Indian Journal of Agricultural Sciences **87** (5): 607–12, May 2017/Article
https://doi.org/10.56093/ijas.v87i5.70124

Effect of plant growth promoting rhizobacteria on coriander (*Coriandrum sativum*) growth and yield under semi-arid condition of India

BRIJESH K MISHRA[1], P N DUBEY[2], O P AISHWATH[3], KRISHNA KANT[4], Y K SHARMA[5] and M K VISHAL[6]

ICAR-National Research Centre on Seed Spices, Ajmer, Rajasthan 305 206

Received: 26 August 2016; Accepted: 14 October 2016

ABSTRACT

Experiment was conducted to evaluate the potential of selected plant growth promoting rhizobacteria (PGPR) towards enhancement of growth and yield of coriander crop (*Coriandrum sativum* L. cv Acr-1) under semi-arid condition in India. Six PGPR isolates showing *in-vitro* indole acetic acid production and tricalcium phosphate solubilization were the prime targets. These rhizobacterial isolates were evaluated for their ability to promote growth and yield of coriander under open field conditions. Highest seedling vigour index was recorded for *B. aerophilus* Cor-15 (1178.50) followed by *B. megaterium* (1125.20) and minimum was observed with control. The maximum total chlorophyll content was assayed with *B. subtilis* NRCSS-I which was 1.38 mg/g f wt and 1.30 mg/g f wt at 45 and 90 DAS respectively. The highest Pox activity was recorded with *B. megaterium* ISB28 (4.31 IU/min/g) in coriander shoot tissues at 90 DAS followed by *B. aerophilus* cor-15. At harvest stage, maximum plant height was recorded with *B. aerophilus* Cor-15 (84.36cm) which was at par with *B. megaterium* (82.90 cm). Coriander seed yield ranged from 1128.80 to 1650.94 kg/ha and the maximum seed yield of 1650.94 kg/ha was recorded with *B. aerophilus* Cor-15 being at par with *B. subtilis* strains and the minimum in control. Maximum essential oil yield was recorded with *B. megaterium* ISB-28 (5.86 l/ha) followed by *B. aerophilus* Cor-15 (4.64 l/ha) and least was observed with control (3.09 l/ha).

Key words: *Bacillus* spp, *Coriandrum sativum,* Essential oil, Plant growth promoting rhizobacteria, Spices

Coriander (*Coriandrum sativum* L.) is an annual herb (2n=22), which belongs to the family Apiaceae and generally grown as an important spice crop in winter season of India. It shows broad adaptation, growing well under different types of soil and weather conditions (Simon 1990). Coriander plants are cultivated both for fresh green leaves as well as dried seeds. The dried seeds are mainly used either whole or in ground form as spice for adding taste and flavour to different food stuffs whereas, green leaves are sprinkled to garnish a variety of dishes. Coriander leaves and seeds, contain essential oil in varying quantity, impart flavour and aroma in foods and possess medicinal properties (Mandal and Mandal 2015). In India, during 2013-14, coriander was cultivated on 447000 ha area with seed production of 31400 metric tonnes. Rajasthan, Gujarat, Madhya Pradesh, Karnataka, Telangana and Uttar Pradesh states are main producers of coriander seed however cultivation of coriander for green leafy purpose is thoroughly distributed in entire India across the year (Annonymous 2014). Rajasthan and Gujarat are two major seed spice producer states of India. About one-third of total coriander production in Rajasthan comes from of south western Rajasthan which has sub-humid to semi-arid climate. The variety Ajmer coriander-1(Acr-1) is most popular variety due to its resistance towards the prominent stem gall disease that had created havoc in recent past in districts of Kota and Baran (Hadoti region) of Rajasthan. In this area coriander is not only a spice crop but a main source of farm income under low-input agro-ecosystems in Rajasthan, India (Malhotra and Vashitha 2007).

