultural activities can affect the global or local scale. An example of global-scale agro-environmental problem is the increase in atmospheric concentrations of the greenhouse gases (GHG) and carbon dioxide (CO$_2$) through deforestation and nitrous oxide (N$_2$O) arising from crop production. Agriculture is the largest water consumer and the main source of nitrate, ammonia, and phosphate pollution. These pollutants affect the local scale; some examples are the salinization of irrigated lands and the buildup of nitrate fertilizer residues in groundwater and surface water [77–81].

Most of the negative environmental impacts generated by the intensification of agricultural activities can be reduced or prevented [77]. The use of new technological approaches, physicochemical- or biological-based, could remove pollutants from nature. Biological-based methods are preferred due to the low cost and because they are less harmful to the environment. Atlas and Pramer [82] defined the term bioremediation as “the use of biological agents to reclaim soils and waters polluted by substances hazardous to human health and/or the environment.” In other words, bioremediation is a biological-based method involving the use of living organisms, such as plants or microorganisms (bacteria, fungi, and algae), to remove pollutants from the environment [83].

Degradation of pollutants by a microorganism demands favorable conditions of nutrients, temperature, pH, and oxygen. Bacteria and fungi are commonly used in bioremediation strategies, because they are ubiquitous and capable in withstanding different environmental conditions, so they can be used for a broader range of application. There are two main mechanisms of bioremediation: biosorption and bioaccumulation. Biosorption involves sequestration of pollutants thought binding onto surfaces, such as the cell wall. Bioaccumulation involves transport and accumulation of pollutants in the cells and, in some cases, the transformation of pollutants into less harmful compounds [78, 83]. The degradation of target pollutants can also be achieved by employing nonliving subcellular entities of biological origin as bioremediators [84]. To overcome the instability due to the rapid decline in the inoculated cell amount during its competition with indigenous microorganisms, some authors have proposed solutions. For example, a new strategy for the efficient removal of phenylurea herbicides from contaminated soil uses transgenic plants. Transgenic *Arabidopsis thaliana* plants expressing a bacterial N-demethylase
(PdmAB) that demethylated isoproturon were constructed. The synergistic relationship between the transgenic plant and *Sphingobium* sp., which is capable of mineralizing the intermediate of isoproturon excreted from the transgenic plant in the rhizosphere, is an innovative strategy of treatment [85].

Endophytes can remove pollutants by employing either the biosorption or the bioaccumulation mechanisms [83, 86–90]. They have the ability of decreasing and/or removing contaminants from soil, water, sediments, and air. Endophytic fungi have a great potential to manage toxic pollutants; many studies report those fungi to clean up environmental pollutants, such as white rot fungi like *Phanerochaete chrysosporium* that can degrade pesticides, dyes, and xenobiotics [91, 92]. There are several examples of endophytic microorganisms with promising applications in bioremediation [93]. As an example, symbiotic fungal endophytes from agricultural, coastal, and geothermal native grasses colonized tomato plants and conferred disease, salt, and heat tolerance, respectively. Coastal plant endophyte colonized rice and conferred salt tolerance. In addition, coastal and geothermal plant endophytes conferred drought tolerance to monocot and eudicot hosts [88]. In leguminous plants including soybean, salinity is correlated with poor yield and reduction in plant growth [94]. Basidiomycetous endophytic fungus *Porostereum spadiceum* was reported to produce six types of gibberellins that reduce the effects of salinity in soybean by modulating endogenous phytohormones of the seedlings [95].

Heavy metals are one example of pollutants generated by agricultural activity that bioremediators can remove. The use of some pesticides and fertilizers can introduce into the environment copper (Cu), and some insecticide and herbicides can contain lead (Pb). Fungi have emerged as potential biocatalysts to access heavy metals and transform them into less toxic compounds [92, 96]. Endophytic fungi isolated of *Portulaca oleracea* growing in metal–contaminated soils increased the biomass *Brassica napus*. The results indicated that the endophytic fungus strain had the potential to remove heavy metals from contaminated water and soils [97]. Bioremediation of Pb–contaminated soil occurs by cultivation of *Solanum nigrum* combined with *Mucor circinelloides* [22]. Endophyte isolates from *Phragmites* also showed potential to metal tolerance and absorption of Cu, Pb, and chromium (Cr) [98].

