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PIRIFORMOSPORA INDICA AUGMENTS GROWTH, ROOT DEVELOPMENT AND EARLY FLOWERING IN CHILLI (*CAPSICUM ANNUUM* L.) PLANTS

Elizabeth T. Jojy[1*], Joy Michal Johnson[1], Sajeena A.[2], Rafeekher M.[3], Radhakrishnan N.V.[1] and Ambily Paul[4]

[1]Department of Plant Pathology, College of Agriculture (Kerala Agricultural University), Vellayani, Thiruvananthapuram, Kerala 695522, India.

[2]Integrated Farming System Research Station, Karamana, Thiruvananthapuram, Kerala 695002, India.

[3]Department of Floriculture and Landscaping, College of Agriculture (Kerala Agricultural University), Vellayani, Thiruvananthapuram, Kerala 695522, India.

[4]AINP on Pesticide Residue, College of Agriculture (Kerala Agricultural University), Vellayani, Thiruvananthapuram, Kerala 695522, India.

*Corresponding author E-mail: elizabethjojy132@gmail.com

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ABSTRACT

The symbiotic fungal root endophyte, *Piriformospora indica* confers the colonized plants with multifarious opportunities of growth promotion as well as disease tolerance. The endophyte is axenically cultivable and capable of colonizing innumerable hosts, belonging to different plant families. In this study, growth promotion potential of *P. indica* was evaluated in chilli plants **(***var*. Vellayani Athulya**)**. The improvement in vegetative and flowering parameters due to the endophyte was compared to the non-colonized control plants grown in pro-trays as well as field conditions. Early germination was noticed in seeds sown in *P. indica* grown medium. Mature pear-shaped chlamydospores were observed inside the roots of *P. indica*-colonized chilli plants. *P. indica* colonized-chilli plants had higher root as well as shoot lengths and its enhanced fresh weights; besides increased leaf, and secondary and tertiary root numbers. Further, the endophyte considerably reduced the days taken for first flower initiation and flowering; and also enhanced the flower and fruit production in chilli plants. The results highlight remarkable effect of the fungus in improving germination and survival rate of seedlings under field condition, stimulation of early flowering, growth promotion and enhanced yield in the colonized chilli plants in comparison to control. The study demonstrated that *P. indica* is a potential biofertilizer for improving crop productivity and it can be developed into a cheap, environmentally safe biofertilizer which can provide better and promising crop yield to farmers.

Key words**:** *P. indica*, root endophyte, biofertilizer, growth promotion, chilli, biometric parameters

Introduction

Chilli (*Capsicum annuum* L.) is a well-known solanaceous vegetable, widely accepted and cultivated throughout the world. It is a native of South America, introduced to India by Portuguese due to their fiery hotness and flavour, which makes it an inevitable constituent in Indian cuisines. They contain higher amounts of vitamins (A, C and D) (Mishra *et al*., 2017), and proteins, fibre, folic acids, minerals, antioxidants and capsaicinoids (Manda *et al*., 2020). Among the various *Capsicum* spp. known till date, the most cultivated species of chilli is *C. annuum* followed by *C. frutescens* (Than *et al*., 2008).

In India, chilli is cultivated in 7.33 lakh hectare with an average production of 1.76 million tonnes of chilli (Horticultural Statistics at a Glance, 2018). Of the total production, 70 per cent is consumed in India and remaining 30 per cent is marketed internationally. Chilli accounts to a major share (42%) of the Indian spice exports to different countries. In spite of being a universally grown

spice crop, its production worldwide is threatened by various constraints resulting in yield reduction and low-quality harvests (Saxena *et al*., 2016; Shaker *et al*., 2019). This causes a subsequent, sudden surge in the domestic demand for chillies and further, reduces exportable surplus. Therefore, to maintain India's dominance in the long run, local as well as international demands need to be satisfied with quality food, by advocating justice to farmers (producers) and the end users (consumers). Mostly, farmers resort to excess use of chemical fertilizers and pesticides to alleviate the situation, which may bring in adverse environmental issues. Recently, there have been lots of huge cue and cry to promote organic, safe-to-eat and sustainable products. In this scenario, biofertilizers hold a better solution to boost crop productivity by reducing dependency on chemical fertilizers (Mitter *et al*., 2021).