Plant-associated bacteria that are able to colonize roots are called rhizobacteria and can be classified into beneficial, deleterious, and neutral groups on the basis of their effects on plant growth. Beneficial rhizobacteria that stimulate plant growth are usually referred to as Plant- Growth-Promoting Rhizobacteria (PGPR), a group that includes different bacterial species and strains belonging to different genera such as *Acetobacter*, *Azospirillum*, *Azotobacter*, *Bacillus, Burkholderia, Herbaspirillum,* and *Pseudomonas* (Glick 1995). PGPR may promote growth directly, e.g. through fixation of atmospheric nitrogen, solubilization of minerals (phosphorus and potassium), production of siderophores that solubilize and sequester iron, or production of plant growth regulating hormones (Grover *et al*. 2009). Inoculation of crop plants with different strains of PGPR increased not only the yield but also quality of several medicinal herbs

[1]Senior Scientist (e mail: bkmmicro@gmail.com), [2]Senior Scientist (e mail: pnd.nrcss@gmail.com), [3]Senior Scientist (e mail: aishwath9@gmail.com), [4]Principal Scientist (e mail: kknrcss@gmail.com), [5]Principal Scientist (e mail: yksharma.nrcss@rediffmail.com), [6]Scientist (e mail: mukeshvishal.rns@gmail.com)

including spice crops (Kumar *et al*. 2013, Sahay and Patra 2014). Due to the emerging importance of organic coriander crop, both at national and international market, through this manifesto we tried to study the native PGPR that may have the ability to promote growth and yield of coriander (cv Acr-1).

MATERIALS AND METHODS

For this study, PGPR were isolated from roots of different plants (*Coriandrum sativum*, *Foeniculum vulgare* Mill. and *Plantago ovata* Forsk.) cultivated in state of Rajasthan, India. In present investigation six promising PGPR were selected based on screening for Indoleacetic acid (IAA) production and phosphate solubilizing activity before being applied in present investigation (Mishra *et al*. 2013). In order to identify the rhizospheric bacterial strains, amplification of the 16S rDNA for obtaining amplicons of ~1.5 kbp were carried out, which were sequenced and compared with GenBank data in NCBI. Primarily *Azotobactor vinelandii* (one isolate), *B. subtilis* (two isolate), *B. megaterium* (one isolates), and *Pseudomonas stutzeri* (one isolate) were identified and applied for seed treatment of coriander before sowing in the experimental fields.

Micro plot trial was carried out in the experimental farm of National Research Centre on Seed Spices, Ajmer, Rajasthan, India {26°45' N latitudes and 74°64' E longitude with average annual temperature of 24.7 °C (with mean minimum 19.8°C and mean maximum 32.0°C) and average annual rainfall 557 mm}, using a randomized block design with four replicates. The soil under study was sandy loam in texture and classified as Typic Ustorthents (USDA), E 0.8 dS/m, pH 8.1 and organic carbon content 0.23%. The major available nutrients like N, P and K were quantified as 118.0, 18.50 and 135 kg/ha, respectively. Unsterile field soil was used to evaluate the plant growth promotion potential of the selected PGPR using coriander (*C. sativum* cv. Acr-1) as a host plant (Malhotra and Vashitha 2007). Each treatment was raised on micro plot of 4 m length 3 m width, with 12 rows and inter row spacing of 25 cm. Inoculums of PGPR isolates were prepared by growing the nutrient broth up to 48 h at 25°C till the desired population of 8.0 log CFU/ mL was obtained. Surface-sterilized coriander seeds were then soaked in the bacterial suspension for 4 h at 25°C on a shaker at 100 rpm in a BOD incubator cum shaker. Control seeds were soaked in nutrient broth without bacterial inoculation. Plant growth parameters like seedling vigour index, length of root and shoot, fresh and dry weight of roots and shoots were recorded periodically and irrigation water was applied as per visible requirement of the crop. Values for plant growth parameters (mean of 20 plants with four replicates) at 45 and 90 days after sowing (DAS) were recorded. Harvesting was carried out after 132 days of sowing and data was recorded at the same time. The harvested plant samples were oven-dried at 75°C for 72 h. Oven-dried shoot tissue was ground and sieved through a 0.5 mm sieve. Plant samples were then analyzed for nutrient uptake using standard protocols for nitrogen (Subbiah and Asija 1956), phosphorus (Olsen *et al*. 1954) and potassium (Jackson 1973).