Phytoremediation is the process that uses plants associated with microorganisms to remediate contaminants from soil, sludge, sediments, wastewater, and groundwater [92, 96]. Plants naturally harbor endophytes that may have natural tolerance and adaptation toward the pollutants. Studies explored the potential of using endophytes associated with plants for removal of pollutants in this process of phytoremediation [86, 88, 96, 99]. Plants growing in metal–contaminated soils accumulate the pollutant consumed directly or indirectly by humans and animals [100, 101]. Besides the human risk, polluted soil slows plant growth and reduces the biomass accumulation, compromising some crop productivity [102, 103]. Endophytic fungi resistant to different metals, including cadmium, lead, zinc (Zn), chromium, manganese (Mn), and cobalt (Co), are associated with plant species present in contaminated sites, indicating that these microorganisms have metal bioremediation potential [83, 97–99, 104, 105]. Chromium toxicity influences a number of processes that can lead to low yield. The accumulation of Cr from industrial activities in soil is a serious threat to some crops [106–108]. To minimize the Cr effects from contaminated soils, it is possible to use plants that harbor endophytic fungi that act as bioremediators. In experiments, strains of *Aspergillus fumigatus*, *Rhizopus* sp., *Penicillium radicum*, and *Fusarium proliferatum* isolated from healthy plants were able to remove Cr from soil and culture media as well as biotransform it from highly toxic hexavalent to least toxic trivalent form, instead of simply storing it. Roots of *Lactuca sativa* colonized by those endophytes restored its normal growth into Cr-contaminated soil, making them potential candidates as biofertilizer.
in Cr-contaminated soil. Likewise, *Rhizopus* sp. and *F. proliferatum* reduced the translocation of Cr to the leaves, making it safer for human consumption [102]. Other biofertilizer candidates to be used in fields affected with heavy metals are the endophytic *Mucor* sp. MHR-7 that presented tolerance to chromium, manganese, cobalt, copper, and zinc by biotransformation and/or accumulation of those metals in its hyphae. Co-cultivation of MHR-7 reduced in 90% the Cr absorption and promoted growth in mustard cultivation [103].

Studies reported the use of *Mucor* sp. in another remediation strategy called phytoextraction. Phytoextraction refers to the removal of heavy metal from the soil through their uptake by a metal-accumulating plant. One limitation is the long growth cycle of those plants. One strategy is to combine plants with endophytes that promote stress tolerance to toxicity and high biomass accumulation, increasing metal accumulation in plant tissues. Oilseed rape plants combined with *Mucor* sp. strains promoted stress tolerance to Cd and Pb, increasing biomass of plants and reducing the concentrations of those metals in the soil [109]. Similar results were found using the fungal endophyte *Peyronellaea* associated with maize under heavy metal stress [110], and the *Microsphaeropsis* sp. strain isolated from *Solanum nigrum* has also been studied for their biosorption capacity of cadmium [111]. Mercury volatilization and bioaccumulation of this metal in plant tissues mediated by endophytic fungi were demonstrated with *Aspergillus* sp. A31, *Curvularia geniculata* P1, *Lindgomycetaceae* P87, and *Westerdykella* sp. P71 on maize and *Aeschynomene fluminensis* [112].

Similar to metal pollutants, triphenylmethane (TPM) dyes are water-soluble organic compounds extensively used in industrial processes and have adverse effects on living organisms. TPM is phytotoxic for several cultivated plants, such as *Sorghum bicolor*, *Triticum aestivum*, *Vigna radiata*, *Lemna minor*, and *Zea mays* [83]. A *Diaporthe* sp. endophyte presented biosorption and biodegradation potential on TPM dyes. The microorganism removed TPM dyes through biodegradation and biosorption [113]. Other endophytes, *Pleurotus ostreatus*, *Polyporus picipes*, and *Gloeophyllum odoratum*, also demonstrate potential to remove TPM dye [114, 115].

5. Conclusion

Endophytic microorganisms are inestimable natural resources for solving problems in different areas such as human health, veterinary, industrial and ecological systems, and agronomy. In contrast to current agricultural practices that degrade systems and produce food with high concentrations of various contaminants, endophytes are a sustainable alternative to increase crop productivity. For this, they can be exploited by the ability to control pests, to promote plant growth, and by the bioremediation potential. This is possible because these microorganisms are able to induce resistance mechanisms in the host, release compounds with biological activity, compete for space and nutrients with pathogens, provide nutritional elements present in the soil, stimulate the production of phytohormones and cytokines, and neutralize the presence of pollutants in the system. Ultimately, bioprospecting and the use of endophytes in agriculture are a viable alternative to the need of increased food production with quality and sustainably.

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References

[1] Yuan Z, Zhang C, Lin F. Role of diverse non-systemic fungal endophytes in plant performance and response to stress: Progress and approaches. Journal of Plant Growth Regulation. 2010;29:116-126. DOI: 10.1007/s00344-009-9112-9

[2] Rosenblueth M, Martínez-Romero E. Bacterial endophytes and their interactions with hosts. Molecular Plant-Microbe Interactions. 2006;19:827-837. DOI: 10.1094/MPMI-19-0827

[3] Heimpel GE, Mills N, editors. Biological Control—Ecology and Applications. 1st ed. Cambridge: Cambridge University Press; 2017. DOI: 10.1017/9781139029117

[4] Card S, Johnson L, Teasdale S, Caradus J. Deciphering endophyte behaviour: The link between endophyte biology and efficacious biological control agents. FEMS Microbiology Ecology. 2016;92(8):1-19. DOI: 10.1093/femsec/fiw114

[5] Latz MAC, Jensen B, Collinge DB, Jørgensen HJL. Endophytic fungi as biocontrol agents: Elucidating mechanisms in disease suppression. Plant Ecology & Diversity. 2018;11:555-567. DOI: 10.1080/17550874.2018.1534146

