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Plant Growth Promoting *Pseudomonas* spp. from Diverse Agro-Ecosystems of India for *Sorghum bicolor* L.

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Abstract

Fluorescent *Pseudomonas* spp. comprise an important group of rhizosphere bacterial community affecting plant growth. Sorghum is an important fifth largest cereal crop in world. 75 fluorescent *Pseudomonas* spp. were isolated from diverse agro-ecosystems of India and evaluated for their plant growth promoting ability initially by paper cup method. Fourteen selected isolates were further evaluated under glass house conditions. Plants inoculated with bacteria showed higher growth and nutrient uptake than controls. Seedlings treated with selected isolate P17 showed highest root volume (0.3 cm^3), shoot length (36.2 cm), dry mass (152 mg), leaf area (31 cm^2), chlorophyll (23 spad units), carbohydrates (30%), phosphorus (1.3%), nitrogen (2.2%) and other nutrients. Among the evaluated isolates *Pseudomonas* sp. P17 strain was identified as a potential PGPR for nutrient uptake and plant growth in sorghum. This finding has potential for integrated plant nutrient management in rainfed agro-ecosystems where farmers tend to rely on cost effective technologies for enhanced profitability.

Keywords: *Pseudomonas* spp; Plant growth; Rhizobacteria; Soil nutrition; Agro-ecosystems; Sorghum

Introduction

Sorghum (*Sorghum bicolor* L.), is an important rainfed crop grown world over on 42 million ha in 98 countries and Nigeria, India, USA, Mexico, Sudan, China and Argentina are the major producers [1]. In India, sorghum was planted in 7.7 million ha with production of 7.24 million tonnes and productivity of 940 kg. ha^{-1} [2].

Soil microorganisms play important role in determining plant productivity. For successful functioning of introduced microbial bio-inoculants, exhaustive efforts have been made to explore soil microbial diversity of indigenous community, their distribution and behaviour in soil habitats [3]. Soil microorganisms are directly responsible for re-cycling of nutrients [4].

Considering the ill-effects of inorganic fertilizers on soil health, adoption of integrated nutrient management (INM) has been advocated for sustainable agriculture. Efforts to supplement nutrients through biofertilizers as part of INM helped the rainfed farmers significantly [5]. Microorganisms that facilitate nutrients availability and use could form sustainable solutions for present and future agricultural practices [6]. Microbes that indirectly or directly promote plant growth are referred to as plant growth promoting rhizobacteria (PGPR) [7]. Species of *Pseudomonas* comprise a large portion of the total culturable bacterial population in the rhizosphere. Due to the ubiquity and versatility of pseudomonads, there is a considerable interest in exploiting these bacteria for diverse agricultural applications such as plant growth promotion and pest management etc., [8].

Information on fluorescent *Pseudomonas* spp. from diverse agro-ecosystems and their plant growth promoting potential particularly in sorghum is scanty. In this paper, we report isolation and variations among 75 isolates of *Pseudomonas* spp. from 23 different agro-ecological regions of India with respect to their ability to promote nutrient uptake and growth in sorghum.

Materials and Methods

Bacterial cultures and seed bacterization

Seventy-five soil samples of different crops representing 31 locations from 13 states of India were used for isolation of fluorescent *Pseudomonas* spp. [9]. Sorghum seeds of cv. CSV-15 procured from Directorate of Sorghum Research, Hyderabad, India were bacterized with *Pseudomonas* isolates as described by Dileep Kumar and Dube [10].

Physico-chemical characterization of soil samples

Physical characters like pH, electrical conductivity (EC), particle size and chemical characters like macronutrients (N, P, K) and organic carbon content were characterized for all the collected soil samples and similar characterization was also done for the soil used for plant experiments (Table 3) [11].

Screening for plant growth promoting *Pseudomonas* isolates

Preliminary screening of *Pseudomonas* spp. isolates for their plant growth promotion (PGP) by seed bacterization was done as explained by Ali et al. [12]. Three bacterized seeds were sown in each paper cup containing sterile soil and six replicates were maintained with untreated control. 15 days after sowing (DAS) root length, shoot length and dry mass of seedlings (by drying to constant weight at 65°C) were recorded and relative increase was calculated as against un-inoculated control.

Pot experiments and nutrient analysis

Fourteen *Pseudomonas* spp. isolates viz, P1, P2, P4, P5, P13, P14, P17, P20, P21, P22, P23, P28, P29 and P35 shortlisted from previous experiment with >50% enhancement in dry mass of seedlings (Table

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1) were selected for pot culture experiments. Pot experiments with bacterized seeds were conducted as described by Sindhu et al. [13]. After 30 DAS root volume, shoot length, leaf area (measured by LI 3100 Lincoln Nebraska USA leaf area meter), total chlorophyll (measured by Minolta Spad chlorophyll meter-502) and dry mass of root and shoot were recorded.

