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Impact of phosphofungi isolated from rhizosphere soil of medicinal plants on growth, yield and phosphate uptake in Sorghum

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A total of 13 phosphate solubilizing fungi were isolated and screened using Pikovaskaya's medium from 15 rhizosphere soils of medicinal plants by serial dilution. Among them, 4 isolates were selected with maximum solubilization index and further evaluated their phosphate solubilization. PSF 10 (*Talaromycesamestolkiae*) showed good results in phosphate solubilization parameters including solubilization index (3.21), decreased pH (3.2 from initial pH 6.8), estimation of organic acid (39.01g/L), and phosphate present in culture broth (25µg/ml). The sorghum seeds showed 96% germination and growth and yield parameters with plant heights of 30.8, 63.9, 95.1, 138.8, and 182.6cm, at 15, 30, 45, 60 days and at harvest stage, respectively; leaf nos. of 4, 6, 13, 14, 15 at 15, 30, 45 , 60 late sowing and harvest respectively; root length (17.8cm), the weight of biomass (fresh weight -59.6g and dry weight – 12.7g) and yield parameters includes weight of spike/plant (75g), number of grains/plant (2338), weight of grains/plant (86.50 g), and 1000 grains weight (38.5g). The highest phosphorus uptake in the plants was recorded (0.399%) and the maximum P (Kg/ha) accessible in rhizosphere soil was recorded as 344.29 Kg/ha. Due to the observation of good results in the phosphate solubilization, improving the yield of sorghum and also phosphorus uptake, available phosphate in rhizosphere soil of sorghum, PSF 10 (*Talaromycesamestolkiae*) was recommended as phosphate bioinoculum in the agricultural field to improve growth and yield in sorghum and fertility of the soil.

Keywords: Organic acid, plant phosphorus, soil phosphorus, solubilization index, sorghum

INTRODUCTION

Sorghum is the world's 5th most important cereal, a multipurpose crop and it has great potential to become one of the utmost economically chief crops in India (Sharif *et al.* 2014). Sorghum bicolor belongs to the family Poaceae and is extensively grown worldwide in food, fodder, and the production of alcoholic beverages. Sorghum mainly contains carbohydrates and dietary fiber is the main component (Steiner *et al.* 2016). Among the macronutrient, phosphorus plays the most important and essential mineral, which is in need for the greatest yield of crops and also assists in growth and reproduction (Mahantesh and Patil, 2011).It occupies a vital factor in stalk and stems length, flower and seed formation, crop maturity and production, crop quality, and resistance to plant disease.

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But due to the inadequacy ofphosphate in soil, its lack is a major constraint for crop production (Aadarsh *et al.*2011) and it can severely limit plant growth and productivity. Vessey and Heisinger (2001) report that magnification of plant phosphorus nutrition might be due to the exciting of root growth or the Extension of root hairs by specific microorganisms thus no direct growth in the opportunity of soil P is always anticipated. Singh and Reddy (2011) reported that inoculation with phosphofungi along with rock phosphate can replace the chemical fertilizer in alkaline soil and help upgrade crop production. A varied group of soil microflora was described to be associated with solubilizing insoluble P complex authorize plants to easily absorb P (Walpola and Yoon, 2012). So, the PSM converts these insoluble phosphates into soluble forms through distinct mechanisms. They execute the process of acidification, chelation, exchange reaction, and production of gluconic acid (Nisha *et al.* 2014). The organic and inorganic acids from the microbes metamorphose tricalcium phosphate

into di- and monobasic phosphates (Walpola and Yoon, 2012) with the net result of amplifying the availability of the element to the plants. The kind of organic acids produced and their amounts differ with the contrasting organisms (Mahamuni, 2012).

Not only providing P to the plants the PSM also facilitates the growth of plants by restoring the efficiency of Nitrogen fixation, accelerating the accessibility of other trace elements, synthesizing incorporate growth-promoting matter including siderophore (Wani *et al.* 2007b) and antibiotics (Lipping *et al.* 2008), and providing protection to plants opposed to soil-borne pathogens (Hamdali*et al.* 2008). Consequently, these microbial groups when used singly or in union with other rhizosphere microbes have shown considerable measurable results on plants in conventional agronomic soil. The crucial mechanism of mineral phosphate solubilization is the activity of organic acid synthesized by soil microorganisms and by the activity of the phosphatase enzyme. Production of these organic acids resulted in the acidification of the microbial cell and its surroundings (Nisha *et al.* 2014).