[6] Jaber LR, Alananbeh KM. Fungal entomopathogens as endophytes reduce several species of *Fusarium* causing crown and root rot in sweet pepper (*Capsicum annuum* L.). Biological Control. 2018;126:117-126. DOI: 10.1016/j.biocontrol.2018.08.007

[7] Walters D, Newton A, Lyon G. Induced Resistance for Plant Defence—A Sustainable Approach to Crop Protection. Oxford: Blackwell Publishing; 2007. p. 272

[8] Agrios GN. Plant Pathology. 5th ed. San Diego: Elsevier Academic Press; 2005. p. 952

[9] Jones JDG, Dangl JL. The plant immune system. Nature. 2006;444:323-329. DOI: nature05286

[10] Bastias DA, Martínez-Ghersa MA, Ballaré CL, Gundel PE. Epichloë fungal endophytes and plant defenses: Not just alkaloids. Trend in Plant Science. 2017;22(11):939-948. DOI: 10.1016/j.tplants.2017.08.005

[11] Iason GR, Taylor J, Helfer S. Community-based biotic effects as determinants of tree resistance to pests and pathogens. Forest Ecology and Management. 2018;417:301-312. DOI: 10.1016/j.foreco.2018.01.037

[12] Araújo WL, Marcon J, Maccheroni W Jr, Van Elsas JD, Van Vuurde JW, Azevedo JL. Diversity of endophytic bacterial populations and their interaction with *Xylella fastidiosa* in citrus plants. Applied and Environmental Microbiology. 2002;68:4906-4914. DOI: 10.1128/aem.68.10.4906-4914.2002

[13] Bastias DA, Ueno AC, Assefh CRM, Alvarez AE, Young CA, Gundel PE. Metabolism or behavior: Explaining the performance of aphids on alkaloid-producing fungal endophytes in annual ryegrass (*Lolium multiflorum*). Oecologia. 2017;185:245-256. DOI: 10.1007/s00442-017-3940-2

[14] Waller F, Mukherjee K, Deshmukh SD, Achatz B, Sharma M, Schäfer P, et al. Systemic and local modulation of plant responses by *Piriformospora indica* and related *Sebacinales* species. Journal of Plant Physiology. 2008;165:60-70. DOI: 10.1016/j.jplph.2007.05.017

[15] Yedidia I, Benhamou N, Kapulnik Y, Chet I. Induction and accumulation of PR proteins activity during early stages of root colonization by the mycoparasite *Trichoderma harzianum* strain T-203.
[16] Mejía LC, Herre EA, Sparks JP, Winter K, García MN, Van Bael SA, et al. Pervasive effects of a dominant foliar endophytic fungus on host genetic and phenotypic expression in a tropical tree. Frontiers in Microbiology. 2014;5:479. DOI: 10.3389/fmicb.2014.00479

[17] Ji SH, Gururani MA, Chun SC. Expression Analysis of Rice Pathogenesis-related Proteins Involved in Stress Response and Endophytic Colonization Properties of gfp-tagged Bacillus subtilis CB-R05. Applied Biochemistry and Biotechnology. 2014;174:231-341. DOI: 10.1007/s12010-014-0073-3

[18] Liu D, Chen L, Zhu X, Wang Y, Xuan Y, Liu X, et al. Klebsiella pneumoniae SnebYK mediates resistance against Heterodera glycines and promotes soybean growth. Frontiers in Microbiology. 2018;9:1134. DOI: 10.3389/fmicb.2018.01134

[19] Martinuz A, Schouten A, Sikora RA. Systemically induced resistance and microbial competitive exclusion: Implications on biological control. Phytopathology. 2012;102:260-266. DOI: 10.1094/PHYTO-04-11-0120

[20] Cabanás CGL, Schilirò E, Valverde-Corredor A, Mercado-Blanco J. The biocontrol endophytic bacterium Pseudomonas fluorescens PICF7 induces systemic defense responses in aerial tissues upon colonization of olive roots. Frontiers in Microbiology. 2014;5. DOI: 10.3389/fmicb.2014.00427

[21] Siddiqui IA, Shaukat SS. Suppression of root-knot disease by Pseudomonas fluorescens CHA0 in tomato: Importance of bacterial secondary metabolite, 2,4-diacetylphloroglucinol. Soil Biology and Biochemistry. 2003;35:1615-1623. DOI: 10.1016/j.soilbio.2003.08.006

[22] Jacobs S, Zechmann B, Molitor A, Trujillo M, Petutscheg N, Lipka V, et al. Broad-spectrum suppression of innate immunity is required for colonization of Arabidopsis roots by the fungus Piriformospora indica. Plant Physiology. 2011;156:726-740. DOI: 10.1104/pp.111.176446

[23] Molitor A, Kogel KH. Induced resistance triggered by Piriformospora indica. Plant Signaling and Behavior. 2009;4:215-216. DOI: 10.4161/psb.4.3.7814

[24] Cosme M, Lu J, Erb M, Stout MJ, Franken P, Wurst S. A fungal endophyte helps plants to tolerate root herbivory through changes in gibberellin and jasmonate signaling. New Phytologist. 2016;211:1065-1076. DOI: 10.1111/nph.13957