Analysis of the macro- (NPK) secondary- (Na, Ca) and micro- (Fe, Cu, Mn, Zn) nutrients in the experimental plants was carried out following the protocols of Tandon [11]. Total carbohydrate content was estimated by anthrone method [14].

Statistical Analysis

Data obtained from all experiments were subjected to analysis of variance (ANOVA). Mean values between treatments were compared using Fisher's least significant difference (L.S.D) test ($P<0.05$). All plant growth parameters were given equal importance to follow Z-score ranking and to identify the promising *Pseudomonas* isolate showing best plant growth promotion.

Results

Isolation of fluorescent *Pseudomonas* spp.

Pseudomonas spp. isolated from different soil samples showing fluorescein production on King's B medium were selected and purified. 75 fluorescent *Pseudomonas* spp. were isolated from soil samples obtained from 31 different locations representing 13 states of India (Figure 1). Isolates were designated as P1 to P75 and added to the culture collection of Central Research Institute for Dryland Agriculture, Hyderabad. All the isolates were stored as 30% glycerol stocks at -20°C and revived periodically for further studies.

Characterization of soil samples

Of the 31 soil samples characterized, five were from western plains, one from western Himalayas, six from northern plains, two from central highlands, 11 from Deccan plateau, four from eastern ghats, and one each from eastern plateau and Chattisgarh-Mahanadi basin agro-ecological regions of India. The annual mean rainfall of these regions ranged from 150-1450 mm (lowest in western plains and highest in Chattisgarh-Mahanadi basin). The annual mean maximum soil temperatures ranged between 28-47°C with lowest being in western Himalayas and highest in western plains (Table 1).

Figure 1: India map showing soils samples from different agro-ecosystems. Figures in parentheses in legends represent number of samples collected.

Eight samples showed acidic pH from 6.0-6.9 with Phulbani sample recording lowest pH. Four soil samples were neutral with pH 7.0-7.2 and 19 were alkaline (pH 7.3-8.6) with Bijapur sample showing highest pH 8.6. Electrical conductivity (EC) of the samples ranged between 0.02 (Phulbani, Orissa) and 1.79 $dS.m^{-1}$ (Hisar, Haryana). Organic carbon (OC) content ranged between 0.12 (Phulbani) and 0.5% (Rajendranagar, Andhra Pradesh). Total available nitrogen content ranged from 62 (Hayatnagar, Andhra Pradesh) to 183 $kg.ha^{-1}$ (Arjia, Rajasthan). Similarly phosphorus (P_i) content ranged from 6.3 (Akola, Maharashtra) to 20.1 $kg.ha^{-1}$ (Parbhani, Maharashtra). Potassium content varied widely across samples with the highest being in 500.4 $kg.ha^{-1}$ Solapur (Maharashtra) and lowest of 55.6 $kg.ha^{-1}$ in Baribrahmana (Table 2).

Screening for plant growth promotion

Most of the *Pseudomonas* spp. isolates promoted growth of sorghum seedlings. While 69 isolates showed increase in root length, 70 isolates showed increase in shoot length and dry mass as compared to un-inoculated control (Table 4). All the isolates were grouped into three categories based on increase in dry mass viz, <25%, 25-50% and >50%. Of the 75 isolates, 45% of them showed <25% enhancement of dry mass, whereas 29% of them enhanced dry mass in the range of 25-50% and 17% of them showed >50% increment in dry mass (Figure 2). Remaining 7% isolates showed dry mass of less than control and were considered as deleterious rhizobacteria (Figure 2). 14 isolates viz, P1, P2, P4, P5, P13, P14, P17, P20, P21, P22, P23, P28, P29 and P35 that showed more than 50% enhancement in dry mass of seedlings were considered as potential strains for further pot-culture studies.

Pot experiments and nutrient analysis

Seed bacterization of sorghum with fluorescent *Pseudomonas* spp. enhanced sorghum plant growth significantly (Figure 3, Table 5). Root volume in control was 0.17 cm^3 whereas, in treatments it ranged between 0.18 and 0.30 cm^3. Inoculation of sorghum with P1 and P17 showed maximum root volume of 0.30 cm3 compared to other treatments. Significant increase in shoot length was observed with P17 (36.2 cm) inoculation followed by P1 (33.5 cm) and P22 (32.2 cm). Highest root dry mass was recorded in P2 (78.4 mg) followed by P17 (69.1 mg) and P35 (66.9 mg). Maximum shoot dry mass was recorded in plants treated with P17 (83.1 mg) followed by P1 (69 mg) and P22 (68 mg). Inoculated plants also showed higher leaf area compared to control. Leaf area of plants inoculated with P17 was 31.6 cm^2 followed by P22 (27 cm^2) and P20 (22 cm^2) than un-inoculated control plants (9.8 cm^2). Similar results were also recorded in case of chlorophyll content. P17 treated plants recorded highest chlorophyll content of 23 spad units followed by P22 and P23 treatments which were 22 and 21 spad units respectively compared to control (8 spad units). Overall increase in plant dry mass was highest in P17 treated plants (152 mg) followed by P22 (132 mg) and P23 (128 mg) (Table 5).

