**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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\(^2\)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 (Daneshkhhah 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

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

<table>
<thead>
<tr>
<th>P. indica treated seeds/ colonized crop plants</th>
<th>Beneficial effects</th>
<th>Yield attributes</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orchid seeds</td>
<td>Improved seed germination</td>
<td>Seed quality and yield</td>
<td>(Blechert et al., 1999)</td>
</tr>
<tr>
<td>Vegetable crops</td>
<td>Induced seed germination</td>
<td>Seed value and yield</td>
<td>(Varma et al., 2012b)</td>
</tr>
<tr>
<td>Arabidopsis thaliana</td>
<td>Enhanced seed production</td>
<td>Seed class and yield</td>
<td>(Shahollari et al., 2007)</td>
</tr>
<tr>
<td>Barley</td>
<td>Seed viability and survival</td>
<td>Vegetative and grain yield</td>
<td>(Harrach et al., 2013)</td>
</tr>
<tr>
<td>Higher plants</td>
<td>Early seed germination</td>
<td>Seed yield</td>
<td>(Adya et al., 2013)</td>
</tr>
<tr>
<td>Helianthus annus</td>
<td>Seed yield</td>
<td>Higher seed yield with increased oil content</td>
<td>(Bagde et al., 2010)</td>
</tr>
<tr>
<td>Lower plants, Gymnosperms and Angiosperms</td>
<td>Higher seed yield</td>
<td>Seed quality and yield</td>
<td>(Varma et al., 2012b)</td>
</tr>
<tr>
<td>Jatropha and Populus</td>
<td>Early seed germination</td>
<td>Seed yield</td>
<td>(Varma et al., 2013)</td>
</tr>
</tbody>
</table>
Table 3: Priformospora indica maintains the sustainability of diverse crop species under adverse environmental conditions

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

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 (Wallet 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 procumbens 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 (Zuccaro 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). Pinindica 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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