[25] Tan RX, Zou WX. Endophytes: A rich source of functional metabolites. Natural Products Reports. 2001;18:448-459. DOI: 10.1039/b100918o

[26] Sessitsch A, Reitter B, Berg G. Endophytic bacterial communities of field-grown potato plants and their plant-growth-promoting and antagonistic abilities. Canadian Journal of Microbiology. 2004;50:239-249. DOI: 10.1139/w03-118

[27] Sturz AV, Kimpinski J. Endoroot bacteria derived from marigolds (Tagetes spp.) can decrease soil population densities of root lesion nematodes in the potato root zone. Plant and Soil. 2004;262:241-249. DOI: 10.1023/B:PLSO.0000037046.86670.a3

[28] Vinayarani G, Prakash HS. Fungal endophytes of turmeric (Curcuma longa L.) and their biocontrol potential against pathogens Pythium aphanidermatum and Rhizoctonia solani. World Journal of Microbiology
[29] Singh SP, Gaur R. Endophytic Streptomyces spp. underscore induction of defense regulatory genes and confers resistance against Sclerotium rolfsii in Chickpea. Biological Control. 2017;104:44-56. DOI: 10.1016/j.biocontrol.2016.10.011

[30] Kang W, Zhu X, Wang Y, Chen L, Duan Y. Transcriptomic and metabolomic analyses reveal that bacteria promote plant defense during infection of soybean cyst nematode in soybean. BMC Plant Biology. 2018;18:86. DOI: 10.1186/s12870-018-1302-9

[31] Viterbo A, Horwitz BA. Mycoparasitism. In: Borkovich KA, Ebbole DJ, editors. Cellular and Molecular of Filamentous Fungi. Washington: ASM Press; 2010. pp. 676-677. DOI: 10.1128/9781555816636.ch42

[32] Arnold AE, Mejia LC, Kyllo D, Rojas EI, Maynard Z, Robbins N, et al. Fungal endophytes limit pathogen damage in a tropical tree. Proceedings of the National Academy of Sciences. 2003;100:15649-15654. DOI: 10.1073/pnas.2533483100

[33] Souza JT, Bailey BA, Pomella AWV, Erbe EF, Murphy CA, Bae G, et al. Colonization of cacao seedlings by Trichoderma stromaticum, a mycoparasite of the witches’ broom pathogen, and its influence on plant growth and resistance. Biological Control. 2008;46:36-45. DOI: 10.1016/j.biocontrol.2008.01.010

[34] Amira MB, Lopez D, Mohamed AT, Khouaja A, Chaar H, Fumanal B, et al. Beneficial effect of Trichoderma harzianum strain Ths97 in biocontrolling Fusarium solani causal agent of root rot disease in olive trees. Biological Control. 2017;110:70-78. DOI: 10.1016/j.biocontrol.2017.04.008

[35] Preto G, Martins F, Pereira JA, Baptista P. Fungal community in olive fruits of cultivars with different susceptibilities to anthracnose and selection of isolates to be used as biocontrol agents. Biological Control. 2017;110:1-9. DOI: 10.1016/j.biocontrol.2017.03.011

[36] Ribeiro AS, Polonio JC, Costa AT, Santos CM, Rhoden SA, Azevedo JL, et al. Bioprospection of cultivable endophytic fungi associated with the ornamental plant Pachystachys lutea. Current Microbiology. 2018;75:588-596. DOI: 10.1007/s00284-017-1421-9

[37] Glick BR. The enhancement of plant growth by free living bacteria. Canadian Journal of Microbiology. 1995;41:109-117. DOI: 10.1139/m95-015

[38] Madhaiyan M, Suresh Reddy BV, Anandham R, et al. Plant growth–promoting Methylobacterium induces defense responses in groundnut (Arachis hypogaea L.) compared with rot pathogens. Current Microbiology. 2006;53:270. DOI: 10.1007/s00284-005-0452-9

[39] Wakelin SA, Warren RA, Harvey PR, et al. Phosphate solubilization by Penicillium spp. closely associated with wheat roots. Biology and Fertility of Soils. 2004;40:36-43. DOI: 10.1007/s00374-004-0750-6

[40] Rasouli-Sadaghiani M, Malakouti MJ, Khavazi K, Miransari M. Siderophore efficacy of fluorescent pseudomonades affecting labeled iron (59Fe) uptake by wheat (Triticum aestivum L.) genotypes differing in Fe efficiency. In: Miransari M, editor. Use of Microbes for the Alleviation of Soil Stresses. New York: Springer; 2014. pp. 121-132. DOI: 10.1007/978-1-4939-0721-2_7

[41] Berninger T, Mitter B, Preininger C. The smaller, the better? The size
effect of alginate beads carrying plant growth-promoting bacteria for seed coating. Journal of Microencapsulation. 2016;33:127-136. DOI: 10.3109/02652048.2015.1134690

[42] Santoyo G, Moreno-Hagelsieb G, Orozco-Mosqueda MC, Glick BR. Plant growth-promoting bacterial endophytes. Microbiological Research. 2016;183:92-99. DOI: 10.1016/j.micres.2015.11.008