Studies on root endophytes thriving in symbiotic association are currently gaining importance. Beneficial endophytes can enhance the overall performance of their respective hosts while reducing yield losses due to stresses. *Piriformospora indica*, a renowned fungal root endophyte, aids in improving better growth and development of primed or colonized host plants (Waller *et al*., 2005; Srivastava and Varma, 2014). The root colonizing beneficial fungus was isolated from xerophytic plant roots, thriving in Indian deserts (Varma *et al*., 1999). It lacks host specificity, colonizes innumerable terrestrial plants and is axenically cultivable on simple or complex media. The fungus grows intra- and inter-cellularly within the roots of colonized plants and produces pear-shaped chlamydospores. *P. indica* boosts crop production and yield in addition to stress alleviation, even in the existing situations of sudden climatic fluctuations (Verma *et al*., 1998; Fakhro *et al*., 2010; Das *et al*., 2012; Ghabooli *et al*., 2013; Lin *et al*., 2019). In the present study, we could establish that extensive colonization of *P. indica* in chilli roots resulted in improvement in vegetative and yield characters, owing to the endophytic establishment within the host.

Materials and Methods

Cultivation of *P. indica*

P. indica (accession number INBA3202001787) was cultured on potato dextrose agar (PDA) medium, pH of 6.5. The culture plates were incubated at 27±1°C, 75 per cent relative humidity and 12 h light/dark photoperiod. Liquid cultures of the endophyte in potato dextrose broth (PDB) were also maintained.

Co-cultivation study

P. indica co-culturing with chilli plants was performed as per method of Johnson *et al*., (2011) with slight modifications. Modified PNM medium was used for co-cultivation. PNM and half strength Murashige and Skoog (MS) media were prepared and poured in sterilized Petri plates (120 mm diameter) and jam bottles respectively. *P. indica* culture discs of 5 mm were placed in the centre of PNM Petri plates, and incubated at room temperature (27±1°C) for two weeks till the fungus attains full growth. Simultaneously, surface-sterilized chilli seeds (*var.* Vellayani Athulya) were transferred to jam bottles with half strength MS medium. To allow uniform germination, bottles were incubated at 4ºC in refrigerator for 24 h and then, at room temperature. Later, the germinated seeds were aseptically placed on *P. indica*-grown PNM plates for their co-cultivation and further growth.

The seedling roots were examined for *P. indica* colonization at 1, 3, 5, 7, 10 and 15 days after colonization (DAC). Random root samples from the colonized chilli plants were washed carefully to remove any attached debris and then, sliced into 0.5 cm long pieces. Root bits were softened by overnight suspension in 10 per cent KOH solution, washed in two to three changes of clean water and acidified in 1 per cent 1N HCl for three min. Then, root bits were stained using lactophenol-cotton blue and observed under the Leica microscope (Model-DM300, USA).

Preparation of *P. indica* multiplication medium

Pro-tray medium was used for large scale production of *P. indica*, as per the method described by Jojy *et al*., (2020). Coir pith: powdered cow dung (1:1) mix was added with 2 per cent gram flour, filled in autoclavable polypropylene covers and consecutively autoclaved at 121°C for 2 h for three days. Eighteen-day old fungal mycelium grown in PDB pH 6.5 was mixed with the medium in clean trays, under sterile conditions and incubated for 10 days for the complete growth of the fungus. This *P. indica*-multiplied medium was used for further experiments.

In vivo co-cultivation study

Chilli seeds (*var*. Vellayani Athulya) were used for the experiment. Surface-sterilized seeds were sown in clean separate pro-trays filled with *P. indica* mass-multiplied and control (devoid of *P. indica*) media respectively and kept for germination. The days taken to initiate germination and for 50 per cent germination were noted.

The study comprised of two *in vivo* experiments. Chilli seedlings raised in pro-trays formed the initial experiment which included two treatments namely control (-Pi) and *P. indica*-colonized plants (+Pi). A replication

of twenty plants was maintained in each treatment. The plants were uprooted carefully and various biometric observations such as plant height (cm), shoot length (cm), shoot weight (g), number of leaves, leaf area (cm^2), root length (cm), number of secondary as well as tertiary roots and root weight (g) were recorded at 3, 5, 7, 10, 15 and 30 days after germination (DAG).