Inoculation of sorghum with *Pseudomonas* spp. not only enhanced plant growth but also increased nutrient uptake significantly (Table

Location	State	Agro-ecological Sub Region	Climate	Soil Type	Mean Annual Rainfall (mm)	Max. Soil Temperature (°C)
Bari Brahmana	Jammu & Kashmir	Western Himalayas	Subhumid	Alluvial deep Inceptisols	1180	28
Jodhpur	Rajasthan	Western Plain	Arid	Black-medium Inceptisols/ Vertisols	150	47
Arjia	Rajasthan	Northern Plain	Semiarid	Black-medium vertic inceptisols/ vertisols	656	44
Junagadh	Gujarat	Western Plain	Semiarid	Medium-deep Vertisols	650	42
Sardar Krishinagar	Gujarat	Western Plain	Arid	Desert-very deep Aridisols	550	41
Rewa	Madhya Pradesh	Central Highlands	Subhumid	Black-mediumdeep Vertisols	1087	39
Rajkot	Gujarat	Western Plain	Arid	Black-medium deep-deep Vertisols	615	42
Akola	Maharashtra	Deccan Plateau	Semi arid	Black-medium deep-deep vertic inceptisols/ Vertisols	825	41
Gunegal	Andhra Pradesh	Deccan Plateau	Semi arid	Deep Alfisols	850	35
Kadiri	Andhra Pradesh	Deccan Plateau	Arid	Black-medium deep Vertisols	450	42
Bijapur	Karnataka	Deccan Plateau	Semi arid	Black-medium deep-deep Vertisols	680	42
Ongole	Andhra Pradesh	Eastern Ghats	Semi arid	Medium-deep Vertisols/ Alfisols	900	43
Guntakal	Andhra Pradesh	Eastern Ghats	Semi arid	Medium-deep Vertisols/ Alfisols	900	42
Maruteru	Andhra Pradesh	Eastern Ghats	Semi arid	Deep Vertisols	800	43
Warangal	Andhra Pradesh	Deccan Plateau	Semi arid	Medium-deep Vertisols	850	38
Hayathnagar	Andhra Pradesh	Deccan Plateau	Semi arid	Deep Alfisols	850	36
Karimnagar	Andhra Pradesh	Deccan Plateau	Semi arid	Medium-deep Vertisols	850	44
Solapur	Maharashtra	Deccan Plateau, Eastern Ghats	Semi arid	Black-medium deep-deep Vertic/ Vertisols	723	43
Phulbani	Orissa	Eastern Plateau (Chhotanagpur) and Eastern Ghats	Subhumid	Red/yellow deep Alfisols	1299	43
Parbhani	Maharashtra	Deccan Plateau	Semi arid	Deep Vertisols	850	40
Bhopal	Madhya Pradesh	Central (Malwa & Bundelkhand) Highlands	Semi arid	Deep Vertisols	800	42
Jagdalpur	Chattisgarh	Chattisgarh/Mahanadi Basin	Subhumid	Red/yellow deep Alfisols	1450	43
Faizabad	Uttar Pradesh	Northern Plain	Subhumid	Alluvial deep Inceptisols	1057	40
Udaipur	Rajasthan	Northern Plain	Semi arid	Black-medium deep-deep vertic inceptisols/ Vertisols	656	44
Jhansi	Uttar Pradesh	Northern Plain	Semi arid	Inceptisols	550	42
Hisar	Haryana	Western Plain	Arid	Alluvial-very deep Aridisols	412	41
Varanasi	Uttar Pradesh	Northern Plain	Subhumid	Alluvial deep Inceptisols	850	39
Ballowal Saunkhri	Punjab	Northern Plain	Subhumid	Red loamy soils	750	40
Kovilpatti	Tamilnadu	Eastern Ghats	Semi arid	Black deep Vertisols	743	40
Rajendranagar	Andhra Pradesh	Deccan Plateau	Semi arid	Deep Alfisols	850	39
Suryapet	Andhra Pradesh	Deccan Plateau	Semi arid	Deep Alfisols	850	44

Table 1: Agro-ecological regions, climatic conditions and their soil types of India used for isolation of fluorescent *Pseudomonas* spp.