[43] Shahzad R, Khan AL, Bilal S, Asaf S, Lee IJ. Plant growth-promoting endophytic bacteria versus pathogenic infections: An example of Bacillus amyloliquefaciens RWL-1 and Fusarium oxysporum f. sp. lycopersici in tomato. PeerJ. 2017;5:e3107. DOI: 10.7717/peerj.3107

[44] Liffourrena AS, Lucchesi GI. Alginate-perlite encapsulated Pseudomonas putida A (ATCC 12633) cells: Preparation, characterization and potential use as plant inoculants. Journal of Biotechnology. 2018;278:28-33. DOI: 10.1016/j.jbiotec.2018.04.019

[45] Woodward AW, Bartel B. Auxin: Regulation, action, and interaction. Annals of Botany. 2005;95:707-735. DOI: 10.1093/aob/mci083

[46] Sun L, Wang X, Li Y. Increased plant growth and copper uptake of host and non-host plants by metal-resistant and plant growth-promoting endophytic bacteria. International Journal of Phytoremediation. 2016;18:494-501. DOI: 10.1080/15226514.2015.1115962

[47] Glick BR, Todorovic B, Czarny J, Cheng Z, Duan J, McConkey B. Promotion of plant growth by bacterial ACC deaminase. Critical Reviews in Plant Sciences. 2007;26:227-242. DOI: 10.1080/07352680701572966

[48] Sun Y, Cheng Z, Glick BR. The presence of a 1-aminocyclopropane-1-carboxylate (ACC) deaminase deletion mutation alters the physiology of the endophytic plant growth-promoting bacterium Burkholderia phytofirmans PsJN. FEMS Microbiology Letters. 2009;296:131-136. DOI: 10.1111/j.1574-6968.2009.01625.x

[49] Nikolic B, Schwab H, Sessitsch A. Metagenomic analysis of the 1-aminocyclopropane-1-carboxylate deaminase gene (acdS) operon of an uncultured bacterial endophyte colonizing Solanum tuberosum L. Archives of Microbiology. 2011;193:665. DOI: 10.1007/s00203-011-0703-z

[50] Spaepen S, Vanderleyden J, Remans R. Indole-3-acetic acid in microbial and microorganism-plant signaling. FEMS Microbiology Reviews. 2007;31:425-448. DOI: 10.1111/j.1574-6976.2007.00072.x

[51] Cohena AC, Travaglia CN, Bottini R, Piccoli PN. Participation of abscisic acid and gibberellins produced by endophytic Azospirillum in the alleviation of drought effects in maize. Botany. 2009;87:462-487. DOI: 10.1139/B09-023

[52] Bhore SJ, Ravichantar N, Loh SY. Screening of endophytic bacteria isolated from leaves of Sambung Nyawa Gynura procumbens Lour Merr. for cytokinin-like compounds. Bioinformation. 2010;5:191-197. DOI: 10.6026/97320630005191

[53] Scherling C, Ulrich K, Ewald D, Weckwerth W. A metabolic signature of the beneficial interaction of the endophyte Paenibacillus sp. isolate and in vitro–grown poplar plants revealed by metabolomics. APS Publications. 2009;22:1032-1037. DOI: 10.1094/MPMI-22-8-1032

[54] Singh A. Soil salinization and waterlogging: A threat to environment and agricultural sustainability. Ecological Indicators. 2015;57:128-130. DOI: 10.1016/j.ecolind.2015.04.027
[55] Ivleva NB, Groat J, Staub JM, Stephens M. Expression of active subunit of nitrogenase via integration into plant organelle genome. PLoS One. 2016;11(8):e0160951. DOI: 10.1371/journal.pone.0160951

[56] Hurek T, Reinhold-Hurek B. Azorarcus sp. strain BH72 as a model for nitrogen-fixing grass endophytes. Journal of Biotechnology. 2003;106:169-178. DOI: 10.1016/j.jbiotec.2003.07.010

[57] Ahemad M. Phosphate-solubilizing bacteria-assisted phytoremediation of metalliferous soils: A review. 3 Biotech. 2015;5:111-121. DOI: 10.1007/s13205-014-0206-0

[58] Ezawa T, Smith SE, Smith FA. P metabolism and transport in AM fungi. Plant and Soil. 2002;224:221-230. DOI: 10.1023/A:102025832

[59] Nautilial CS, Bhadauria S, Kumar P, Lal H, Mondal R, Verma D. Stress induced phosphate solubilization in bacteria isolated from alkaline soils. FEMS Microbiology Letters. 2000;182:291-296. DOI: 10.1111/j.1574-6968.2000.tb08910.x

[60] Van Der Heijden MG, Bardgett RD, Van Straalen NM. The unseen majority: Soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecology Letters. 2008;11:296-310. DOI: 10.1111/j.1461-0248.2007.01139.x

[61] Khan KS, Joergensen RG. Changes in microbial biomass and P fractions in biogenic household waste compost amended with inorganic P fertilizers. Bioresource Technology. 2009;100:303-309. DOI: 10.1016/j.biortech.2008.06.002

[62] Kuklinsky-Sobral J, Araújo WL, Mendes R, et al. Isolation and characterization of soybean-associated bacteria and their potential for plant growth promotion. Plant and Soil. 2005;273:91-99. DOI: 10.1007/s11104-004-6894-1