The second experiment was conducted as field trials. The experiment was laid out in two seasons - *rabi* (2019-2020) and summer (2020-2021), at the Department of Vegetable Science and Instructional farm respectively, in the College of Agriculture, Vellayani. Land preparation was done and the total area was divided into equal plots and thirty-day old chilli seedlings from the treatments were transplanted at a spacing 45 cm × 45 cm in the respective plots with *P. indica*-colonized and control plants. Manuring, irrigation practices and other cultural operations were done as per the package of practices (POP) of crops, published by Kerala Agricultural University (KAU). Statistical design used in the experiment was random block design (RBD) consisting of 2 treatments and 15 replications. Observations on vegetative growth characters (shoot length (cm), number of branches and leaves) along with reproductive parameters (days to flowering, number of flowers bloomed and fruits formed per plant) were recorded at 15 days interval, following transplantation of chilli plants in field. Further, natural incidence of foliar fungal disease, anthracnose incited by *Colletotrichum capsici* in chilli plants under field conditions was also recorded in rabi and summer seasons.

Results

P. indica has successfully and extensively colonized in roots of chilli plants

Root bits from *P. indica*-colonized chilli plants were observed under the microscope for presence of mycelium and chlamydospores inside the roots. Roots of chilli plants showed profuse colonization of *P. indica*. Endophytic hyphae made its way into the epidermal cell layers of chilli roots and finally reaching the cortex. The chlamydospores of *P. indica* were observed inside the roots of chilli plants confirmed its successful endophytic root colonization in the plants. Mycelial growth of the fungus was observed in the root bits at 3 DAC. There was an enhancement in the size and number of chlamydospores from 5 to 15 DAC (Fig. 1a and 1b).

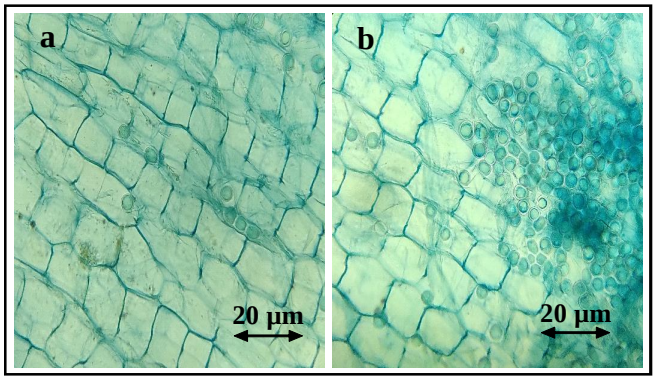

Fig. 1: *P. indica* chlamydospores observed within the roots of colonized chilli plants [Picture represents hyphae and chlamydospores of the fungal endophyte, *P. indica* in the chilli root cortical cells at (a) 5 and (b) 15 days after colonization.]

Round, hyaline and double walled chlamydospores were observed at 5 DAC which later, enlarged to assume the shape of root cells. Root colonization efficiency was found to be the maximum in the chilli roots at 15 DAC (Fig. 2).

P. indica enhanced vegetative and reproductive growth parameters in the colonized chilli plants

Chilli seeds were allowed to germinate in *P. indica* mass-multiplied medium as well as control medium devoid of *P. indica*. Early germination of chilli seeds was seen in the endophytic fungus multiplied medium. Seeds germinated 5 days after sowing in *P. indica*-multiplied pro-tray medium against 8 days in control. About 15 days after germination (DAG), the colonized chilli seedlings displayed a significantly higher plant height of 3.08 cm and leaf area of 2.20 cm^2 compared to 2.70 cm and 1.62 cm^2 in the control seedlings. Number of secondary (14.40) and tertiary roots (5.30) were considerably higher in the colonized seedlings than in non-colonized. Enhanced shoot and root weights were observed as 0.07 g and 0.014 g respectively in the fungus colonized plants compared to 0.05 g and 0.005 g in control. At 30 DAG, all the biometric characters were significantly enhanced. The plant height was improved to 25.91 cm in the colonized chilli plants