6,7). Total carbohydrates content of treated plants was in the range of 17.3 to 30.6% with highest by P17 where as untreated plants had 15.4%. Phosphorus uptake was also significantly higher in treated plants with *Pseudomonas* isolates in general and P1 and P17 (1.35%) in particular compared to control (0.38%). Nitrogen uptake was also significantly higher in P17 treatment (2.254%) followed by P22 and P23 (2.24% in both). Similarly, sodium uptake in plants increased on treatment with P22 (0.54%) followed by P17 (0.52%) and P23 (0.51%). However, potassium uptake was more in P17 treated plants (2.9%) followed by P22 (2.85%) and P1 (2.54%). P5, P13 and P35 treated plants showed significantly higher Ca uptake of 0.88%, 1.02% and 1.15% respectively (Table 6).

Seed bacterization of sorghum with *Pseudomonas* isolates significantly increased the uptake of micronutrients (Table 7). Inoculation with P17 and P35 enhanced the Cu content (14 ppm) followed by P1 and P5 (12 ppm) compared to control (7 ppm). Higher quantity of Fe was accumulated in plants inoculated with P17 (3500 ppm) followed by P35 (2901 ppm) and P22 treatments (2527 ppm). Mn uptake was maximum in P17 treatment (237 ppm) followed by P28 (227 ppm) P4 (183 ppm) compared to control (74 ppm). Zn uptake was more on inoculation with P22 (936 ppm) followed by P17 (433 ppm) and P13 (429 ppm) than control (159 ppm) (Table 7). Overall impact of P17 treatment on nutrient uptake and plant growth was 70-220% and 30-290% respectively (Figure 4,5).

Discussion

The microbial biodiversity of a region is mainly determined by agro-ecological systems and constituents of plant root exudates that decide the type and density of microbial population in a given crop production system [15]. Efficient colonization and/or physiological adaptation to adverse soil conditions are the options for soil bacteria to survive [16]. In the present study, with an aim of obtaining isolates of *Pseudomonas* spp., different crop production systems of diverse agro-ecological regions were surveyed (Figure 1) and 75 isolates were obtained. Fourteen isolates were found to enhance >50% dry mass of sorghum seedlings (Table 4). Of these, 9 isolates were from semi-arid deep alfisols belonging to agro-ecological region, 1 isolate each from semi-arid medium deep inceptisols/vertisols (deccan plateau), semi-arid medium deep vertisol (deccan plateau), semi-arid black medium deep vertic inceptisol (northern plain), sub-humid alluvial deep inceptisol (western himalayas) and semi-arid medium deep vertisol (western plain) (Table 1). This indicates the congenial conditions of

S. No.	Location	pH	EC (dS.m^{-1})	OC (%)	Particle Size (%)			Macronutrients (kg/ha)		
					Sand	Silt	Clay	N	P	K
01	Bari Brahmana	7.2	0.04	0.38	79.5	7.14	13.36	114.9	12.4	55.6
02	Jodhpur	8.1	0.12	0.41	26.2	12.6	61.2	92.90	7.90	190.1
03	Arjia	8.3	0.14	0.24	63.7	13.1	23.2	182.6	8.50	109.4
04	Junagadh	6.9	0.10	0.16	60.7	9.20	30.1	102.9	19.9	129.5
05	Sardar Krishinagar	8.0	0.04	0.43	84.1	4.10	11.8	98.40	11.6	85.10
06	Rewa	7.4	0.10	0.17	28.0	23.3	48.7	113.9	9.00	407.5
07	Rajkot	8.1	0.10	0.38	26.6	12.1	61.3	93.50	8.00	188.8
08	Akola	8.3	0.13	0.18	18.8	19.1	62.1	116.2	6.30	76.70
09	Gunegal	6.5	0.49	0.37	74.3	7.70	18.0	63.30	9.10	71.00
10	Kadiri	6.8	0.09	0.17	60.5	9.20	30.3	103.6	19.6	129.2
11	Bijapur	8.6	1.40	0.27	20.4	17.7	61.9	58.20	9.40	378.2
12	Ongole	7.6	0.05	0.44	83.2	4.20	12.6	97.20	12.1	86.30
13	Guntakal	7.3	0.12	0.26	84.2	4.80	11.0	98.10	2.50	61.00
14	Maruteru	7.0	0.11	0.17	60.4	9.80	29.8	101.4	19.7	124.2
15	Warangal	7.8	0.27	0.41	82.3	4.80	12.9	99.70	16.0	118.0
16	Hayatnagar	6.3	0.48	0.34	73.0	7.00	20.0	62.00	8.90	70.00
17	Karimnagar	7.4	0.13	0.27	83.9	4.60	11.5	99.20	2.70	61.70
18	Solapur	8.1	0.12	0.30	11.4	13.8	74.8	73.70	8.00	500.4
19	Phulbani	6.0	0.02	0.12	55.4	11.1	33.5	104.8	14.5	195.1
20	Parbhani	7.1	0.13	0.18	61.4	9.80	28.8	99.80	20.1	122.1
21	Bhopal	7.1	0.12	0.16	63.1	9.90	27.0	101.2	19.6	119.5
22	Jagdalpur	6.1	0.04	0.13	56.2	12.1	31.7	102.2	16.4	188.4
23	Faizabad	8.1	0.29	0.18	28.5	32.2	39.3	125.7	8.40	160.3
24	Udaipur	8.4	0.14	0.19	19.1	20.4	60.5	112.4	7.40	78.30
25	Jhansi	8.1	0.12	0.42	27.5	13.2	59.3	93.10	8.10	191.2
26	Hisar	7.4	1.79	0.15	55.9	17.5	26.6	150.3	10.9	163.1
27	Varanasi	8.2	0.31	0.19	29.5	31.5	39.0	119.4	8.90	159.3
28	Ballowal Saunkhri	8.1	0.32	0.21	29.9	32.2	37.9	115.1	9.10	149.6
29	Kovilpatti	8.0	0.80	0.36	29.8	5.85	64.35	86.30	6.70	272.3
30	Rajendranagar	6.7	0.12	0.50	69.4	7.80	22.8	65.00	9.20	69.50
31	Suryapet	6.9	0.15	0.46	71.4	8.20	20.4	68.20	9.40	89.00