Lack of phosphorus leads to chlorosis, necrosis, and stunted growth in plants (Mahantesh and Patil, 2011). In acute cases of phosphate deficiency, symptoms include characteristics of stunting, purpling, or browning appearing first on the lower leaves and base of the stem and working up words on the plants extremely on cereal crops. Keeping in view the significance of phosphate in crop production and upgrading its solubility, this fieldwork was conducted with PSF inoculants on growth, yield, and phosphate uptake of sorghum crops.

MATERIALS AND METHODS

Rhizosphere soil sample collection

Rhizosphere soil samples were collected at 10–15cm depth of roots from different medicinal plants around the dry deciduous forest regions of Malnad areas of Shivamogga (D). The collected soil samples were placed in sterile polythene bags and they were brought into the laboratory under aseptic condition and maintained at 4^0C until they were further used for isolation of phosphofungi (Jain and Singh, 2015; Chatli *et al.* 2008).

Isolation of phosphate solubilizing fungi

For isolation of phosphofungi, about 1g of rhizosphere soil was suspended in 9 ml of sterilized 0.85% of saline solution and serially diluted. The respective dilutions were plated on sterile solidified Pikovskaya's agar medium by spread plate method and incubated at room temperature for 7 days. After incubation, the plates were examined for solubilizing zone around fungal colonies and those colonies was showing solubilizing zone they were selected, and sub-cultured on fresh media for further study (Nelofer*et al.* 2016; Verma and Ekka, 2015).

Microscopic characterization

Identification of phosphate solubilizing fungi was done by the lactophenol cotton-blue (LPCB) mounting technique. LPCB wet mount mixture is a broadly used method of microscopic observation of fungi. The specimen was stained with LPCB stain, the coverslip was placed above the specimen and observed under the microscope (40X magnification), and characters were noted by observing spore shape, spore size, spore arrangement, and arrangement of hyphae and identified by referring to the standard manuals (Aneja 2009; Booth 1971; Funder, 1961).

Screening of phosphate solubilizing Fungi

To screen the Phosphofungi, each isolated fungal cultures were point inoculated on Pikovskaya's agar plates and incubated at room temperature for 7 days. The arrival of a halo zone around the fungal colony indicates the phosphate solubilizing activity of the fungus and the solubilization index of each PSF was calculated by using the following formula (Tomer *et al.* 2017; Elias *et al.* 2016).

$$SI = \frac{\text{Colony diameter + Halo zone diameter}}{\text{Colony diameter}}$$

Measurement of pH and estimation of organic acid

The familiar solubilization mechanism of insoluble phosphate is by the acidification of the medium

due to declare of different organic acids produced by phosphate solubilizing fungi. Culture supernatant was collected by centrifuging the PSF culture filtrate at 1000rpm for 10min for measurement of pH and estimation of organic acid. The sterile uninoculated broth was in the service of control. Inceptive pH and change in pH after incubation was written down by digital pH meter (Jain and Singh, 2015). And about 50ml of culture supernatant in a conical flask was put on with a few drops of phenolphthalein indicator and titrated against 0.1N NaOH solution. The titrable acidity was expressed in g/L (Wang *et al.* 2018; Khan and Gupta, 2015).

Quantitative estimation of phosphate

The isolates were inoculated into 100ml of sterile Pikovskaya's broth in a 250ml conical flask and incubated at room temperature for 7 days at 100rpm in an orbital shaker incubator. After incubation, culture filtrate was collected and centrifuged at 3000rpm for 30min. Estimation of phosphate in the supernatant was done by the Vanadomolybdate yellow colour method, absorbance was measured at 420nm and it was expressed in µg/ml. The amount of phosphate was calculated from a standard curve of KH_2PO_4 (Verma and Ekka, 2015).

Screening for siderophore production

About 60.5mg of Chrome azurol Sulfonate (CAS) was added to 50mL of distilled water and this was mixed with 10mL of the Iron solution prepared 1mM Ferric chloride in 10mM Hydrochloric acid. The resultant solution was added to the HDTMA solution (72.9mg of HDTMA in 40 mL of distilled water) with constant stirring and sterilization. The sterilized dark purple liquid was added to sterile Pikovskaya's medium containing without Tricalcium phosphate to make CAS agar. PSF cultures were point inoculated on CAS agar plates and incubated at room temperature for 7 days (Ghosh *et al.* 2017; Raval and Desai, 2015).