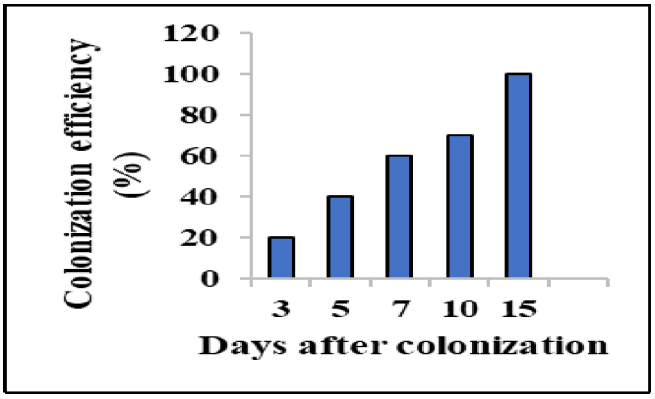

Fig. 2: Root colonization efficiency was highest in the colonized chilli roots at 15 DAC. The graph shows the colonization percentage of the examined root bits at 3, 5, 7, 10 and 15 DAC. The data represented graphically is based on 10 independent biological replicates.

Table 1: Effect of *P. indica*-colonisation on different biometric characters of chilli seedlings at 15 and 30 days after germination.

Observations	15 DAG		30 DAG	
	- P. indica	***+ P. indica***	***- P. indica***	***+ P. indica***
Days to initiate germination	8	5	8	5
Days to 50% germination	13	9	13	9
Shoot length (cm)	1.26 ± 0.05	1.45 ± 0.05	7.98 ± 0.59	11.00 ± 0.89
Root length (cm)	1.44 ± 0.07	1.63 ± 0.05	9.80 ± 0.92	14.91 ± 0.97
Plant height (cm)	2.70 ± 0.12	3.08 ± 0.06	17.78 ± 1.09	25.91 ± 1.61
Number of leaves	2.00 ± 0.00	2.00 ± 0.00	10.90 ± 0.74	14.80 ± 0.79
Leaf area (cm^2)	1.62 ± 0.18	2.20 ± 0.07	2.44 ± 0.51	4.21 ± 0.50
Number of secondary roots	9.30 ± 0.95	14.40 ± 0.97	35.40 ± 0.84	44.00 ± 0.94
Number of tertiary roots	3.30 ± 0.95	5.30 ± 0.68	19.50 ± 0.85	25.40 ± 0.70
Shoot wt. (g)	0.05 ± 0.01	0.07 ± 0.008	0.86 ± 0.04	1.45 ± 0.07
Root wt. (g)	0.005 ± 0.001	0.014 ± 0.002	0.50 ± 0.05	1.26 ± 0.20

compared to 17.78 cm in control (Table 1). Similarly, number of secondary and tertiary roots (44.00 and 25.40); shoot and root weights (1.45 g and 1.26 g) were remarkably increased in *P. indica*-colonized chilli plants.

Biometric observations were recorded in the *P. indica*-colonized and control chilli seedlings at 15 and 30 days after germination (DAG) under controlled conditions. Chilli seeds (*var.* Vellayani Athulya) were sown in *P. indica* multiplied (+ *P. indica*) and control (- *P. indica*) media. The data are statistically analyzed using paired t-test and expressed as mean ± standard deviation (n=10).

Field studies were carried out in the rabi and summer seasons using chilli plants colonized with *P. indica* and control plants (without *P. indica*). One month after sowing, chilli seedlings raised in pro-trays were transplanted in field during rabi and summer (Fig. 3). During each season, number of leaves and branches along with shoot length were recorded at 15 days interval till the end of the crop period (Fig. 4) and all the observations increased significantly in *P. indica*-colonized plants over the control.

Fig. 3: Field view of control and *P. indica*-colonized chilli plants. [15-day old chilli seedlings (var. Vellayani Athulya) were transplanted in field during two seasons, Rabi and Summer. Two treatments viz. – *P. indica* (control) and + *P. indica* were laid down in two plots. (a) The picture depicts field taken up in the Department of Vegetable Sciences, College of Agriculture, Vellayani during Rabi season; (b) Second field in the Area 1, Instructional farm, College of Agriculture, Vellayani during Summer season.]