[63] Dias AC, Costa FE, Andreote FD, Lacava PT, Teixeira MA, Assumpção LC, et al. Isolation of micropropagated strawberry endophytic bacteria and assessment of their potential for plant growth promotion. World Journal of Microbiology and Biotechnology. 2009;25:189-195. DOI: 10.1007/s11274-008-9878-0

[64] Puente ME, Li CY, Bashan Y. Endophytic bacteria in cacti seeds can improve the development of cactus seedlings. Environmental and Experimental Botany. 2009;66:402-408. DOI: 10.1016/j.envexpbot.2009.04.007

[65] Puente ME, Li CY, Bashan Y. Rock-degrading endophytic bacteria in cacti. Environmental and Experimental Botany. 2009;66:389-401. DOI: 10.1016/j.envexpbot.2009.04.010

[66] Ma Y, Rajkumar M, Zhang C, Freitas H. Beneficial role of bacterial endophytes in heavy metal phytoremediation. Journal of Environmental Management. 2016;174:14-25. DOI: 10.1016/j.jenvman.2016.02.047

[67] Rajkumar M, Ae N, Freitas H. Endophytic bacteria and their potential to enhance heavy metal phytoextraction. Chemosphere. 2009;77:153-160. DOI: 10.1016/j.chemosphere.2009.06.047

[68] Crowley DE, Römheld V, Marschner H, et al. Root-microbial effects on plant iron uptake from siderophores and phytosiderophores. Plant and Soil. 1992;142:1-7. DOI: 10.1007/BF00010169

[69] Marques AP, Pires C, Moreira H, Rangel AO, Castro PM. Assessment of the plant growth promotion abilities of six bacterial isolates using Zea mays
as indicator plant. Soil Biology and Biochemistry. 2010;42:1229-1235. DOI: 10.1016/j.soilbio.2010.04.014

[70] Radzki W, Mañero FG, Algar E, García JL, García-Villaraco A, Solano BR. Bacterial siderophores efficiently provide iron to iron-starved tomato plants in hydroponics culture. Antonie Van Leeuwenhoek. 2013;104:321-330. DOI: 10.1007/s10482-013-9954-9

[71] Long HH, Schmidt DD, Baldwin IT. Native bacterial endophytes promote host growth in a species-specific manner; phytohormone manipulations do not result in common growth responses. PLoS One. 2008;3:e2702. DOI: 10.1371/journal.pone.0002702

[72] Pillay V, Nowak J. Inoculum density, temperature, and genotype effects on in vitro growth promotion and epiphytic and endophytic colonization of tomato (Lycopersicon esculentum L.) seedlings inoculated with a pseudomonad bacterium. Canadian Journal of Microbiology. 1997;43:354-361. DOI: 10.1139/m97-049

[73] Sessitsch A, Coenye T, Sturz A, Vandamme P, Barka EA, Salles J, et al. Burkholderia phytofirmans sp. nov., a novel plant-associated bacterium with plant-beneficial properties. International Journal of Systematic and Evolutionary Microbiology. 2005;55:1187-1192. DOI: 10.1099/ijs.0.63149-0

[74] Sheibani-Tezerji R, Rattei T, Sessitsch A, Trognitz F, Mitter B. Transcriptome profiling of the endophyte Burkholderia phytofirmans PsJN indicates sensing of the plant environment and drought stress. MBio. 2015;6:e00621-e00615. DOI: 10.1128/mBio.00621-15

[75] Trognitz F, Scherwinski K, Fekete A, Schmidt S, Eberl L, Rodewald J, et al. Interaction between potato and the endophyte Burkholderia phytofirmans. In: Abwehrstrategien gegen biotische Schaderreger Züchtung von Hackfrüchten und Sonderkulturen. Tagungsband der 59. Jahrestagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs; 25-27 November 2008; Raumberg-Gumpenstein. Austria. 2008. pp. 63-66

[76] Dong Z, Canny MJ, McCully ME, Roboredo MR, Cabadilla CF, Ortega E, et al. A nitrogen-fixing endophyte of sugarcane stems (a new role for the apoplast). Plant Physiology. 1994;105:1139-1147. DOI: 10.1104/pp.105.4.1139

[77] Bruinsma J. World Agriculture: Towards 2015/2030. London: Routledge; 2003

[78] Henis Y. Bioremediation in agriculture: Dream or reality? In: Rosen D, Tel-Or E, Hadar Y, Chen Y, editors. Modern Agriculture and the Environment: Proceedings of an International Conference, held in Rehovot, Israel, 2–6 October 1994, under the auspices of the Faculty of Agriculture, the Hebrew University of Jerusalem. Dordrecht: Springer Netherlands; 1997. pp. 481-489

[79] Parris K. Impact of agriculture on water pollution in OECD countries: Recent trends and future prospects. International Journal of Water Resources Development. 2011;27:33-52. DOI: 10.1080/07900627.2010.531898

[80] Tilman D. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proceedings of the National Academy of Sciences. 1999;96:5995-6000. DOI: 10.1073/pnas.96.11.5995