Seed germination and seedling vigor

The percentage of seed germination and seedling vigor of sorghum seeds for field application was tested. The seed germination was done by the standard blotter method (Sane and Mehta, 2015) and for detection of seedling vigor, the paper towel method was followed (Mahadevamurthy*et al.* 2016) using the following formula.

$$\% \text{ Seed germination} = \frac{\text{No. of seed germinated}}{\text{Total no. of seeds placed}} \times 100$$

Seedling Vigor index = [Mean Shoot Length + Mean root Length] × Seed germination

Preparation of bioinoculum

The PSF inoculants were prepared by mixing the spore suspension with the carrier material (Lignite) in a ratio of 1:4 (spore suspension: carrier material). The inoculants were mixed with sterile water and the slurry was prepared, then the sorghum (*Sorghum bicolor*) seeds were mixed with the slurry in such a way that each seed was coated with a layer of PSF inoculants and air-dried, these air-dried seeds were used for field application (Saxena *et al.* 2015).

Plant growth and yield parameters

After screening and quantification of phosphate solubilization by PSF under laboratory conditions, the inoculums were amended in soils and evaluated on plant growth and yield of sorghum, such as growth parameters including length of the plant, leaves number, root length, fresh and dry weight, and yield parameters include the spike weight (g)/ plant, Number of grains/ plant, the weight of grains (g)/ plant and weight of 1000 grains (g) (Malviya *et al.* 2011; Yadav *et al*. 2011; Afzal *et al.* 2005).

Estimation of plant phosphorous

Phosphorous uptake of sorghum plants was determined by the Vanadomolybdate phosphoric yellow colour method. 0.5g of powdered sample of sorghum plant was digested in a triacid mixture comprising conc. Nitric acid, Perchloric acid, and Sulphuric acid (7:3:1 v/v). The digested remainder was made up to 100ml. Ten ml of digested remainder and 10ml of Vanadomolybate reagent were mixed and volume made up to 50ml. The intensity of the developed yellow colour is due to the Phosphovanadomolybdate complex. The

absorbance of phosphorous was taken at 410nm. Plant phosphorus was measured by the following formula (Abbas *et al.* 2013; Malviya *et al*. 2011) -

$$P\ \%\ in\ Plant = \frac{P(ppm\ in\ plants) \times Volume\ of\ digest \times 100}{Weight\ of\ plant}$$

***Soil Analysis for Available P (Kg/ha*)**

The available phosphorus (Kg/ha) in the rhizosphere soil of sorghum after harvesting the crop was extracted using Olsen's method. Here sodium bicarbonate (0.5M NaHCO3) was used for the extraction process. The sodium bicarbonate solution extracts some exchangeable or surface-absorbed Al-P, Fe-P, Ca-P, and other forms of Phosphates. Olsen extracts of air-dried soil – the extracted phosphorus was estimated by Olsen's reagent, available phosphate was colorimetrically determined using the ascorbic acid method, and the intensity of blue colour was read by using a spectrophotometer at 730nm (Hefnawy*et al.* 2017).

RESULTS AND DISCUSSION

Isolation ofphosphate solubilizing fungi

Total of 13 phosphate solubilizing fungi were isolated from 15 different rhizosphere soil samples of medicinal plants around dry deciduous forest areas of Malnad regions of Shivamogga district showed solubilization zone around them and were labeled as PSF 1 to PSF 13 listed below in (Table1).

Microscopic characterization

The isolated phosphate solubilizing fungi were identified based on their culture characteristics, colony colour, morphology, spore arrangement, and structure of hyphae observed under the microscope regarding standard fungal manuals (Table1).

Screening of Phosphate Solubilizing Fungi

For screening the isolated PSF for a more efficient isolate, the solubilization index (SI) of those 13 fungal colonies was measured by inoculating them onto Pikovasky's agar media and the solubilization indices of 13 PSF was in the range of 1.29 to 3.21 (Table 1). Among them, 4 isolates (PSF 5, PSF 7, PSF 8, and PSF 10) (Fig.1) were selected with maximum solubilization indexed colonies and they were further evaluated for their phosphate solubilization under laboratory and field applications.

Measurement of pH and estimation of organic acid

The organic acids produced by PSF reduce the pH in the culture media leading to P solubilization and decreased pH was observed in Pikovskaya's broth when inoculating the PSF into the broth. The selected 4 fungal cultures reduce the pH of the broth was recorded ranging from 4.3 to 3.2 from initial pH of 6.89 (Table2). The estimation of the amount of acid present in the culture broth of selected 4 PSF ranging from 39.01g/L to 30.16g/L was estimated using strong alkali (Table 2).