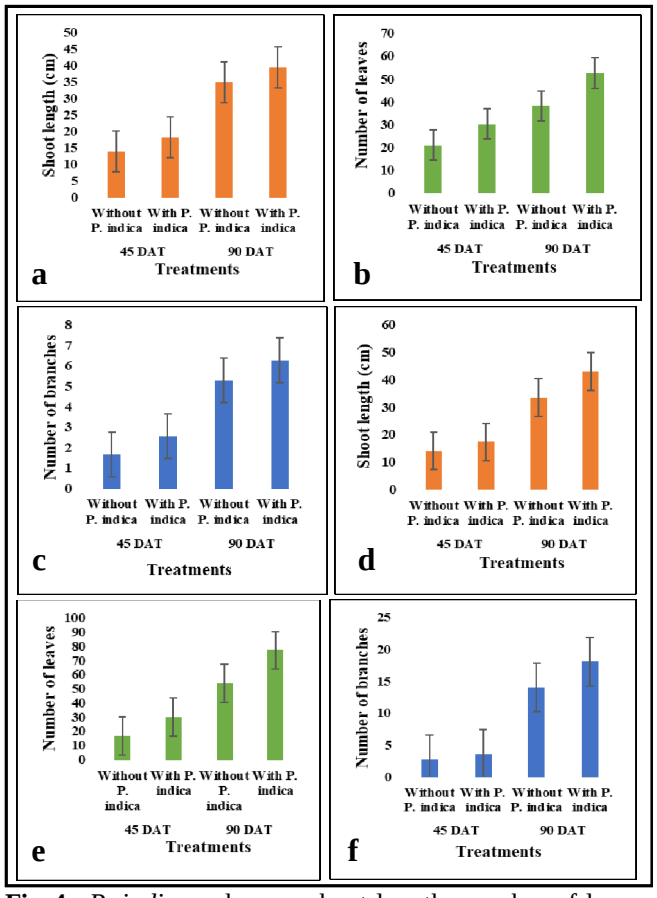

Fig. 4: *P. indica* enhances shoot length, number of leaves and branches in the colonized chilli plants (var. Vellayani Athulya) at 45 and 90 days after transplanting (DAT) compared to the control plants laid in rabi (a, b, c) and summer seasons (d, e, f) under field conditions. The observations were recorded from two treatments viz. without *P. indica*/- *P. indica* and with *P. indica*/+ *P. indica*. Data are based on 10 independent biological replicates and bars represent SEs.

Table 2: Effect of *P. indica*-colonisation on different biometric characters of chilli plants at 45 and 90 days after transplanting under field condition .

Observations	45 DAT		90 DAT	
	- P. indica	***+ P. indica***	***- P. indica***	***+ P. indica***
Shoot length (cm)	15.85 ± 0.56	19.76 ± 0.63	31.70 ± 0.68	45.70 ± 0.95
Root length (cm)	15.64 ± 0.82	21.05 ± 0.76	40.80 ± 0.79	51.20 ± 0.79
Plant height (cm)	31.49 ± 0.83	41.05 ± 0.88	51.50 ± 0.79	62.00 ± 0.81
Number of leaves	27.40 ± 0.97	35.60 ± 0.84	72.50 ± 0.85	96.90 ± 0.97
Leaf area (cm^2)	4.21 ± 0.56	6.41 ± 0.30	11.50 ± 0.52	15.50 ± 0.50
Number of secondary roots	45.10 ± 0.88	57.40 ± 0.52	58.00 ± 0.82	68.50 ± 0.80
Number of tertiary roots	23.00 ± 0.82	28.60 ± 0.97	41.10 ± 0.74	57.70 ± 0.49
Shoot wt. (g)	1.59 ± 0.07	2.44 ± 0.10	5.23 ± 0.12	6.52 ± 0.06
Root wt. (g)	1.28 ± 0.04	1.79 ± 0.07	6.24 ± 0.12	8.03 ± 0.08

In rabi season, the field was laid out at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram during 2019-2020 (Fig. 3a). At 45 days after transplanting (DAT), the colonized chilli plants recorded increased shoot length of 18.26 cm, 30.33 leaves and 2.57 branches compared to 14.08 cm, 21.09 and 1.67 respectively in control. These observations were further enhanced in the presence of the endophyte at 90 DAT, where the shoot length, number of leaves and branches increased to 39.50 cm, 52.67 and 6.27 respectively. The experiment was repeated at Department of Vegetable Sciences, College of Agriculture, Vellayani, in the summer season (2020-2021) (Fig. 3b). A similar trend of improved biometric parameters was noticed in the treated plants. At 45 and 90 DAT, chilli plants colonized with *P. indica* produced maximum shoot length, leaves and branches compared to control plants.