[81] Yu J, Wu J. The Sustainability of agricultural development in China: The agriculture–environment nexus. Sustainability. 2018;10:1776. DOI: 10.3390/su10061776
[82] Atlas RM, Pramer D. Focus on bioremediation. ASM News. 1990;56:352-354

[83] Sim CSF, Chen SH, Ting ASY. Endophytes: Emerging tools for the bioremediation of pollutants. In: Bharagava RN, Chowdhary P, editors. Emerging and Eco-Friendly Approaches for Waste Management. Singapore: Springer Singapore; 2019. pp. 189-217

[84] Zaccaria M, Dawson W, Cristiglio V, Reverberi M, Ratcliff LE, Nakajima T, et al. Designing a bioremediator: Mechanistic models guide cellular and molecular specialization. Current Opinion in Biotechnology. 2020;62:98-105. DOI: 10.1016/j.copbio.2019.09.006

[85] Yan X, Huang J, Xu X, Chen D, Xie X, Tao Q, et al. Enhanced and complete removal of phenylurea herbicides by combinational transgenic plant-microbe remediation. Applied and Environmental Microbiology. 2018;84:e00273-e00218. DOI: 10.1128/AEM.00273-18

[86] Anyasi RO, Atagana HI. Endophyte: Understanding the microbes and its applications. Pakistan Journal of Biological Sciences. 2019;22:154-167. DOI: 10.3923/pjbs.2019.154.167

[87] Manzotti A, Jørgensen HJL, Collinge DB, Jensen B. Phytohormones in plant-endophyte interactions: Investigating the role of these compounds in the recruitment of tomato root fungal endophytes. Plant Biology. 2017;9:89-105. DOI: 10.1007/978-3-319-65897-1_6

[88] Rodriguez RJ, Henson J, Van Volkenburgh E, Hoy M, Wright L, Beckwith F, et al. Stress tolerance in plants via habitat-adapted symbiosis. The ISME Journal. 2008;2:404-416. DOI: 10.1038/isemj.2007.106

[89] Tonial F, Maia BHLNS, Gomes-Figueiredo JA, Sobottka AM, Bertol CD, Nepa A, et al. Influence of culturing conditions on bioprospecting and the antimicrobial potential of endophytic fungi from Schinus terebinthifolius. Current Microbiology. 2016;72:173-183. DOI: 10.1007/s00284-015-0929-0

[90] Savi DC, Aluizio R, Glienke C. Brazilian plants: An unexplored source of endophytes as producers of active metabolites. Planta Medica. 2019;85:619-636. DOI: 10.1055/a-0847-1532

[91] Gadd GM. Geomycology: Biogeochemical transformations of rocks, minerals, metals and radionuclides by fungi, bioweathering and bioremediation. Mycological Research. 2007;111:3-49. DOI: 10.1016/j.mycres.2006.12.001

[92] Krishnamurthy YL, Naik BS. Endophytic fungi bioremediation. In: Endophytes: Crop Productivity and Protection. Switzerland: Springer Nature Switzerland AG; 2017. pp. 47-60

[93] Stepniewska Z, Kuznia A. Endophytic microorganisms—Promising applications in bioremediation of greenhouse gases. Applied Microbiology and Biotechnology. 2013;97:9589-9596. DOI: 10.1007/s00253-013-5235-9

[94] Dinler BS, Antoniou C, Fotopoulos V. Interplay between GST and nitric oxide in the early response of soybean (Glycine max L.) plants to salinity stress. Journal of Plant Physiology. 2014;171:1740-1747. DOI: 10.1016/j.jplph.2014.07.026

[95] Hamayun M, Hussain A, Khan SA, Kim H-Y, Khan AL, Waqas M, et al. Gibberellins producing endophytic fungus Porostereum spadiceum AGH786 rescues growth of salt affected soybean. Frontiers in Microbiology. 2017;8:686. DOI: 10.3389/fmicb.2017.00686

[96] Dixit R, Malaviya D, Pandiyan K, Singh UB, Sahu A, Shukla R, et al. Bioremediation of heavy metals from soil
and aquatic environment: An overview of principles and criteria of fundamental processes. Sustainability. 2015;7:2189-2212. DOI: 10.3390/su7022189

[97] Deng Z, Zhang R, Shi Y, La H, Tan H, Cao L. Characterization of Cd-, Pb-, Zn-resistant endophytic Lasiodiplodia sp. MXSF31 from metal accumulating Portulaca oleracea and its potential in promoting the growth of rape in metal-contaminated soils. Environmental Science and Pollution Research. 2014;21:2346-2357. DOI: 10.1007/s11356-013-2163-2

[98] Sim CSF, Tan WS, Ting ASY. Endophytes from Phragmites for metal removal: Evaluating their metal tolerance, adaptive tolerance behaviour and biosorption efficacy. Desalination and Water Treatment. 2016;57:6959-6966. DOI: 10.1080/19443994.2015.1013507

