



E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(4): 3250-3254
Received: 25-05-2019
Accepted: 27-06-2019

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Fungal endophytes in improving plant tolerance to drought stress: A review

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Abstract

Plant lives are continuously being challenged with numerous biotic and abiotic stresses at some point of their life cycle that exert profound deleterious outcomes on growth and development. Plants rent diverse physiological, biochemical and molecular mechanisms to combat these stress elements. Microorganism-mediated plant tolerance, especially plant drought tolerance is crucial, despite the fact that surprisingly much less well-known, fungal endophyte-mediated plant drought tolerance has been described for several cases. Unlike mycorrhizal fungi, non-mycorrhizal fungi may additionally mediate the effects of water stress by means of adjusting, regulating or modifying plant physiological, biochemical and metabolic sports. Right here is the evidence for fungal endophyte-mediated plant drought tolerance and mechanisms.

Keywords: Abiotic stress, drought tolerance, fungal endophytes

Introduction

Meaning of 'endophyte' we characterize endophytes dependent on the definition proposed by Hallmann *et al.* (1997) [13], as 'those microorganisms that can be disengaged from surface-purified plant tissue or extricated from inside the plant, and that don't effect the plant'.

It has been evaluated that over 80% of plants with symbiotic relationship with fungi (Smith and Read, 1997) [31] Species of growths that dwell inside living plant tissue without causing manifestations of infection in their host are known as contagious endophytes. Parasitic endophytes colonize in both monocot and dicots plants which recommends that this advantageous interaction originated before the monocot-dicot split 140-150 million years ago (Shu-Miaw *et al.*, 2004) [30]. It is suggested that phototroph-growth affiliations empowered plants to initially colonize land (Selosse and Le Tacon, 1998) [28]. This mutualistic association could have helped plants adjust to new natural burdens, for example, drying up, sun oriented radiation, and progressively outrageous temperatures differences (Selosse and Le Tacon, 1998) [28].

Parasitic endophytes remain a significant segment of the present biological systems, and many empower their hosts to flourish in extreme conditions. Studies demonstrate that contagious endophytes can upgrade the dry spell, salt, and soil temperature resilience of their host plant notwithstanding expanding protection from parasitic growths and herbivores (Rodriguez *et al.*, 2009) [25]. With developing worries about environmental change and its impacts on agriculture, finding out about parasitic endophyte presented dry season resistance has turned out to be progressively significant. By affecting plant morphology, advancement, and physiological and biochemical reactions to stretch, contagious endophytes can induce mechanisms of dry spell evasion, dry season resilience, and dry season recuperation in their hosts.

Role in the ecosystem

Parasitic endophytes assume important role in biological systems by ensuring plants against numerous biotic and abiotic stresses, expanding their flexibility, and helping plants to adjust to new environments (Strobel and Daisy, 2003; Schulz 2006; Rodriguez and Redman, 2008; Aly *et al.*, 2011; Friesen 2013) [32, 27, 24, 1, 12]. Biotic stress from which endophytes can give protection against plant pathogens, creepy crawlies and nematodes. Abiotic stresses incorporate supplement constraint, dry spell, salination and outrageous pH esteems and temperatures. Consequently, plants give spatial structure, assurance from drying up, supplements and, on account of vertical transmission, scattering to the up and coming age of hosts (Schulz 2006; Aly *et al.*, 2011) [27, 1]. Endophytes may assume a job in the biological system by influencing plant development through opposing parasitic contagious collaborations. A model is the cooperation between the pathogen *Ustilago maydis* and the endophyte *Fusarium verticillioides* inside their host plant have (Maize, *Zea mays*), whereby

the endophyte is equipped for diminishing the pace of pathogen development, conceivably by emitting metabolites that separate plant intensifies that breaking point *U. maydis* development (Rodriguez Estrada *et al.*, 2012) [23]. A further job of some parasitic endophytes in environments might be to start the organic debasement of a dead or biting the dust host plant which begins the procedure of supplement reusing (Strobel and Daisy, 2003; Zhang *et al.*, 2006; Vega *et al.*, 2010; Aly *et al.*, 2011; Boberg *et al.*, 2011) [32, 40, 36, 1, 5].