Further, observations on various biometric characters revealed that these characters were significantly increased in the *P. indica*-colonized chilli plants over the control

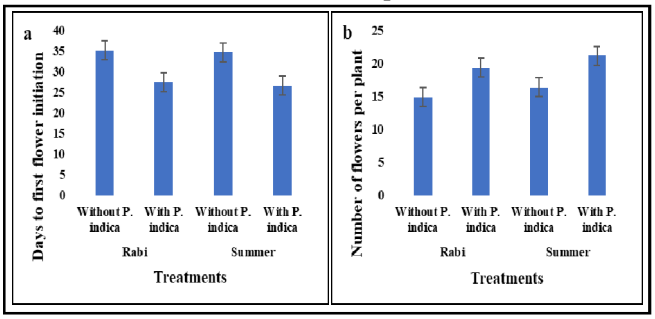

Fig. 5: *P. indica*-colonized chilli plants exhibited earliness in flowering. [After transplanting, the plants were observed for flowering symptoms. The days taken to initiate first flowering and number were recorded. The graphs show (a) days to first flower initiation; (b) number of flowers per plant in *P. indica*-colonized and control chilli plants during rabi and summer seasons under field conditions. The data are based on 10 independent biological replicates and bars represent SEs.]

under field situations. *P. indica*-colonized plants showed better root architecture along with higher root and shoot biomass. At 45 DAT, the colonized chilli plants displayed plant height of 41.05 cm with 35.60 leaves and leaf area of 6.41 cm^2; which were significantly high compared to the control plants. The number of secondary roots (57.40) and tertiary roots (28.60) were found to be increased substantially in the colonized plants than in control. The shoot weight and root weight were 2.44 g and 1.77 g respectively compared to 1.59 g and 1.28 g in control. Similar trend was recorded in the endophyte colonized plants at 90 DAT. The *P. indica*-colonized plants exhibited a plant height of 62.00 cm. Number of secondary roots (68.50) and tertiary roots (57.70) were higher in the colonized chilli plants in comparison to 58.00 secondary roots and 41.10 tertiary roots in control plants. Increase in plant biomass by *P. indica* contributed to higher shoot (6.52 g) and root weight (8.03 g) (Table 2). Stronger growth promoting effects of the endophyte had resulted in higher yield in chilli during both the seasons in comparison to non-treated plants (data not shown).

Biometric observations were recorded in the *P. indica*-colonized and control chilli plants at 45 and 90 days after transplanting (DAT) under field conditions. Chilli seeds (*var.* Vellayani Athulya) were sown in *P. indica* multiplied (+ *P. indica*) and control (- *P. indica*) media. About 15 days after germination, seedlings were transplanted in the field and observations were recorded at specific intervals. The data is statistically analyzed using paired t-test and the values are expressed as mean ± standard deviation (n=10).

Endophyte induced early flowering in chilli plants under field conditions

The days taken for flower initiation was observed to be minimum in *P. indica*-colonized chilli plants (Fig. 5a). During the rabi season, the endophyte reduced the number of days to 27.50 as against 35.20 in control. Similarly, in the summer season, flowering started in 26.60 days (early)

