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Review Article

Piriformospora indica a Powerful Tool for Crop Improvement*

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Root-inhabiting *Piriformospora indica* has a great potential application in the pursuit of physiological and agronomical functional traits for crop improvement. *P. indica* imitates the aptitude of typical arbuscular mycorrhizal fungi in numerous realistic growth promotional aspects. Owing its exceptional advantage to be cultivated axenically, *P. indica* is often used as bioregulator, biofertilizer and bioprotector in many crop species. A large set of published papers suggested the paramount importance and biology behind the *P. indica* exploitation as biological agents in agriculture sector to improve water absorption, mineral uptake, photosynthesis, plant growth and development and crop fitness. This review will highlight the *P. indica* mediated improved biomass, seed germination and development and crop productivity under favourable environmental conditions and its efficacy towards crop sustainability in rapid environmental changes.

Key Words: **Biomass Production; Environmental Conditions; *Piriformospora indica*; Microbes Interaction; Seed Germination and Development; Sustainable Agricultures**

Introduction

Piriformospora indica, a root colonizing and growth promoting basidiomycete fungus, was recognized in the Indian Thar desert. *P. indica* has been found to be a potent new candidate symbiont for providing enormous growth-promoting activity to a broad spectrum of plants, including agricultural and medicinal crops (Tsimilli-Michael and Strasser, 2013). In this perspective, *P. indica* has become a paramount tool in improving the productivity of several crops such as *Brassica campestris* sp. chinensis, *Lycopersicon esculentum*, *Hordeum vulgare*, *Piper nigrum*, *Glycine max*, *Cicer arietinum* *Arabidopsis* sp., *Oryza sativa* and *Nicotiana tabacum* under natural and/or stress conditions (Ansari *et al.*, 2013; Trivedi *et al.*, 2014a; Trivedi *et al.*, 2014b). Because of no side effect, there is an increasing demand of herbal medicines. To satisfy this demand with low cost availability in the market, the utmost significance of *P. indica* has been realized (Das *et al*., 2012). It often acts as a bioregulator, biofertilizer and bioprotector in monocot as well as dicotyledonous plant species (Singh *et al.,* 2003).

Agricultural crops growing under open field conditions are repeatedly hit by various abiotic and biotic stresses. In this regard, contribution of plant breeders to develop stress tolerant varieties has been documented. Further, parallel hard work by molecular biologists have explored the knowledge of change in gene expression and proteins during stress. The mechanism of stress tolerance *via* transgenic approach has received great attention over the past two decades (Gill and Tuteja, 2010). Several reports accumulated over the last few decades support

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**The article is dedicated to Prof. Ajit Varma who has significantly contributed to the field.*

P. indica the role of crop tolerance to a number of abiotic as well as biotic stresses (Franken, 2012). According to this viewpoint, the importance of *P. indica* in sustaining ecosystems is becoming increasingly clear (Barazani and Baldwin, 2013). *P. indica* reduces the harmful impact of stress on photosynthetic concert of the host plants (Trivedi *et al.,* 2014b) and stabilizes growth and nutrition under salinity, drought and heat (Sherameti *et al.,* 2008; Baltruschat *et al.,* 2008; Varma *et al.,* 2012a). *P. indica* induces antioxidant system, the expression of abiotic stress-responsive genes and protein to confer tolerance in different plant species such as Chinese cabbage (Sun *et al.,* 2010), *Arabidopsis thaliana* (Sherameti *et al.,* 2008) and *Hordeum vulgare* cv. Ingrid (Baltruschat *et al.,* 2008). The regulation of growth and various development processes of *Oncidium* orchid through miRNAs were elicited by the root symbiotic fungus *P. indica* (Ye *et al.,* 2014).

Recent reports also suggest that the overexpression of cyclophilin A-like protein from *P. indica* leads to salinity stress tolerance in tobacco and *E. coli* (Trivedi *et al.,* 2014a; Trivedi *et al.,* 2014b). It also confers biotic stress tolerance such as viral and fungal pathogens in many crops (Ansari *et al.,* 2013; Andrade-Linares *et al.,* 2013). *P. indica* defends plants from cyst nematode infection and development in *Arabidopsis* roots (Daneshkhah *et al.,* 2013). The beneficial relations among the growth promoting endophyte *P. indica* and plant roots are indeed valuable its wide spectrum of applications in agriculture. The outcome of the literature appraised herein will help us to aware physiological significance of *P. indica* for crops beneficial traits viz., bio-control agent, mineral uptake, abiotic stress tolerance and biotic resistance, which exploitation might be practical in bio-safety point of view towards sustainable agriculture irrespective of breeding and transgenic approaches.