EC=Electrical conductivity and OC= Organic carbon; N= Nitrogen, P=Phosphorus and K=Potash

Table 2: Physico-chemical properties and macronutrient status of soil types used for the isolation of *Pseudomonas* spp.

Physical characters	
pH	7.4
EC	0.075 dS.m^{-1}
Chemical characters	
Total 'N'	201.9 kg. ha^{-1}
Total 'P'	21.0 kg. ha^{-1}
Total 'K'	197.84 kg. ha^{-1}
Organic carbon	0.32%

Table 3: Physico-chemical characters of soil used for plant growth studies.

the soil perhaps facilitated the plant growth promotion (PGP) activity of these isolates as soil nutritional conditions are reported to be influencing the performance of PGPRs [17].

Present experiments on sorghum clearly indicated that *Pseudomonas* spp. can be used to enhance the plant growth as reported earlier [18,19]. Bacterial inoculated seedlings of different crops showed enhanced plant growth as reported by Kloepper et al. [20], Glick [21] and Dey et al. [22]. In the present study, a significant increase ($P<0.05$) in root and shoot length and dry mass of sorghum seedlings was observed due to seed bacterization (Table 5). The plant growth promotion could be attributed to the exertion of direct and/or indirect action of PGP traits [23].

Seed bacterization of sorghum with *Pseudomonas* spp. also enhanced the uptake of essential macro and micro-nutrients resulting in overall increase of plant growth (Table 6,7). It is in concurrence with the observations of Paul, et al. [24] and Kourosh et al. [25] who reported enhanced uptake of nutrients in black pepper and sweet basil due to seed bacterization with *Pseudomonas* spp. Increased nutrient uptake by plants inoculated with plant growth promoting bacteria has been attributed to the production of plant growth regulators at the root interface, which stimulate root development and better absorption of water and nutrients from soil [26,27]. In the present study, we observed significant impact ($P<0.05$) of *Pseudomonas* spp. on plant growth promotion in various parameters like root volume, shoot length, dry mass, chlorophyll content, leaf area etc. and enhanced macro and micro-nutrients uptake. Besides plant growth, inoculated plants clearly showed increased accumulation of nitrogen which is in agreement with observations of Puente et al. [28]. Esitken et al. [29] demonstrated that root inoculation of *Bacillus* and *Pseudomonas* sp. increased nutrient content (P, Fe, Zn, K and Mg) and plant growth of

Isolate	Increase in root length	Increase in shoot length	Increase in dry mass	Isolate	Increase in root length	Increase in shoot length	Increase in dry mass
*P1	44	100	134	P39	38	29	29
*P2	39	86	127	P40	30	29	25
P3	26	10	50	P41	-13	-01	-05
*P4	24	76	62	P42	26	22	02
*P5	82	31	100	P43	13	25	34
P6	06	10	14	P44	31	32	17
P7	07	29	45	P45	35	45	19
P8	77	13	35	P46	45	18	05
P9	46	39	50	P47	37	32	18
P10	-25	-01	-04	P48	13	27	12
P11	-28	-02	-14	P49	14	37	07
P12	05	24	10	P50	32	37	16
*P13	27	76	65	P51	23	47	24
*P14	30	78	69	P52	36	63	17
P15	12	34	34	P53	52	57	06
P16	07	38	21	P54	32	57	22
*P17	44	53	96	P55	29	56	12
P18	05	11	03	P56	-12	-03	-01
P19	12	39	34	P57	29	46	14
*P20	77	28	95	P58	40	50	47
*P21	72	25	75	P59	23	35	14
*P22	70	23	70	P60	19	32	20
*P23	98	37	105	P61	10	13	10
P24	14	38	48	P62	17	36	06
P25	15	39	45	P63	33	46	21
P26	11	51	27	P64	21	41	27
P27	10	43	31	P65	16	34	17
*P28	22	68	59	P66	28	41	20
*P29	32	78	76	P67	16	47	08
P30	12	43	41	P68	32	39	28
P31	28	35	14	P69	40	38	07
P32	15	32	17	P70	21	28	28
P33	21	35	28	P71	17	36	14
P34	-04	19	39	P72	40	28	13
*P35	43	24	63	P73	40	25	14
P36	24	36	16	P74	31	32	14
P37	-16	-04	-03	P75	17	16	01
P38	20	29	07				

*isolates that were further selected for evaluation by pot culture studies

Table 4: Relative percentage increase in root, shoot length and dry mass of sorghum seedlings on seed bacterization with *Pseudomonas* spp. (15 DAS).