A study of grass endophytes by Vazquez de Aldana *et al.*, 2013) [35] demonstrates that the command endophyte taxa of grasses are additionally found as regular airborne parasites. They guess that the progress from an endophyte to a saprobe requires sporulation after host senescence for a portion of these animal types to finish their life cycle. Being built up in tissues, endophytes have quick access to plant supplements accessible during plant senescence (Rodriguez and Redman, 2008; Aly *et al.*, 2011) [24, 1].

Fungal endophytes for conferring abiotic stress, including impacts of climate change

A review of grass endophytes by Vazquez de Aldana *et al.* (2013) [35] demonstrates that the command endophyte taxa of grasses are likewise found as basic airborne growths. They theorize that the progress from an endophyte to a saprobe requires sporulation after host senescence for a portion of these animal categories to finish their life cycle. Being built up in tissues, endophytes have quick access to plant supplements accessible during plant senescence (Rodriguez and Redman, 2008; Aly *et al.*, 2011) [24, 1]. A huge number of class 2 endophytes have been observed to be fit for living space adaption giving resilience to environment explicit particular weights, for example, soil pH, temperature and saltiness (Rodriguez *et al.* 2009) [25]. Rodriguez and Redman (2008) [24] showed that grass species adjusted to waterfront and geothermal living spaces harbor advantageous contagious endophytes that give saltiness and warmth resilience, separately. *Leymus mollis* (dune grass) plants from a few seaside shoreline living spaces in the USA were demonstrated to be advantageous with the endophyte *Fusarium culmorum* which, when immunized into salt sensitive non-beach front plants, presented salt resilience to those plants (Rodriguez and Redman, 2008) [24]. This relationship however is more complex as it was discovered that the endophyte harbors a virus in a tripartite mutualistic symbiosis and that the virus is an essential partner for bestowing heat tolerance to host plants, whereas virus-free endophytes were incapable of conferring this trait (Marquez *et al.*, 2007) [16]. These habitat-specific symbionts also have a broad host range and have been shown to be able to confer habitat-specific tolerance to other plant species. For instance, an endophyte from waterfront plants can colonize the model monocot, rice, and give salt resilience, while endophytes from different environments (rural, seaside and geothermal) can give malady obstruction however not salt or warmth resistance to the model dicot tomato (Rodriguez and Redman, 2008) [24]. Strangely, all these endophytes gave dry season resistance to plants paying little mind to the environment of beginning (Rodriguez and Redman, 2008) [24]. Diminished water accessibility and expanded soil salinization is a developing test to edit development in numerous pieces of the world (Egamberdieva *et al.*, 2008; Egamberdieva and Lugtenberg, 2014) [9, 10] and this issue is relied upon to increment because of environmental change impacts. The capacity of parasitic endophytes to present pressure resistance to plants may give a

novel technique to relieving the effects of worldwide environmental change on farming plant networks (Rodriguez and Redman, 2008). Redman *et al.* (2011) [24, 21] demonstrated that some class 2 contagious endophytes can give salt and dry spell resistance to two business rice assortments which were not adjusted to these anxieties. Additionally, these endophytes decreased water utilization by 20%–30% while expanding development rate, regenerative yield and biomass of nursery developed plants. They additionally gave cold resilience to development chamber and nursery developed plants. These discoveries show that the fuse of parasitic symbionts might be a helpful system in both moderating effects of environmental change on significant harvests and growing agrarian generation onto minimal grounds (Redman *et al.* 2011) [21]. Going to endophytes that can possibly advance plant development, *P. indica* (presented in the segment contagious endophytes for giving nuisance and ailment opposition) is known for its advancement of vegetative development, early blossoming, seed setting and seed germination which has been over and over seen with species from different plant families (Franken, 2012) [11]. A broad arrangement of phytohormones and phytohormone flagging systems appear to be associated with intervening plant development limited time exercises which lead to expanded early root development advancement lastly to more noteworthy biomass. The degree of development advancement is normally around half, however noteworthy variety exists, due to some degree to changeability in the natural and exploratory conditions wherein the plants are developed. Impressive research has been done on the component of salt pressure resistance met to plants colonized with *P. indica* and this quality has been shown for grain just as wheat, rice and tobacco and includes the enlistment of a high cancer prevention agent condition for the detoxification of responsive oxygen species and an upgraded photosynthetic productivity (Johnson *et al.*, 2014) [14]. *Piriformospora indica's* wide host benefits just as its agreeability for central organic examinations are appealing properties for research and its capability to change the profitability of agrarian harvests economically is energizing. As for grain, *P. indica* collaborations have indicated improved grain yield (Waller *et al.*, 2005) [34] and at low temperatures with higher supplement input, *P. indica* likewise seemed to trigger blooming before and still increment grain yield. These outcomes demonstrate that *P. indica* could be created as a powerful harvest treatment in low temperature-focused on grain and may can possibly build yield under colder developing situations on the stipulation that sufficient supplements are provided. In any case, not withstanding these depicted advantages, Franken (2012) [11] states that it might be hard to put *P. indica* available in light of the fact that (i) the parasite was first separated in India and is ensured by patent in numerous nations making any business prospect dependent on the patent proprietor to assembling it or permitting it for production, and (ii) it at times has unexplained negative consequences for plant development. Regardless, a powder plan of *P. indica* has been created under the exchange name 'ROOTONIC' and is right now conveyed in field preliminaries in India (Varma *et al.*, 2013; Shrivastava and Varma, 2014) [29, 34]. There are additionally different endophytes of grain that can possibly be profitable in horticultural settings. Murphy *et al.* (2015) [17] separated endophytic organisms from wild grain (*H. murinum* subsp. *murinum* L.) and notwithstanding different other biotic advantages recently portrayed (in the area 'Parasitic endophytes for presenting irritation and infection opposition'), in any event one of these