Quantification of Phosphate

The concentration of phosphate present in the culture filtrate of selected 4 PSF recorded ranged from 60µg to 25µg was estimated by vanadomolybdate yellow colour method using the standard curve of KH_2PO_4(Table 2).

Screening for siderophore production

Siderophores are secondary metabolites act as solubilizing agents for iron from minerals or organic compounds under conditions of iron limitation. The selected 4 PSF showed positive results for siderophore production by change the colour of media from blue to pink detected on CAS agar media (Fig. 2).

Seed germination and seedling vigor

The seed germination percentage of the sorghum was recorded as 96% and the seedling vigor of the selected radish seeds was calculated as 1014.72 and 1367.04 on the 7th and 14th day after incubation respectively (Fig 3). The seeds were treated with PSF inoculants such as PSF 5, PSF 7, PSF 8, and PSF 10, each PSF inoculants was mixed with sterile water, and the slurry was prepared, then the seeds were soaked in the slurry

Table 1: Isolation and identification of phosphate solubilizing fungi

Scientific name	Code No.	Culture	Solubilization Index (SI)
Datura fastuosa	PSF 1	*Aspergillus* sp.	2.47
Moringa oleifera	-	-	-
Leucus aspera	PSF2	*Aspergillus* sp.	2.70
Phyllanthus acidus	PSF 3	*Alternaria* sp.	2.16
Argemone mexicana	PSF 4	*Aspergillus* sp.	1.29
Achyranthus aspera	**PSF 5**	***Penicillium* sp.**	**3.03**
Centella asiatica	PSF 6	*Penicillium* sp.	2.51
Asparagus racemosus	**PSF 7**	***Talaromyces* sp.**	**3.02**
Gymnemasylvestres	**PSF 8**	***Aspergillus aculeatus***	**3.08**
Tinospora cordifolia	PSF 9	*Penicillium* sp.	1.60
Costusingneus	**PSF 10**	***Talaromycesamestolkiae***	**3.21**
Saracaasoca	PSF 11	*Aspergillus* sp.	2.71
Calotropis procera	-	-	-
Calotropis gigantea	PSF 12	*Penicillium* sp.	1.49
Vitex nigundo	PSF 13	*Aspergillus* sp.	1.33

Table 2: Phosphate solubilizing parameters

Culture code	Culture	pH	Organic acid	Conc. of P (µg)	siderophore
PSF 5	*Penicillium* sp.	3.8	32.9	45	+
PSF 7	*Talaromyces* sp.	4.3	30.16	60	+
PSF 8	*Aspergillus aculeatus*	4.0	34.9	45	+
PSF 10	*Talaromyces amestolkiae*	3.2	39.01	25	+

Table. 3: Plant height and number of leaves of Sorghum

	Plant growth parameters									
	Plant height					Number pf leaves				
Culture code	15 days	30 days	45 days	60 days	At harvest	15 days	30 days	45 days	60 days	At harvest
Control	20.5	53.6	84.8	117.5	150.2	3	6	10	12	13
PSF 5	21.1	54.2	85.4	118.1	150.9	3	6	12	14	15
PSF 7	21.9	55.1	86.3	120.4	154.8	3	7	12	13	14
PSF 8	22.3	55.4	86.6	121.8	157.1	3	6	13	15	15
PSF 10	30.8	63.9	95.1	138.8	182.6	4	6	13	14	15

Table 4: Plant growth parameters of Sorghum

Plant growth paramers			
		Biomass (g)	
Culture code	Root length (cm)	Fresh weight	Dry weight
Control	16.1	29.7	4.7
PSF 5	16.9	41.8	8.9
PSF 7	16.6	29.9	5.2
PSF 8	16.8	30.2	5.9
PSF 10	17.8	59.6	12.7

and mixed in such a way that each seed coated with a layer of PSF inoculants and air-dried, these air-dried seeds were directly sowed in the field.