P. indica Colonization and Interaction with Other Microorganisms

P. indica is very versatile fungus with a broad spectrum of colonization to diverse plant species (Verma *et al*., 1998). It forms thin-walled, haphazardly septate, hyaline and multinucleate hyphae and produces ovoid shaped chlamydospores to stabilize the interaction (Das *et al.,* 2013). In colonized crop plants, it confer various physiologically functional traits such as water and mineral uptake, photosynthesis, improved biomass, increased productivity and enhanced plant fitness to environmental stress (Tsimilli-Michael and Strasser, 2013; Ansari *et al.,* 2013; Sun *et al.,* 2010; Achatz *et al.,* 2010). *P. indica* interacts with a diverse group of microorganisms such as *Sebacina vermifera*, *Pseudomonas fluorescens* (rhizobacteria), *Chlamydomonas reinhardtii*, *Gaeumannomyces graminis,* and other soil fungi (i.e., *Aspergillus niger, A. sydowii* and*Rhizopus stolonifer*).

P. indica entire genome is organized to 1,884 scaffolds structure (size: 1 kb; N50: 51.83 kb), comprising 2,359 overlapping DNA sequence together with a typical read coverage of 22 plus a genome range of 24.97 Mb (Zuccaro *et al.,* 2009; Varma *et al.,* 2012b). The expected entire DNA content *P. indica* nuclei varies from 15.3 to 21.3 Mb (Varma *et al.,* 2012b). Further, the transcript plenitude for glyceralehyde-3-phosphate dehydrogenase (GAPDH) and translation elongation factor 1-a (TEF) amplified with respect to time succeeding the *P. indica* invasion, which signifies the involvement of constitutively expressed promoters (Bütehorn et al. 2000; Zuccaro *et al.,* 2011). This suggests that both functional native promoters might be exploited for overexpression study during the course of plant-fungus interaction (Zuccaro *et al.,* 2011; Lahrmann 2014).

P. indica invaded roots of *H. vulgare* were reported resistant against *Fusarium* infections (Deshmukh *et al.,* 2014). These authors provided evidences that pathogenesis-related (PR) proteins do not affect *P. indica*-mediated response to confer resistance against *Fusarium* infections.*P. indica* was found to diminish the severity of disease caused by *Verticillium dahliae*. The interaction of *P. indica* with the Pepino mosaic virus (PepMV) was evaluated in hydroponically grown *L. esculentum*; where, the authors observed 30% reduction on the disease severity by *V. dahliae* (Fakhro *et al.,* 2010). The growth of pathogenic fungi *viz., Aspergillus sydowii, Rhizopus stolonifer* and *Aspergillus niger* has been reported to be entirely obstructed by *P. indica*. However, stimulation was noticed in the growth of the alga *Chlamydomonas reinhardtii* upon cultured the alga with *P. indica*. Though *P. indica* interacts with diverse class of bryophyte including mosses and liverworts, no growth promotion was observed as a result of this interaction (Pham *et al.,* 2004). It has been reported that *P. indica*, *S. vermifera* and *Trichoderma* species act as effective biocontrol agent for take-all diseases in *T. aestivum* (Ghahfarokhi and Goltapeh, 2010). *P. indica* was reported to support the growth and development of *Azotobacter chroococcum*, *Azospirillum brasilensis* and *Bradyrhizobium* spp.; however, *P. indica*-mediated inhibition was noted in *Pseudomonas fluorescens* (Malla and Pokhare, 2008).

P. indica Colonization Improves the Growth and Development of Various Crops under Favorable Conditions

The root-inhabiting endophytic fungus *P. indica* interacted symbiotically with plants and promotes growth of many crops (Ansari *et al.,* 2013). *P. indica* colonized *Stevia rebaudiana* showed increased vegetative yield (Rai *et al.,* 2001). The growth of *Spilanthes calva* and*Withania somnifera* plants was increased in a field when testing with *P. indica* (Varma *et al.,* 2013). *Artemisia annua* was relatively better in leaf area and fresh biomass upon colonization with *P. indica* (Rai *et al.,* 2001).

Positive response of *P. indica* in secondary metabolites production, flowering and biomass in *Coleus forskohlii* has been realized-reported (Das *et al.,* 2012). In chickpea and black lentil, the endogenous content of N, P and K was reported to be higher upon *P. indica* colonization, leading to better growth performance of plants (Nautiyal *et al.,* 2010). Inoculation of *P. indica* and *R leguminosarum* to *Phaseolus vulgaris*, in addition to vermicompost treatments, resulted increase in length and dry weight of roots and shoots (Tuladhar *et al.,* 2013). *P. indica* effectively increases the growth of *Linum album* via improving the antioxidant machinery (Kumar *et al.,* 2013). *P. indica* colonized *Piper nigrum* plants shows increased leaf number and improved fresh weight (Anith *et al*., 2011).