detaches had the option to build grain yield in a supplement insufficient grain cultivar (by up to 29%). The best effect one of these endophytic confines had on grain yield and shoot dry weight was accomplished under the most minimal supplement input. Such strains may in this manner have the option to help by diminishing manure inputs while keeping up worthy yields. Proceeding with the topic of improving plant execution, the class 4 or DSE root-colonizing organisms, that are portrayed by their hazily melanized septa, are an intriguing gathering of endophytes that are available in a wide scope of earthly biological systems, yet are particularly normal in polar and elevated living spaces (Rodriguez *et al.*, 2009) [25]. In these cold and water-focused on conditions, arbuscular mycorrhizal parasites, the average mutualists of grass roots at lower elevations and scopes, are basically missing (Newsham, 2011) [19] and it has been recommended that DSE species may go about as surrogate mycorrhiza in these natural surroundings (Bledsoe *et al.*, 1990) [4]. Inoculation of monocotyledonous and dicotyledonous plant species with these organisms builds root and shoot biomass, and shoot nitrogen and phosphorous substance. Meta-examinations performed by Newsham (2011) [19] on information from 18 research articles, in which plants had been vaccinated with DSE species, showed that they can improve plant execution under controlled conditions, especially when the vast majority of the nitrogen is accessible in a natural structure, for example, proteins, peptides and amino acids in the rhizosphere. Plants clearly don't profit by DSE species when roots can promptly get to inorganic nitrogen (Newsham, 2011) [19].

Secondary metabolites with other plant-beneficial activities

Genomic sequencing of endophytic parasites has demonstrated that, notwithstanding the perception that these life forms contain quality groups encoding certain optional metabolites, some are not communicated under standard research facility development conditions. This brings up the issue concerning which physiological and ecological conditions are required for endophytic organisms to express these optional metabolites (Brakhage, 2013; Netzker *et al.*, 2015) [6, 18]. Sometimes, as saw with *Epichloe* the host genome is required for huge articulation of the endophyte's auxiliary metabolite pathways. For instance, plant flagging is required to initiate articulation of the parasitic quality bunches for lolitrem B biosynthesis by *E. festucae* var. *lolii* with the goal that it is profoundly communicated in planta however articulation is low or imperceptible in culture-developed contagious mycelia. The same applies to other secondary metabolites such as lolines and epoxy-janthitrems of *Epichloe* species that produce little or no compound when grown ex planta (Porter, 1994; Tapper and Lane, 2004) [20, 33], despite attempts to circumvent this under in culture conditions as found with loline production (Blankenship *et al.*, 2001) [3]. In other cases, endophyte secondary metabolites may be triggered by the limitation of food sources, competition with other organisms, the presence of plant components (including exudates), the presence of other fungi and bacteria as well as their metabolites and their presence in plants attacked by pathogens and pests. Several examples of conditions under which the expression of secondary metabolites have been induced are published. For instance, flavonoids present in root exudates of host plants prompt the declaration of *Rhizobium* Nod-factors. Likewise, the absence of a host improvement in culture media may clarify why the generation of biomolecules