Plant growth parameters of sorghum

Among the selected 4 PSF inoculants, PSF 10 (Talaromycesamestolkiae) showed maximum plant growth parameters in sorghum (Fig.4**)** including, plant height and several leaves were, 30.8cm and 4 leaves, 63.9cm and 6 leaves, 95.1cm and 13 leaves, 138.8 cm and 14 leaves, 182.6 and 15 leaves were recorded at 15th, 30th, 45th and 60th days of sowing and at harvest respectively (Table3). The root length was measured as 17.8cm after harvesting the crop. The fresh and dry weight of the plant is one of the important growth parameters, fresh and dry weight was measured as 59.6g and 12.7g

Table 5 : Yield parameters of sorghum after harvesting

Inoculants	Yield Parameters			
	Weight of spike/plant (g)	Number of grains/plant	Weight of grains/plant	Weight of 1000 grains
Control	19	264	9.76	37.1
PSF 5	26	521	19.27	37.4
PSF 7	24	463	17.13	37.3
PSF 8	44	1129	41.77	37.9
PSF 10	75	2338	86.50	38.5

Table 6 : Effect of PSF inoculants on plant Phosphorus uptake (%) and available Phosphorus in rhizosphere soil of Sorghum after harvest the crop

Culture code	Plant phosphorus uptake (%)	Available P in soil (Kg/ha)	
		P^H of the soil	Phosphate
Control	0.178	7.35	198.15
PSF 5	0.289	7.49	213.98
PSF 7	0.371	7.41	332.12
PSF 8	0.265	7.58	239.11
PSF 10	0.399	7.51	344.29

respectively compared to the control plants (Table4).

Yield parameters of sorghum

The data on the influence of PSF inoculants on the weight of spike/plant, number of grains/plant, the weight of grins/plant, and weight of 1000 grains of the economic part of the sorghum that is grains after harvesting is represented in table 5. The maximum weight of spike/plant (75 g), number of grains/plant (2338), the weight of grains/plant (86.50), and weight of 1000 grains (38.5 g) were recorded in the plant treated with PSF 10 (*Talaromyces amestolkiae*) compared to the control plants (Fig.5).

Estimation of Plant Phosphorous

The data on the influence of the selected 4 PSF inoculants on phosphate uptake (%) in the sorghum plants are represented in Table6 and Fig. 6. The plant P uptake (%) by the crops was estimated and the maximum plant phosphorus uptake was recorded in sorghum plants treated with PSF 10 (*Talaromyces amestolkiae*) was 0.399% compared to the control plants.

Soil analysis for available P (Kg/ha)

The data on the influence of selected 4 PSF inoculants to evaluate the available P (kg/ha) in the rhizosphere soil of crop plants after harvesting were represented in Table 6. The maximum P (kg/ha) available in the rhizosphere soil of crop sorghum, was recorded at PSF 10 (*Talaromyces amestolkiae*) compared to the control plants.

PSMs play an important role in supplementing phosphorus to the plants, allowing sustainable use of phosphate fertilizers. In the present research work, different rhizosphere soil samples from medicinal plants of Malnad areas of Shivamogga were collected and Phosphate Solubilizing Fungi were isolated by serial dilution method. Then they were further characterized and their phosphate solubilizing capacity was done in vitro. The results obtained in our work were correlated with earlier findings.Nelofer*et al*. (2016) have serially diluted the soil samples and inoculated them in Pikovskaya's agar by pour plate method. Among the 45 soil samples, 11 were given colonies with clear zones that were considered phosphate-solubilizing strains. Tomer *et al*.(2017) have studied the solubilization index of three bacterial isolates ranging from 7.2 to 62mm, while Elias et al. (2016) obtained SI of 359 fungal isolates ranged from 1.10 to 3.05.

Major mechanism of mineral phosphate solubilization is the action of organic acid synthesized by soil microorganisms. Production of these organic acids results in acidification of the microbial cell and its surroundings. Hence the

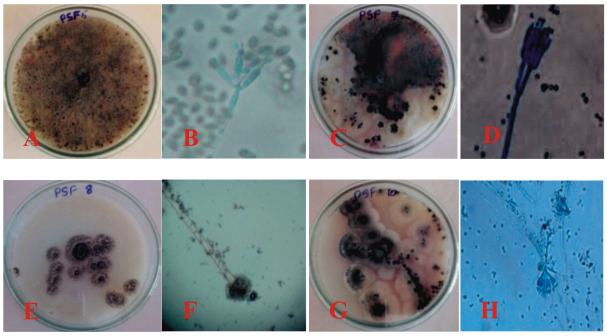

Fig.1: Pure culture and microscopic observation of *Penicillium oxalicum* (A and B), *Talaromyces* sp. (C and D), *Aspergillus aculeatus* (E and F), *Talaromycesamestolkiae*(G and H)