Its colonization with *Lycopersicon esculentum* was reflected in various aspects of growth and development (Fakhro *et al.,* 2010). Association of *P. indica* with *Cicer arietinum* plants was resulted into

Table 1: *Piriformospora indica* mediated improved productivity of various crops

Crop type	*P. indica* mediated improved productivity	Reference
Stevia rebaudiana	Improved vegetative growth	(Rai *et al.,* 2001)
Spilanthes calva and *Withania somnifera*	Increased growth	(Varma *et al.,* 2013)
Artemisia annua	Increased leaf area fresh biomass	(Rai *et al.,* 2001)
Coleus forskohlii	Modulation of secondary metabolites production, flowering and growth performance	(Das *et al.,* 2012)
Chickpea and black lentil	Improved endogenous NPK and growth performance	(Nautiyal *et al.,* 2010)
Phaseolus sp.	Improved root length and root dry weight	(Tuladhar *et al.,* 2013)
Phaseolus sp.	Elevated shoot length and shoot dry weight	(Tuladhar *et al.,* 2013)
Linum album	Enhanced growth	(Kumar *et al.,* 2013)
Piper nigrum	Increased leaf number and improved fresh weight	(Anith *et al.,* 2011)
Lycopersicon esculentum	Better growth and development	(Fakhro *et al.,* 2010)
Cicer arietinum	Increased total dry weight	(Nautiyal *et al.,* 2010)
Brassica rapa	Auxin mediated plant growth and development	(Michal-Johnson *et al.,* 2013)

better vegetative growth (Nautiyal *et al.,* 2010). The growth approval in *Brassica rapa* was directed via auxins during the course of *P. indica* colonization (Michal-Johnson *et al.,* 2013) (Table 1).

P. indica Promotes Seed Germination, Development, Quality and Yield in Different Crops

P. indica-induced seed germination and stimulation of the protocorn development was observed in orchid (Blechert *et al.*, 1999). Recently, the colonization of *P. indica* has been reported to significantly increase the seed germination and formation in various plants including *Oryza sativa, Z. mays, Tridax procumbans, N. tabacum, A. thaliana* and *Brassica oleracea* var capitata (Varma *et al.,* 2012b). Additionally, *P. indica* also promotes the seed germination in leafy vegetables *viz.*, cabbage, endive, Swisschord (palak), Swisschord and red radish, onion, carrot, cauliflower, beetroot, peas and snowpea under extremely low temperatures (Varma *et al.,* 2012b).

The *pii-2* and At5g16590 located in microdomains of plasma membrane was found responsible for *P. indica*-mediated seed development and enhanced seed production in *A. thaliana* (Shahollari *et al.,* 2007). *P. indica*-inoculated *H. vulgare* seeds exhibited higher the viability (Harrach *et al.,* 2013). Moreover, on immersing germinated seedlings in *P. indica*-homogenate, the authors noted a good survival rate under adverse conditions (Harrach *et al.,* 2013). The culture filtrate of *P. indica* has also been reported to facilitate early seed germination in vascular plants (Adya *et al.,*2013). In *Helianthus annus*, *P. indica* culture filtrate influenced the yield of seed oil (Bagde *et al.*, 2010). The colonization of *P. indica* in the roots of bryophytes and pteridophytes gymnosperms and angiosperms was resulted in higher yield of seed (Varma *et al.*, 2012b). In Jatropha and Populus, the interation of *P. indica* improves early seed germination (Varma *et al.,* 2013) (Table 2).

Resilience of *P. indica* to Maintain in the Crop Sustainability Under Adverse Environmental Conditions

Several findings gathered over the last few decades revealed the potential application of *P. indica* in sustaining plant survival under multiple abiotic stresses. The omnipresent fungus *P. indica* has a massive growth promotion capacity with for a wide range of plants and thereby tolerance against environmental adverse conditions. The exclusive mixture of *P. indica* with *Sebacina vermifera* inoculum has been tested in economically important crops for better outcome of plant growth under salinity, drought and heat stress (Franken, 2012). *P.*

Table 2: Beneficial effect of *Piriformospora indica* on crop plant seeds for better yield