by an incipient endophyte disengage is regularly seriously weakened through subculturing (Li *et al.*, 1998) [15]. Since microorganisms in nature live in networks, development of different parasites in co-culture with different living beings has been tried. Co-culture can without a doubt bring about enactment of quiet quality groups or in emphatically expanded articulation (Wu *et al.*, 2015) [39]. For surveys on the impacts of co-refined, we allude to Bertrand *et al.* (2014) [2] and Wu *et al.* (2015) [39]. A fascinating perception is that on account of co-development between *Aspergillus niger* and actinomycetes, a personal physical connection is required to actuate quiet quality bunches in *Aspergillus niger* (Schroeckh *et al.*, 2009) [26]

Fungal endophytes become lost and/or their plant-beneficial activities reduced in domesticated plants

We propose that some wild plants have contagious endophytes which are deficient in their trained relatives. Under states of variable natural and physiological conditions, there will be specific strain to keep up the endophyte inside the plant and to keep its advantageous movement for the plant in ideal structure. It appears to be sensible to expect that plants can lose endophytes when they don't profit by their quality, and furthermore when pesticides and fungicides are much of the time utilized. Likewise, in instances of low or no particular weight, an endophyte might be less powerful due to either the loss of optional metabolites as well as in light of the fact that it will gather transformations against for which there is no choice. The outcome is a decrease in the adequacy of the endophyte and loss of advantageous movement. The accompanying trial perceptions bolster these ideas. (I) Weese *et al.* (2015) [38] gathered *Rhizobium* strains from two fields on which clover was developed. One field had been nitrogen-prepared for a long time, while the control field had not gotten nitrogen compost. They analyzed the nitrogen-fixing movement of gathered *Rhizobium* strains and found that the rhizobial soil network from the nitrogen fertilized field was less mutualistic: the vaccinated clover had 17%–30% less biomass and a decreased chlorophyll content. (ii) Redman *et al.* (2011) [21] demonstrated that immunization of rice plants touchy to salt and dry spell with chosen parasitic endophytes brought about plants which had turned out to be tolerant to these burdens. It gave the idea that, when the plants were developed without these anxieties, endophyte colonization diminished from 100% at planting to 65%. Conversely, plants developed under consistent pressure kept up 100% colonization levels.

The loss of fungal endophytes be further prevented and/or restored

The valuable contagious endophytes in yield plants lies in monitoring how parasitic endophytes may be lost and afterward relieving against this misfortune through all phases of harvest rearing and the board. Those overseeing plant germplasm assets need to think about the accompanying: (I) The lost piece of the advantageous microbiome will be available in and on wild plants gathered from the focuses of birthplace of harvest plants, the topographical region where a gathering of living beings was first tamed and where they are local (Chen *et al.*, 2015) [8]. The key is to ration the plants as well as the entire microbiome related with these plants. Directly, the fundamental focal point of such investigations is on microorganisms, particularly those from the rhizosphere (Bulgarelli *et al.*, 2015) [7], however it is essential that the

center is stretched out to growths present in and on all pieces of the plant.

Conclusion

Due to sessile nature of the plants, plants undergo different mechanism of adaptation or adjustment to cope with extreme conditions. Adaptation may be physiological, biochemical or at molecular level. Apart from these phenotypic adaptations plants also associated with other organism for mutual benefits *i.e.*, symbiotic associations. At the cellular level, plants associated with the microorganisms internally to cope with extreme conditions. Microorganisms produces organic acids, secondary metabolites, amino acids, these microorganisms are known that the association of endophytes are mainly to cope with extreme condition. The isolation and culture of endophytic bacteria and fungus and inoculation with other crops shows increase in their performance in terms of yield and disease resistance. Similar studies on drought tolerance among the treated plants compare to control plants.

The isolation and characterization of the microorganisms is need of the hour. Further investigation on endophytes is to done for commercial exploitation. Drought and salinity are major concerned in near future. These can be addresses by commercial exploitation of the endophytes.