Fig. 2: Seed germination (A) and Seedling vigour (B) of Sorghum

Fig. 3: Sorghum crop in the field

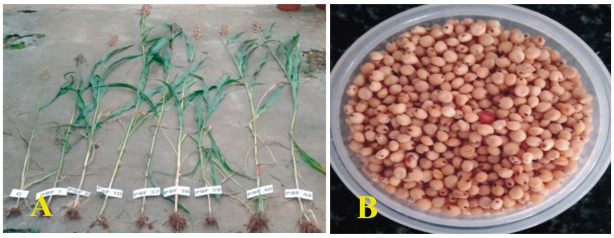

Fig.4: Harvesting the Sorghum (A) and grains of Sorghum (B)

results obtained in our work correlated with results highlighted by earlier reports of Jain and Singh (2015) who have isolated and identified phosphate solubilizing fungi, on applying the inoculation a decrease in pH was observed in liquid medium ranging from 4.0 to 3.2 from the initial pH of 7.5. Similarly, in our work also decreased pH was recorded in PKV broth ranging from 4.3 – 3.0 form the initial pH of 6.8. Khan and Gupta (2015) also checked the ability of acid production of 29 acidophilic fungal isolates that were isolated and 5 isolates LAK-2, BS-1.6, CM-2, DR-1 and DR-2 showed good acid production. The Vanadomolybdate method for estimation of phosphate present in the culture broth was adopted in our work and the results were correlated with earlier findings of Verma and Ekka (2015) who reported that the concentration of phosphate in culture broth ranged from 219.16µg/

Fig 5: Powder form of sorghum plants

ml to 59.17µg/ml. The results obtained in our work were highlighted by earlier reports of Ghosh *et al.,* (2017), who have reported that isolates of *Trichoderma* showed siderophore production in CAS agar plate, *Trichoderma harzianum* produced a maximum percentage of siderophore than *T. viride, T. asperellum,* and *T. longibrac-hiatum*.

Phosphorus (P) is an essential plant nutrient for plant growth. For optimal plant growth, plants require 0.3 – 0.5% P in the dry matter during vegetative growth. The results were highlighted by earlier works of Mahadevamurthy*et al*. (2016) who have isolated 22 rhizospheric fungi from different rhizosphere soil of healthy crop plants and checked the seed germination and seedling vigor. Maximum of 85.75 %, 80 %, and 83 % of seed germination and seedling vigor 985.25, 523, and 673.5 were recorded in pearl millet, brinjal, and tomato respectively. Hence the obtained results were correlated with earlier findings of Yadav *et al.* (2011) who have isolated *Aspergillus*

niger, Penicillium citeinum, and *Trichoderma harzianum*and checked their effect on chickpea plants. Shoot length, root length, shoot dry weight and root dry weight were checked by inoculants. These isolates significantly enhanced the length of chickpea seedlings. The present obtained results also correlated with earlier findings of Afzal *et al.* (2005) who reported that wheat grain yield and biological yield was significantly increased by the treatments and maximum yield was recorded when PSM was used with phosphorus alone or along with organic matter, grains per spike of wheat as compared to control on wheat.

Plant phosphate uptake was determined by the Vanado-molybdate phosphoric yellow colour method while Abbas *et al.* (2013) followed the same method for determining the plant P uptake and results showed that higher plant P contents (0.29) were observed in treatment having the combination of IplelpIe (II) + PSB + Recommended K + ¾ N + ¾ P followed by 0.24. The minimum plant phosphorous content (0.10) was recorded in the control. While Olsen extracts of air-dried soil for analysis of available phosphorus (Kg/ha) were estimated colourimetrically using the ascorbic acid method as followed by earlier findings of Hefnawy*et al.* (2017) who obtained similar results while using Aspergillus niger and Aspergillus fumigatus as PSF.

CONCLUSION

Phosphorus (P) is one of 17 nutrients essential for plant growth and development, making up about 0.2% of plant dry weight. In nature, several different bacterial and fungal species majorly solubilize inorganic and organic forms of the P compound. Therefore primary approach in the agronomic management of phosphate is to scavenge the native/fixed P and also to overcome the fixation of applied P fertilizer. The low-cost practice to activate this objective is to inoculate the soil with phosphate-solubilizing fungi and bacteria. Hence the application of phosphate solubilizing bioinoculum significantly increased the plant height, the number of leaves, root length, and yield of sorghum. This is important because sorghum is the world's 5th most important cereal, a multipurpose crop and it has great potential to become one of the most economically important crops in India. So in the present study was concluded that among the various isolates PSF 10 (*Talaromycesamestolkiae*) was found to be a more beneficial phosphate solubilizer and significantly improved growth, yield, and phosphate uptake of sorghum crop.

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DECLARATION

Conflict of interest: Authors declare no conflict of interest.

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