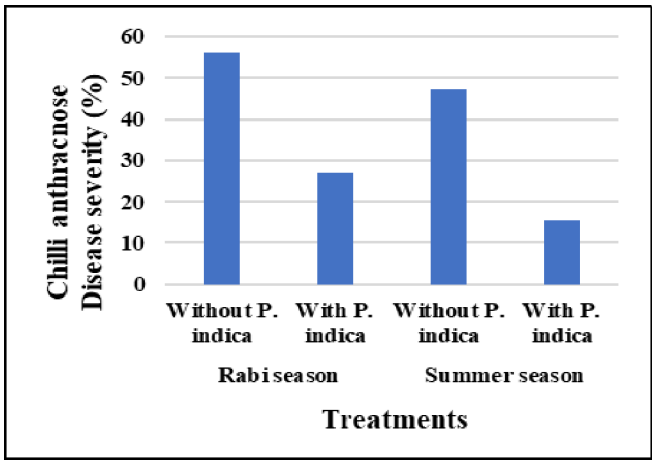

Fig. 6: Natural incidence and severity of anthracnose disease was less in the *P. indica*-colonized / primed chilli plants under field conditions. [The plants in the field were periodically examined for disease symptoms and severity was calculated for both rabi and summer seasons. The graphs represent severity (%) of anthracnose caused by *Colletotrichum capsici* in *P. indica*-primed and control chilli plants in field trials during rabi and summer. Data is based on 20 independent biological replicates.]

after transplanting in the colonized plants against 34.7 days in control chilli plants. *P. indica* also improved the number of flowers produced and set. At 60 DAT, more flowers of 19.40 and 21.20 were noticed in endophyte treated plants during rabi and summer season respectively in comparison with control (14.90 and 16.40) (Fig. 5b). The increased flower production has contributed to the enhanced fruit set and yield (data not shown).

P. indica significantly reduced anthracnose disease severity in the colonized chilli plants

Natural incidence of fungal foliar disease, anthracnose caused by *C. capsici* infecting chilli plants were recorded from the field. In both the seasons, disease severity due to chilli anthracnose was considerably lower in the endophyte colonized chilli plants (Fig. 6). During rabi season, endophyte-colonized chilli plants recorded the lowest disease severity of 27.00 per cent compared to 56.50 per cent in the control plants. Similarly, minimum disease severity of 15.50 per cent was recorded in the colonized plants than 47.00 per cent in control in the summer season.

Discussion

In the light of exceptional ability to colonize varied host plants and to be axenically cultivable *in vitro*, *P. indica*, a root endosymbiotic beneficial fungus gained wide acceptance in today's modern world. This endophyte forms complex, mutual and symbiotic associations with diverse host plants, benefitting them as a biofertilizer cum biocontrol agent. *P. indica* instigated growth promotion in the host crop plants, enhanced nutrient availability, and induced stress resistance; thus, becoming a potential prospect for sustainable agriculture and safe environment (Waller *et al.*, 2005; Mensah *et al.*, 2020).

Root endophytic fungus, *P. indica* initiates symbiotic relationships with various terrestrial plants belonging to different families. In the present study, beneficial as well as mutual interaction of *P. indica* with chilli seedlings was established. Faster and efficient endophytic colonization was noticed in the primed chilli plants. Successful *P. indica* colonization revealed mycelial proliferation and production of chlamydospore within the chilli root cells, which increased to reach maximum number at 15 DAC. The chilli seedlings appeared to be colonized even on the 3rd DAC. *P. indica* hyphae were observed on 3rd DAC and chlamydospores were produced after successful establishment in the plant. Jisha *et al.*, (2019) observed hyphae and chlamydospores within the root cells of the colonized eggplant, cucumber, okra and chilli. Chandran *et al.*, (2021) noticed *P. indica* mycelia in the colonized yard long bean or vegetable cowpea roots at 5 DAC while, chlamydospore production was observed at 7 DAC. Also, clusters of spores were observed on the root surface at 14 DAC. Su *et al.*, (2021) showed electron microscopic images of endophytic hyphae and chlamydospores covering the surface of tobacco roots.

Growth enhancement and better root system induced by *P. indica* have been discussed in many crop plants grouped under different families (Li *et al.*, 2019; Tsai *et al.*, 2020). Coir pith : dried powdered cow dung medium cultured with the endophyte was used to colonize chilli plants in our experiment. Increased plant height together with maximum root lengths was observed in the colonized chilli plants. In addition, *P. indica*-colonized chilli plants displayed greater shoot length, more leaves, higher primary and secondary roots, enhanced shoot and root biomass. Consistent to our findings, Jisha *et al.*, (2019) found that five vegetable seeds including *Capsicum annuum*, inoculated with *P. indica* exhibited early germination, improved shoot and root number as well as lengths. Li *et al.*, (2019) recorded maximum plant height, stem circumference and root biomass as against control in micro propagated banana plant lets. Khalid *et al.*, (2020) reported 21.24 and 36.60 per cent increase in shoot fresh and dry weights respectively in *P. indica*-colonized *Brassica campestris* sp. *chinensis* while root and shoot biomass improved between 48.54 and 139.16 per cent in *P. indica*-primed tobacco seedlings (Su *et al.*, 2021). Similar conclusions of growth enhancement and faster root development were reported in Chinese cabbage (Sun