References

1. Aly AH, Debbab A, Proksch P. Fungal endophytes: unique plant inhabitants with great promises. *Applied Microbiology and Biotechnology*. 2011; 90(6):1829-1845.
2. Bertrand S, Bohni N, Schnee S, Schumpp O, Gindro K, Wolfender JL. Metabolite induction via microorganism co-culture: a potential way to enhance chemical diversity for drug discovery. *Biotechnology Advantages*. 2014; 32(6):1180-1204.
3. Blankenship JD, Spiering MJ, Wilkinson HH, Fannin FF, Bush LP, Schardl CL. Production of loline alkaloids by the grass endophyte, *Neotyphodium uncinatum*, in defined media. *Phytochemistry*. 2001; 58(3):395-401.
4. Bledsoe C, Klein P, Bliss LC. A survey of mycorrhizal plants on Truelove Lowland, Devon Island, N.W.T., Canada. *Canadian Journal of Botany*. 1990; 68(9):1848-1856.
5. Boberg JB, Ihrmark K, Lindahl BD. Decomposing capacity of fungi commonly detected in *Pinus sylvestris* needle litter. *Fungal Ecology*. 2011; 4(1):110-114.
6. Brakhage AA. Regulation of fungal secondary metabolism. *Natural Revolution of Microbiology*. 2013; 11(1):21-32.
7. Bulgarelli D, Garrido-Oter R, Muench PC, Weimann A, Droge J, Pan Y *et al.* Structure and function of the bacterial root microbiota in wild and domesticated barley. *Cell Host Microbe*. 2015; 17(3):392-403.
8. Chen YH, Gols R, Benrey B. Crop domestication and naturally selected species trophic interactions. *Annual Revolution of Entomology*. 2015; 60:35-58.
9. Egamberdieva D, Kamilova F, Validov S, Gafurova L, Kucharova Z, Lugtenberg B. High incidence of plant growth-stimulating bacteria associated with the rhizosphere of wheat grown on salinated soil in Uzbekistan. *Environmental Microbiology*. 2008; 10(1):1-9.
10. Egamberdieva D, Lugtenberg B. Use of plant growth-promoting rhizobacteria to alleviate salinity stress in plants. In: Miransari M (ed.). *Use of Microbes for the Alleviation of Soil Stresses*, Vol. 1. New York, NY: Springer, 2014, 73-96.
11. Franken P. The plant strengthening root endophyte *Piriformospora indica*: potential application and the biology behind. *Application of Microbiology and Biotechnology*. 2012; 96(6):1455-1464.
12. Friesen ML. Microbially mediated plant functional traits. In: *Molecular Microbial Ecology of the Rhizosphere*, Vol. 1. Hoboken NJ, USA: John Wiley & Sons, Inc., 2013, 87-102.
13. Hallmann J, Quadt-Hallmann A, Mahaffee WF, Klopper JW. Bacterial endophytes in agricultural crops. *Canadian Journal of Microbiology*. 1997; 43(10):895-914.
14. Johnson JM, Alex T, Oelmuller R. *Piriformospora indica*: the versatile and multifunctional root endophytic fungus for enhanced yield and tolerance to biotic and abiotic stress in crop plants. *Journal of Tropical Agriculture*. 2014; 52(2):103-22.
15. Li JY, Sidhu RS, Ford EJ, Long DM, Hess WM, Strobel GA. The induction of taxol production in the endophytic fungus– *Periconia* sp from *Torreya grandifolia*. *Journal of Indian Microbiology and Biotechnology*. 1998; 20:259-264.
16. Marquez LM, Redman RS, Rodriguez RJ. A virus in a fungus in a plant: three-way symbiosis required for thermal tolerance. *Science*. 2007; 315(5811):513-515.
17. Murphy BR, Doohan FM, Hodkinson TR. Persistent fungalroot endophytes isolated from a wild barley species suppressseed-borne infections in a barley cultivar. *Bio Control*. 2015; 60(2):281-292.
18. Netzker T, Fischer J, Weber J, Mattern DJ, Konig CC, Valiante V *et al.* Microbial communication leading to the activation of silent fungal secondary metabolitegene clusters. *Front Microbiology*. 2015; 6:299.
19. Newsham KK. A meta-analysis of plant responses to dark septate root endophytes. *New Phytology*. 2011; 190(3):783-793.
20. Porter JK. Chemical constituents of grass endophytes. In: Bacon CW, White JF, Jr (eds). *Biotechnology of Endophytic Fungi of Grasses*. Boca Raton, FL: CRC, 1994, 103-123p.
21. Redman RS, Kim YO, Woodward CJDA, Greer C, Espino L, Doty SL *et al.* Increased fitness of rice plants to abiotic stress via habitat adapted symbiosis: astrategy for mitigating impacts of climate change. *PLoS One*. 2011; 6:14823.
22. Redman RS, Sheehan KB, Stout RG, Rodriguez RJ, Henson JM. Thermotolerance generated by plant/fungal symbiosis. *Science*. 2002; 298(5598):1581.
23. Rodriguez Estrada AE, Jonkers W, CorbyKistler H, May G. Interactions between *Fusarium verticillioides*, *Ustilago maydis*, and *Zea mays*: An endophyte, a pathogen, and their shared plant host. *Fungal Genetics Biology*. 2012; 49(7):578-587.
24. Rodriguez R, Redman R. More than 400 million years of evolutionand some plants still can't make it on their own: Plant stresstolerance via fungal symbiosis. *Journal of Experimental Botony*. 2008; 59(5):1109-1114.
25. Rodriguez RJ, White Jr JF, Arnold AE, Redman RS. Fungal endophytes: Diversity and functional roles. *New Phytologist*. 2009; 182(2):314-330.
26. Schroeckh V, Scherlach K, Nutzmans HW, Shelest E, Schmidt-Heck W, Schuemann J *et al.* Intimate bacterial-fungal interaction triggers biosynthesis of archetypal