[99] Fu X-Y, Zhao W, Xiong A-S, Tian Y-S, Zhu B, Peng R-H, et al. Phytoremediation of triphenylmethane dyes by overexpressing a Citrobacter sp. triphenylmethane reductase in transgenic Arabidopsis. Applied Microbiology and Biotechnology. 2013;97:1799-1806. DOI: 10.1007/s00253-012-4106-0

[100] Wang S, Shi X. Molecular mechanisms of metal toxicity and carcinogenesis. In: Shi X, Castranova V, Vallyathan V, Perry WG, editors. Molecular Mechanisms of Metal Toxicity and Carcinogenesis. Boston, MA: Springer US; 2001. pp. 3-9

[101] Clemens S, Ma JF. Toxic heavy metal and metalloid accumulation in crop plants and foods. Annual Review of Plant Biology. 2016;67:489-512. DOI: 10.1146/annurev-arplant-043015-11230

[102] Bibi S, Hussain A, Hamayun M, Rahman H, Iqbal A, Shah M, et al. Bioremediation of hexavalent chromium by endophytic fungi; safe and improved production of Lactuca sativa L. Chemosphere. 2018;211:653-663. DOI: 10.1016/j.chemosphere.2018.07.197

[103] Zahoor M, Irshad M, Rahman H, Qasim M, Afridi SG, Qadir M, et al. Alleviation of heavy metal toxicity and phytostimulation of Brassica campestris L. by endophytic Mucor sp. MHR-7. Ecotoxicology and Environmental Safety. 2017;142:139-149. DOI: 10.1016/j.ecoenv.2017.04.005

[104] Sun L, Cao X, Li M, Zhang X, Li X, Cui Z. Enhanced bioremediation of lead-contaminated soil by Solanum nigrum L. with Mucor circinelloides. Environmental Science and Pollution Research. 2017;24:9681-9689. DOI: 10.1007/s11356-017-8637-x

[105] An H, Liu Y, Zhao X, Huang Q, Yuan S, Yang X, et al. Characterization of cadmium-resistant endophytic fungi from Salix variegata Franch in three gorges reservoir region, China. Microbiological Research. 2015;176:29-37. DOI: 10.1016/j.micres.2015.03.013

[106] Tchounouw PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and the environment. In: Luch A, editor. Molecular, Clinical and Environmental Toxicology: Volume 3: Environmental Toxicology. Basel: Springer Basel; 2012. pp. 133-164

[107] Gill RA, Ali B, Cui P, Shen E, Farooq MA, Islam F, et al. Comparative transcriptome profiling of two Brassica napus cultivars under chromium toxicity and its alleviation by reduced glutathione. BMC Genomics. 2016;17:885. DOI: 10.1186/s12864-016-3200-6

[108] López-Bucio J, Hernández-Madrígal F, Cervantes C, Ortiz-Castro R, Carreón-Abud Y, Martínez-Trujillo M. Phosphate relieves chromium toxicity in Arabidopsis thaliana plants by interfering with chromate uptake.
Biometals. 2014;27:363-370. DOI: 10.1007/s10534-014-9718-7

Zhu S-C, Tang J-X, Zeng X-X, Wei B-J, Yang S-D, Huang B. Isolation of Mucor circinelloides Z4 and Mucor racemosus Z8 from heavy metal-contaminated soil and their potential in promoting phytoextraction with Guizhou oilseed rap. Journal of Central South University. 2015;22:88-94. DOI: 10.1007/s11771-015-2498-6

Shen M, Liu L, Li D-W, Zhou W-N, Zhou Z-P, Zhang C-F, et al. The effect of endophytic Peyronellaea from heavy metal-contaminated and uncontaminated sites on maize growth, heavy metal absorption and accumulation. Fungal Ecology. 2013;6:539-645. DOI: 10.1016/j.funeco.2013.08.001

Xiao X, Luo S, Zeng G, Wei W, Wan Y, Chen L, et al. Biosorption of cadmium by endophytic fungus (EF) Microsphaeropsis sp. LSE10 isolated from cadmium hyperaccumulator Solanum nigrum L. Bioresource Technology. 2010;101:1668-1674. DOI: 10.1016/j.biortech.2009.09.083

Pietro-Souza W, de Campos Pereira F, Mello IS, Stachack FFF, Terezo AJ, Cunha CN, et al. Mercury resistance and bioremediation mediated by endophytic fungi. Chemosphere. 2020;240:124874. DOI: 10.1016/j.chemosphere.2019.124874

Ting ASY, Lee MVJ, Chow YY, Cheong SL. Novel exploration of endophytic Diaporthe sp. for the biosorption and biodegradation of triphenylmethane dyes. Water, Air, & Soil Pollution. 2016;227:109. DOI: 10.1007/s11270-016-2810-6

Przystaś W, Zabłocka-Godlewska E, Grabińska-Sota E. Biological removal of azo and triphenylmethane dyes and toxicity of process by-products. Water, Air, & Soil Pollution. 2012;223:1581-1592. DOI: 10.1007/s11270-011-0966-7

Gangadevi V, Muthumary J. Isolation of Colletotrichum gloeosporioides, a novel endophytic taxol-producing fungus from the leaves of a medicinal plant, Justicia gendarussa. Mycologia Balcanica. 2008;5:1-4. DOI: 10.1.1.457.1000