et al., 2010; Lee *et al*., 2011), potato (Upadhyaya *et al*., 2013), Arabidopsis (Johnson *et al*., 2011), tissue-culture banana (Li *et al*., 2019), rice (Bakhshandeh *et al*., 2020), brinjal (Swetha and Padmavathi, 2020), tomato (Athira and Anith, 2020; Kaboosi *et al*., 2022), sweet potato (Li *et al*., 2021) and wheat (Li *et al*., 2023).

Colonizing host plants with *P. indica* remarkably increased biomass (Verma *et al*., 1998). Effective endophytic colonization induced better growth parameters in the colonized chilli plants grown indoor and in field. This may be attributed to increased nutrient supply by *P. indica*; thereby improving the vegetative as well as reproductive tissue development (Barazani *et al*., 2005; Franken, 2012, Aslam *et al*., 2019). Oelmüller *et al*., (2009) showed that fungal endophyte obtains the host photo-assimilates in an endosymbiotic relationship. This is observed to help in better mycelial spread and colonization of endophyte within hosts, leading to better plant growth prospects. Also, the plant growth advancement level was recorded as 50 per cent and the improved growth was mainly attributed to good root systems (Waller *et al*., 2005; Baltruschat *et al*., 2008). It was well established that *P. indica* could increase the availability of soil nutrients, its absorption, transportation and translocation in plants which ensures higher inputs for photosynthesis; which in turn enhances photo-assimilates for the promotion of growth, development and yield in crop plants (Johnson *et al*., 2014).

Early flowering is an important morphological trait that appeared to be stimulated by *P. indica*-plant interactions. In our study, the endophyte significantly reduced the days taken for first flower initiation and thus contributed to early flowering. Das *et al*., (2012) found that 81 per cent of flowers in *P. indica*-colonised *Coleus forskohlii* bloomed 7 days earlier, in addition to maximum length and number of inflorescences. Similarly, Pan *et al*., (2017) observed that flowering was earlier by five to six days in *P. indica*-primed Arabidopsis plants. In our study, number of flowers produced by *P. indica*-colonized chilli plants was greater than in control. Kaboosi *et al*., (2022) recorded an improvement in number of flowers by 1.5 times and 40 per cent in co-cultured tomato plants at 10 and 12 weeks after inoculation respectively. The ability to promote early flowering due to *P. indica*-colonisation in plants may be induced by higher gibberellin levels (Kim *et al*., 2017; Xu *et al*., 2018).

Hormones or chemical messengers in host plants have a central role during symbiotic interactions of microbes with plants, thereby inducing growth and organ development. Plant hormones namely auxins, gibberellins and cytokinins are mainly involved in promoting growth and yield in hosts (Xu *et al*., 2018). Sirrenberg *et al*., (2007) revealed endophyte-mediated root biomass enhancement is mainly by stimulating auxin production. Lee *et al*., (2011) suggested that high auxin levels observed in Chinese cabbage roots was attributed in growth enhancement. Many researchers have found the active constituents in the fungal exudates that assist in improved growth and productivity of the co-cultivated plants. Cell wall extracts (CWE) of *P. indica* had been found to stimulate increased biomass and seed formation in Arabidopsis plants (Vadassery *et al*., 2009). *P. indica* employed host putrescine to help in the betterment of growth and colonization within the plant (Kundu *et al*., 2022). *P. indica* co-cultivation also helped to alleviate stress in chilli plants due to anthracnose diseases. This could improve the marketable surplus which was earlier lost to diseases and pests.

Conclusion

In nutshell, our findings demonstrated that *P. indica* is a competent bio-fertilizer, aiding in crop improvement. The fungal endophyte can be employed as an effective biofertilizer, for minimizing the use of chemicals and for aiming for a safe environment. Future thrust is to be laid on studies related to various *P. indica* triggered signalling pathways, plant hormone levels and their cross-talks along with gene expressions involved in the *P. indica*-mediated plant metabolism, symbiosis and mineral uptake.

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