- polyketides in *Aspergillus nidulans*. National Academy Science. 2009; 106(34):14558-14563.
27. Schulz BJE. Mutualistic interactions with fungal root endophytes. In: Schulz BJE, Boyle CJC, Sieber TN (eds). Microbial Root Endophytes, Berlin, Heidelberg: Springer, 2006; 9:261-79.
 28. Selosse M, Le Tacon F. The land flora: A phototroph-fungus partnership? Trends in Ecology and Evolution. 1998; 13(1):15-20.
 29. Shrivastava S, Varma A. From *Piriformospora indica* to rootonic: a review. African Journal of Microbiology Research. 2014; 8(32):2984-2992.
 30. Shu-Miaw C, Chien-Chang C, Hsin-Liang C, Wen-Hsiung L. Dating the Monocot–Dicot Divergence and the Origin of Core Eudicots Using Whole Chloroplast Genomes. Journal of Molecular Evolution. 2004; 58(4):424-441.
 31. Smith S, Read, D. Mycorrhizal symbiosis, 2nd edn., Academy Press, San Diego, London, 1997.
 32. Strobel G, Daisy B. Bio prospecting for microbial endophytes and their natural products Bio prospecting for microbial endophytes and their natural products. Microbiology and Molecular Biology Research. 2003; 67(4):491-502.
 33. Tapper BA, Lane GA. Janthitrems found in a Neotyphodium endophyte of perennial ryegrass. In: Kallenbach R, Rosenkrans CJ, Lock TR (eds). Proceedings of the 5th International Symposium on Neotyphodium/Grass Interactions. Fayetteville, AR: University of Arkansas Press, 2004, 2301.
 34. Varma A, Bajaj R, Agarwal A, Sree KS, Arora M, Prasad R. Memoirs of rootonic- the magic fungus: promotes agriculture. In: Horticulture and Forest Productivity. Noida, India: Amity University, 2013, 429-441p.
 35. Vazquez de Aldana BR, Bills G, Zabal-gogezcoa I. Are endophytes an important link between airborne spores and allergen exposure? Fungal Diversity. 2013; 60(1):33-42.
 36. Vega FE, Simpkins A, Aime MC. Fungal endophyte diversity in coffee plants from Colombia, Hawaii, Mexico and Puerto Rico. Fungal Ecology. 2010; 3:122-138.
 37. Waller F, Achatz B, Baltruschat H, Fodor J, Becher K, Fischer M *et al.* The endophytic fungus *Piriformospora indica* reprograms barley to salt-stress tolerance, disease resistance, and higher yield. Proceedings of National Academy Science. 2005; 102(38):13386-13391.
 38. Weese DJ, Heath KD, Dentinger BTM, Lau JA. Long-term nitrogen addition causes the evolution of less-cooperative mutualists. Evolution. 2015; 69(3):631-642.
 39. Wu C, Kim HK, Van Wezel GP, Choi YH. Metabolomics in the natural products field-a gateway to novel antibiotics. Drug Discovery Today Technology. 2015; 13:11-17.
 40. Zhang HW, Song YC, Tan RX. Biology and chemistry of endophytes. National Proceeding Report. 2006; 23(5):753-771.