P. indica treated seeds/ colonized crop plants	Beneficial effects	Yield attributes	Reference
Orchid seeds	Improved seed germination	Seed quality and yield	(Blechert *et al.,* 1999)
Vegetable crops	Induced seed germination	Seed value and yield	(Varma *et al.,* 2012b)
Arabidopsis thaliana	Enhanced seed production	Seed class and yield	(Shahollari *et al.,* 2007)
Barley	Seed viability and survival	Vegetative and grain yield	(Harrach *et al.,* 2013)
Higher plants	Early seed germination	Seed yield	(Adya *et al.,*2013)
Helianthus annus	Seed yield	Higher seed yield with increased oil content	(Bagde *et al.,* 2010)
Lower plants, Gymnosperms and Angiosperms	Higher seed yield	Seed quality and yield	(Varma *et al.,* 2012b)
Jatropha and Populus	Early seed germination	Seed yield	(Varma *et al.,* 2013)

Table 3: *Priformospora indica* maintains the sustainability of diverse crop species under adverse environmental conditions

Crops	Crop sustainability under adverse conditions	Reference
Economically important crops	Improved biomass under abiotic stress	(Franken, 2012)
Triticum aestivum	Growth sustainability under salt	(Zarea *et al.,* 2012)
H. vulgare	Relieve the plants from the attack of leaf pathogens to maintain plant growth performance	(Molitor *et al.,* 2012)
Wheat (*Triticum* sp.)	Stable growth performance of plant against biotic stress	(Serfling *et al.,* 2012)
Brassica campestris sp. Chinensis	Consistent growth under drought	(Sun *et al.,* 2010)
L. esculentum	Defend plants to sustain plant productivity under biotic stress	(Andrade-Linares *et al.,* 2013)
Arabidopsis sp.	Retention plant productivity under water defict condition	(Sherameti *et al.,* 2008)
Hordeum vulgare cv. Ingrid	Salinity toerance to maintain proper vegetative growth	(Waller *et al.,* 2005)
Hordeum vulgare	Salinity leads to increased productivity	(Baltruschat *et al.,* 2008)

indica colonized *Triticum aestivum* plants showed relatively better survival under high salinity with respect to non-colonized plants (Zarea *et al.,* 2012). *P. indica* colonization relieves *H. vulgare* plants from the attack of leaf pathogens (Molitor *et al.,* 2012) to maintain plant growth performance.

The growth performance of wheat under greenhouse and field conditions was sustained via application of the biocontrol fungus *P. indica* (Serfling *et al.,* 2012). *P. indica* induces antioxidant system via CAS protein in *Brassica campestris* subsp. Chinensis leaves to provide dependable growth under drought (Sun *et al.,* 2010). *P. indica* defends confers tomato plants to confer with the ability to undergo vegetative and generative development under biotic stress (Andrade-Linares *et al.,* 2013). *A. thaliana* productivity can be maintained under water deficit condition via *P. indica* application (Sherameti *et al.,* 2008). Further, sustainability of *Hordeum vulgare* cv. Ingrid and *Hordeum vulgare* under high salinity stress was evidenced upon colonizing their roots with *P. indica* (Waller *et al.,* 2005; Baltruschat *et al.,* 2008) (Table 3).

Conclusions

On the perspective of *P. indica* colonization role in crop plants, Franken (2012) evidenced *P. indica*-mediated improvements in the growth and biomass of a number of crop plants including *Oryza sativa, Saccharum officinarum, Abrus precatorius, Zea mays, Phaseolus vulgaris,* and *Tridax procumbans* under favourable environment. However, a stable growth profile has also been observed in *P. indica*-colonized plants even under adverse environmental conditions (Ansari *et al.,* 2013; Baltruschat *et al.,* 2008; Varma *et al.,* 2012). The plant of colonization and improvement rely on the genome and transcriptome of *P. indica* (Zuccara *et al*., 2011) and *P. indica* transcriptional reactions to infect the dead and healthy root tissues.

To attain the basic compatibility host associated metabolic changes positively direct the expression of *P. indica*'s lifestyles. The mutual interaction of *P. indica* with roots of plants has been paramount significant in crop improvement as genome sequence and transformation systems are accessible (Zuccaro *et al*. 2011; Lahrmann *et al*. 2013; Lahmann 2014). For that reason, it was found that *P. indica* produces auxin IAA which is known for its stimulatory role in plant root growth (Sirrenberg *et al.,* 2013). *P.indica* has been reported to interfere with ethylene signaling in plants where, it promotes the plant growth (Khatabi *et al.,* 2013).

The higher grain yield induced by the fungus was found to be independent of different fertilizers

(Bagde *et al.,* 2010). The present review will be useful in realizing the physiological implications of *P. indica* for bio-safety and sustainable agriculture. However, the exact mechanism underlying *P. indica*-mediated signaling for conferring physiological benefits to host plants is still unclear (Ansari *et al.*, 2013), which needs further fine tune into cell signalling network of various physiological, biochemical and molecular processes.

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