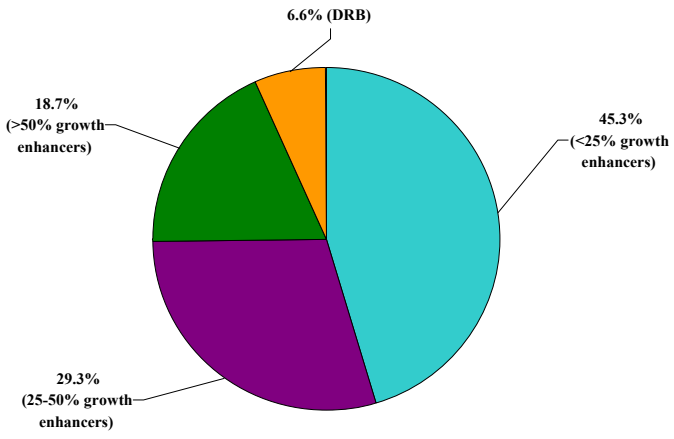

Figure 2: Grouping pattern of plant growth promoting fluorescent *Pseudomonas* spp. on sorghum.

Figure 3: Plant growth promotion of sorghum by *Pseudomonas* sp. P17 in pots (30 days after sowing).

Treatment	RV (cc)	SL (cm)	RDW (mg)	SDW (mg)	TDM (mg)	LA (cm^2)	Total chlorophyll (Spad reading)
P1	0.30^{a} (+0.014)	33.5^{a} (+1.54)	46.4^{d} (+2.14)	69^{a} (+3.16)	115	17.5 (+0.81)	20^{a} (+0.92)
P2	0.25 (+0.012)	26.0^{b-e} (+1.19)	78.4 (+3.61)	45^{b} (+2.06)	123	14.8 (+0.68)	19^{b} (+0.88)
P4	0.28 (+0.013)	23.7^{e} (+1.09)	58^{c} (+2.66)	44^{b} (+2.03)	102	10.0^{ef} (+0.46)	13 (+0.6)
P5	0.20^{d} (+0.009)	23.7^{e} (+1.09)	57^{c} (+2.62)	37^{cd} (+1.71)	94	11.3^{b-f} (+0.52)	17^{d} (+0.78)
P13	0.22^{c} (+0.010)	24.2^{de} (+1.11)	43^{e} (+1.98)	39^{c} (+1.81)	82	10.8^{c-f} (+0.5)	15 (+0.69)
P14	0.20^{d} (+0.009)	25.1^{c-e} (+1.15)	44^{de} (+2.03)	38^{cd} (+1.73)	82	10.4^{d-f} (+0.48)	14 (+0.65)
P17	0.30^{a} (+0.014)	36.2 (+1.66)	69.1^{a} (+3.18)	83.1 (+3.83)	152	31.6 (+1.46)	23 (+1.06)
P20	0.20^{d} (+0.009)	31.1^{a} (+1.43)	44^{de} (+2.04)	62.1 (+2.86)	106	22 (+1.01)	20^{a} (+0.92)
P21	0.20^{d} (+0.009)	25.3^{c-e} (+1.16)	56^{c} (+2.58)	45^{b} (+2.07)	101	12.4^{ab} (+0.57)	17^{d} (+0.78)
P22	0.23^{b} (+0.011)	32.2^{a} (+1.48)	63.6^{b} (+2.93)	68^{a} (+3.15)	132	27 (+1.24)	22 (+1.01)
P23	0.23^{b} (+0.011)	28.2^{b} (+1.3)	61^{b} (+2.81)	67^{a} (+3.08)	128	24 (+1.11)	21 (+0.97)
P28	0.18 (+0.008)	24.5^{c-e} (+1.29)	61^{b} (+2.81)	38^{cd} (+1.76)	99	12.8^{a} (+0.59)	19^{b} (+0.88)
P29	0.22^{c} (+0.010)	25.2^{c-e} (+1.16)	56^{c} (+2.58)	35^{d} (+1.63)	91	12.2^{a-c} (+0.56)	18^{c} (+0.83)
P35	0.20^{d} (+0.009)	26.8^{bc} (+1.23)	66.9^{a} (+3.08)	44^{b} (+2.04)	111	12.4^{ab} (+0.57)	18^{c} (+0.83)
Control	0.17 (+0.008)	20.2 (+0.93)	30 (+1.38)	31.1 (+1.43)	61	9.8^{f} (+0.45)	8 (+0.37)
LSD	0.08	2.4	2.6	3.3		1.4	0.82
CV%	19.10	17.7	23	32		43.3	22.2