The harvested coriander seeds from each treatment were crushed in electric grinder and ground mass was subjected to hydro-distillation for six hours using Clevenger's apparatus. The oil fraction thus collected was used for estimation of total essential oil yield (0.25 to 0.42 per cent) and expressed in litre/ha on the basis of total seed yield.

Total chlorophyll and carotenoids content in leaves were estimated using Dimethyl Sulfoxide (DMSO) solvent. 100 mg of fresh leaf portion was kept into a test tube containing 5 ml of DMSO, the test tube was then placed in an oven at 60 ^{o}C for about 2 h or more (if required) to facilitate complete extraction of the pigments. After extraction and cooling at room temperature, absorbance was recorded at 649, 665 and 480 nm with spectrophotometer running a multiple wavelengths programme. DMSO was used as blank. Calculations for different pigments were made according to Wellburn (1994). Quantities of all these pigments were calculated in mg/g fresh weight.

Chl ‘a’ = (12.19 × A665)-(3.62 × A646)

Chl ‘b’ = (25.06 × A649)-(6.5 × A665)

Total chlorophyll = Chl ‘a’ + Chl ‘b’

Total carotenoids Cx+c = (1000xA480 – 1.29 Chl ‘a’ - 53.78 Chl ‘b’)/220

where: Chl‘a’ = Chlorophyll a, Chl‘b’= Chlorophyll b, Cx+c= concentration of xanthophylls and carotenes.

The activity of peroxidase (POX enzyme) was assayed as per to Chen *et al*. (2000) using plant extracts containing 7.5 µL guaiacol (50 mM in the mixture) and 792 µL Tris HCl buffer (0.05 M, pH 6.0). The reaction was initiated by adding 100 µL of 0.6 M hydrogen peroxide and absorbance was measured by spectrophotometer at 470 nm. A blank consisting of guaiacol, Tris HCl buffer and hydrogen peroxide was used. The enzyme activity was expressed as IU/min/mg fresh weight.

Total viable microbial population in the rhizosphere of coriander plants were estimated according to method of Kaushik *et al*. (2004) using standard plate count nutrient agar growth media. Prepared 10 fold dilutions by diluting the rhizospheric soil samples with a series of 9 ml water blanks according to the requirement. For bacterial population count, poured the pre-sterilized nutrient agar medium (Hi-media) into plates and let them solidify. From the last three dilutions, taken an aliquot of 0.1 ml and spread plate. Incubated the plates at optimum temperature (25±1^{o}C) for 48 hrs. Fungal populations were estimated by using Rose Bengal agar medium supplemented with streptomycin (Hi-media). Calculated the viable bacterial and fungal population in terms of colony forming unit (cfu) per gram of rhizospheric soil sample.

Data were subjected to statistical analysis as per the procedure given by Gomez and Gomez 1984 in SPSS 13.0 software. The appropriate standard error (SEm±) was computed in each case. For the treatment effects which

were found to be significant, the critical difference (CD) at 5 % level of probability was worked out to compare two treatments.

RESULTS AND DISCUSSION

All the rhizobacterial isolates had positive effect on seedling vigour index (SVI) when compared to control. Highest SVI was recorded for *B. aerophilus* Cor-15 (1178.50) followed by *B. megaterium* (1125.20) and minimum was observed with control (Fig 1). All these rhizobacterial isolates accelerated the coriander seed germination and in most of the treatments >75 % germination was recorded at 11.33 DAS except control. Effect of PGPR isolates on coriander plant growth biometric data was recorded at 45 and 90 DAS. At 45 DAS observations revealed that treatment with *B. megaterium* ISB28 produced the highest shoot length being at par with *Bacillus aerophilus* Cor-15, *B. subtilis* NRCSS-I and *B. subtilis* NRCSS-II. Shoot length at 45 DAS ranged from 12.20 to 16.07 cm. The maximum root length was observed with *Pseudomonas stutzeri* ISB9 which was at par with *B. megaterium* ISB28 at 45 DAS and root length varied from 8.64 to 12.87cm. The observations recorded for effect of PGPR on coriander plant growth at 45 DAS also revealed that, fresh shoot weight as well as dry shoot weight was the maximum with *B. megaterium* ISB28 and the same was least with the control (Table 1). However, fresh root weight was the maximum with *B. subtilis* NRCSS-I but dry root weight was maximum with *B. megaterium* ISB28. At 90 DAS shoot length ranged from 47.57 to 62.50 cm for all the treatments and highest shoot length was recorded for *B. megaterium* ISB28 and lowest was recorded for control. Significant difference was recorded in fresh shoot weight, dry shoot weight, root length, fresh root weight and dry root weight at 90 DAS of coriander plants (Table 1). The coriander crop maturity period ranged from 130-132 DAS in different treatments (data not presented). At harvest stage, maximum plant height was recorded with *B. aerophilus* Cor-15 (84.36cm) which was at par with *B. megaterium* (82.90 cm). Coriander seed yield ranged from 1128.80 to 1650.94 kg/ha and the maximum seed yield of 1650.94 kg/ha was recorded with *B. aerophilus* Cor-15 being at par with *B. subtilis* strains and the minimum in control (Table 2). There was significant difference in test weight of coriander seeds produced with different PGPR treatments (Table 2).

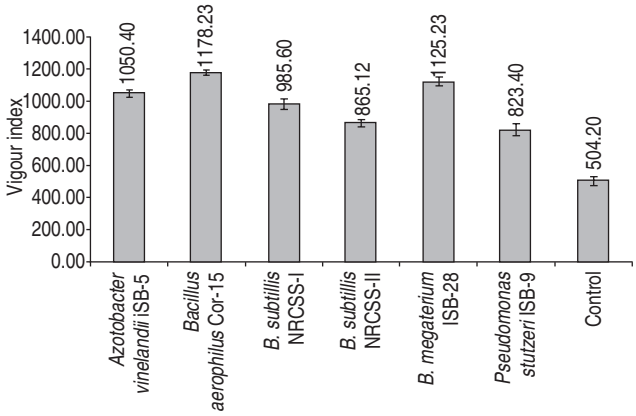

Fig 1 Effect of PGPR on seedling vigour index of coriander.

The beneficial plant–microbe interactions in the rhizosphere are known to be important determinants of plant health and soil fertility (Jeffries *et al*. 2003). Plant growth promoting rhizobacteria (PGPR) represent a diverse range of soil bacteria that stimulate the growth of their host when grown in association. Such rhizosphere microbes benefit by utilization of metabolites secreted by plant roots as a nutrient for their growth and promote plant growth through more than one mechanism, including production of growth stimulating hormones and suppression of plant pathogens (Rana *et al*. 2011).

Essential oil content in the harvested coriander seeds is an important quality parameter because of its fragrance quality, medicinal applications, food flavorings and its use in culinary preparations. In present investigation, significant effect of PGPR treatment on essential oil yield of coriander crop was observed. Maximum essential oil yield was

Table 1 Effect PGPR on plant growth parameters of coriander

Rhizobacterial isolate	Shoot length (cm)		Root length (cm)		Fresh shoot wt. (g)		Fresh root wt. (g)		Dry shoot wt. (g)		Dry root wt. (g)	
	45 d*	90d	45 d	90d	45 d	90d	45d	90d	45 d	90d	45d	90d
Azotobacter vinelandii ISB5	14.50	59.7	10.21	14.43	3.48	67.73	0.52	2.10	0.72	7.47	0.12	0.49
Bacillus aerophilus Cor-15	15.20	58.00	10.69	15.47	5.26	90.27	0.62	2.57	0.68	9.66	0.15	0.74
B. subtilis NRCSS-I	15.76	57.63	11.25	15.10	4.37	83.87	0.78	2.40	0.67	8.57	0.16	0.63
B. subtilis NRCSS-II	15.36	56.30	11.13	14.24	3.78	89.6	0.64	2.30	0.81	9.87	0.18	0.50
B. megaterium ISB28	16.07	62.50	12.05	15.13	6.24	115.53	0.51	2.97	0.88	10.17	0.19	0.86
Pseudomonas stutzeri ISB9	13.09	59.03	12.87	14.83	5.12	79.87	0.46	1.87	0.54	8.37	0.14	0.45
Control	12.20	47.57	8.64	13.67	2.27	42.23	0.35	1.50	0.41	5.82	0.10	0.42
SEm±	1.10	1.90	0.62	0.62	0.68	5.66	0.05	0.23	0.21	0.37	0.02	0.06
CD (P=0.05)	2.24	3.61	1.33	1.33	1.15	16.68	0.12	0.68	0.08	1.09	0.06	0.17