values superscribed by same letter are not significantly different according to fisher's lsd test (P<0.05).
values in the parentheses are standard errors of means.
RV=Root volume; RL=Root length; SL=Shoot length; RDW/ SDW= Root, shoot dry weight TDM=Total Dry Mass; R-S ratio=Root-shoot ratio;
LA= Leaf area
*means of two independent experiments with six replicates each time. values in the parentheses are standard errors of means.

Table 5: Plant growth of sorghum as influenced by seed bacterization with fluorescent *Pseudomonas* spp. (30 days after sowing).

Macronutrients (mg) /100 mg of dry plant material						
Treatment	**Total 'CH'**	**Total 'P'**	**Total 'N'**	**Na**	**K**	**Ca**
P1	25.0* (+1.15)	1.35 (+0.062)	2.212 (+0.102)	0.45 (+0.021)	2.54 (+0.117)	0.63 (+0.029)
P2	21.0 (+0.97)	0.77 (+0.035)	1.652 (+0.076)	0.48 (+0.022)	1.27 (+0.059)	0.48 (+0.022)
P4	19.5 (+0.90)	0.57 (+0.026)	1.512 (+0.070)	0.49 (+0.023)	1.71 (+0.079)	0.46 (+0.021)
P5	19.4 (+0.89)	0.80 (+0.037)	1.736 (+0.080)	0.51 (+0.024)	1.84 (+0.085)	0.88 (+0.041)
P13	18.6 (+0.86)	0.71 (+0.033)	1.876 (+0.086)	0.43 (+0.020)	1.80 (+0.083)	1.02 (+0.047)
P14	17.3 (+0.80)	0.62 (+0.029)	1.708 (+0.079)	0.48 (+0.022)	1.99 (+0.092)	0.44 (+0.020)
P17	30.6 (+1.41)	1.35 (+0.062)	2.254 (+0.104)	0.52 (+0.024)	2.90 (+0.134)	0.84 (+0.039)
P20	24.4 (+1.12)	0.85 (+0.039)	1.722 (+0.079)	0.47 (+0.022)	2.38 (+0.110)	0.49 (+0.023)
P21	23.5 (+1.08)	0.95 (+0.044)	1.806 (+0.083)	0.50 (+0.023)	2.14 (+0.099)	0.69 (+0.032)
P22	29.5 (+1.36)	1.18 (+0.054)	2.240 (+0.103)	0.54 (+0.025)	2.85 (+0.131)	0.42 (+0.019)
P23	29.2 (+1.35)	1.31 (+0.060)	2.240 (+0.103)	0.51 (+0.024)	2.44 (+0.112)	0.45 (+0.021)
P28	20.9 (+0.96)	0.91 (+0.042)	2.114 (+0.097)	0.50 (+0.023)	1.85 (+0.085)	0.52 (+0.024)
P29	23.0 (+1.06)	0.82 (+0.038)	1.946 (+0.090)	0.41 (+0.019)	2.03 (+0.094)	0.85 (+0.039)
P35	23.5 (+1.08)	0.84 (+0.039)	2.184 (+0.101)	0.49 (+0.023)	1.87 (+0.086)	1.15 (+0.053)
Control	15.4 (+0.71)	0.38 (+0.018)	1.148 (+0.053)	0.40 (+0.018)	2.10 (+0.097)	0.38 (+0.018)
CV%	21.1	33.1	18.7	11.4	22	38

*means of two independent experiments with six replicates each time.

Table 6: Macro-nutrient uptake in sorghum as influenced by seed coating with fluorescent *Pseudomonas* spp. (30 days after sowing).

Micronutrients (ppm) / 100 mg of dry plant material				
Treatment	**Cu**	**Fe**	**Mn**	**Zn**
P1	12^{b} (+0.55)	2125^{b} (+98)	179^{ab} (+8.2)	411^{a} (+18.9)
P2	10^{d} (+0.46)	1229^{cd} (+57)	110^{f} (+5.1)	312^{cd} (+14.4)
P4	11^{c} (+0.5)	1293^{c} (+60)	183^{a} (+8.4)	341^{bc} (+15.7)
P5	12^{b} (+0.55)	1075^{d} (+50)	141^{d} (+6.5)	252^{e} (+11.6)
P13	11^{c} (+0.5)	1980^{b} (+91)	175^{a-c} (+8.1)	429^{a} (+19.8)
P14	10^{d} (+0.46)	1538 (+71)	135^{d} (+6.2)	201 (+9.3)
P17	14^{a} (+0.64)	3500 (+161)	237 (+10.9)	433^{a} (+20)
P20	10^{d} (+0.46)	2001^{b} (+92)	173^{bc} (+8)	285^{de} (+13.1)
P21	11^{c} (+0.5)	1764 (+81)	179^{ab} (+8.2)	420^{a} (+19.4)
P22	10^{d} (+0.46)	2527^{a} (+116)	123^{e} (+5.7)	936 (+43.1)
P23	11^{c} (+0.5)	2470^{a} (+114)	169^{c} (+7.8)	248^{e} (+11.4)
P28	10^{d} (+0.46)	1135^{cd} (+52)	227 (+10.5)	243^{e} (+11.2)
P29	9 (+0.41)	2373^{a} (+109)	118^{ef} (+5.4)	266^{e} (+12.3)
P35	14a (+0.64)	2901 (+134)	125^{e} (+5.8)	357^{b} (+16.5)
Control	7 (+0.32)	881 (+41)	74 (+3.4)	159 (+7.3)
LSD	0.37	160.7	9.4	39.2
CV%	18.1	39.1	28.8	51.5

values superscribed by same letter are not significantly different according to Fisher's LSD test (P<0.05) and values in the parentheses are standard errors of means.

Table 7: Micro-nutrient uptake in sorghum as influenced by seed bacterization with fluorescent *Pseudomonas* spp. (30 days after sowing).

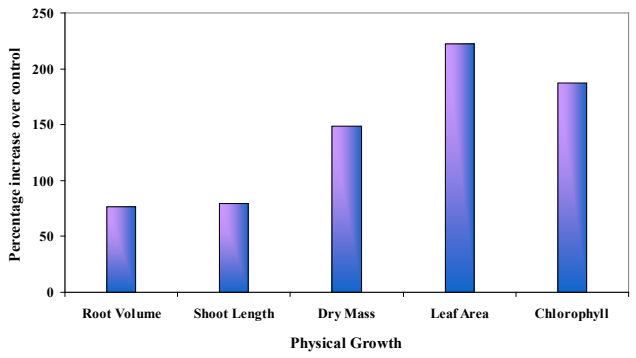

Figure 4: Influence of seed bacterization with *Pseudomonas* sp. P17 on plant growth parameters of sorghum.

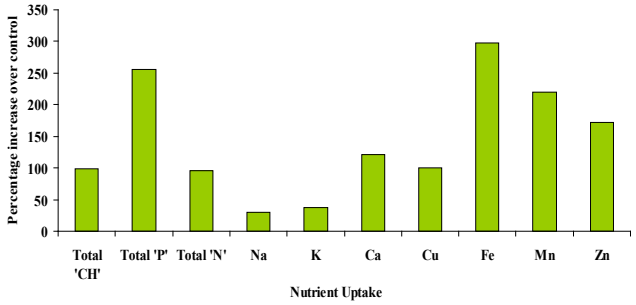

Figure 5: Uptake of macro- and micro-nutrients as influenced by inoculation with *Pseudomonas* sp. P17 in sorghum.

strawberry. Rhizobacteria efficacy on sorghum growth promotion in green house conditions was shown by Idris et al. [30]. Present findings are co-inciding with earlier studies. The importance and role of PGPR traits of *Pseudomonas* spp. in growth promotion of sorghum was shown by Praveen Kumar, et al. [31].

Defreitas and Germide [32] demonstrated that seed treatment with *Pseudomonas* spp. significantly enhanced early growth of winter wheat in low fertility asquith soil. Observations in the present study with *Pseudomonas* sp. P17 strain showed good plant growth enhancement (Figure 3,4) and higher nutrient uptake (Figure 5). Z-score ranking also revealed that P17 ranked as the best isolate among the other *Pseudomonas* isolates studied.

Conclusion

Present studies were carried out with the objective of assessing the plant growth promoting potential of *Pseudomonas* spp. towards *S. bicolor* from diverse rainfed agro-ecosystems. Sorghum is generally cultivated under rainfed conditions and after sowing, generally the crop suffers due to a dry spell. During this period, if the plant is protected with a better vigour, it can tide over the dry spell and grow normally with the resuming of monsoon. A low cost technology like seed bacterization has been found to promote plant growth during early phenophase of the crop that is most vulnerable to dryspells. Isolates obtained from semi-arid deep alfisols are efficient PGPRs than the other isolates which depicts that the origin of the PGPR also plays an important role in determining the behaviour and efficacy of PGPRs in increasing the plant growth. In conclusion, improvement in nutrient uptake and growth of sorghum plants were observed on inoculation with fluorescent *Pseudomonas* sp. P17. Further investigations on this PGPR for its efficiency under field conditions are in progress to promote it as 'low cost' input for improved productivity of rainfed agro-production systems.

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