*d= Days after sowing (DAS)

Table 2 Effect of PGPR on the nutrient uptake, seed and essential oil yield of coriander

Rhizobacterial isolate	Shoot length (cm) at harvest	N uptake (kg/ha)	P uptake (kg/ha)	K uptake (kg/ha)	Test weight (g/1000 seeds)	Seed yield (kg/ha)	Essential oil yield (l/ha)
Azotobacter vinelandii ISB-5	73.00	42.03	12.17	53.19	10.95	1248.73	3.26
Bacillus aerophilus Cor-15	84.36	40.82	11.96	51.58	11.30	1650.94	4.64
B. subtilis NRCSS-I	73.13	40.69	12.21	53.17	11.95	1425.58	4.52
B. subtilis NRCSS-II	71.58	42.18	12.45	60.85	9.20	1424.51	3.82
B. megaterium ISB-28	82.90	41.34	11.97	52.63	10.45	1379.95	5.86
Pseudomonas stutzeri ISB-9	72.10	30.12	12.06	65.40	8.50	1374.30	3.42
Control	68.23	20.29	8.45	46.88	7.80	1128.80	3.09
SEm ±	2.15	2.88	0.56	2.15	0.35	78.52	0.18
CD (P=0.05)	5.47	5.84	1.37	4.52	1.08	231.62	0.47

recorded with *B. megaterium* ISB-28 (5.86 l/ha) followed by *B. aerophilus* Cor-15 (4.64 l/ha) and least was observed in control (3.09 l/ha) which was at par with *Azotobacter vinelandii* and *Pseudomonas stutzeri* (Table 2). Highest coriander seed yield proportionately correspond to high essential oil content. However, all the rhizobacteria treated coriander plants showed significant increase in essential oil content over control except *Azotobacter vinelandii* ISB5 and *Pseudomonas stutzeri* ISB9 (Table 2). *C. sativum* essential oil possess promising antimicrobial and anti-oxidative properties as various chemical components in different parts of the plant, which thus play a great role in maintaining the shelf-life of foods by preventing their spoilage (Rathore *et al*. 2013). *C. sativum* essential oil is used in different ways, viz. in foods and in pharmaceutical products as well as in perfumes (Mandal and Mandal 2015). The essential oil content in *C. sativum* seeds varies from 0.5% to 2.5% (Mahendra and Bisht 2011). There is variation in seed yield and essential oil content of *C. sativum* cultivars grown at different locations. The variation in essential oil yield can be attributed to various factors, viz. cultivar selection, package of practices, agro-ecology, harvesting stage, drying and storage methods etc. (Burt 2004 and Moghaddam 2015). Plant ontogeny has very significant influence on oil yield which varies from place to place and plant to plant (Ozcan and Chalchat 2006).

Uptake of nitrogen, phosphorus and potassium content were significantly higher as compared to control (Table 2). It is well accepted that adequate use of irrigation and chemical fertilizer improve yield and quality of essential oil in many spice crops (Tiwari and Banafar 1995, Garg *et al*. 2004). Application of PGPR isolates may have increased the bio-availability of various nutrients in rhizosphere zone thus enhancing the nutrient uptake in the coriander plants.

Previous studies have shown the positive effect of PGPR in promoting the germination and growth of *C. sativum* plants as well as other seed spices crops of India (Kumar *et al*. 2013). Similar results with the inoculation of *B. megaterium* ISB-28 and *B. subtilis* NRCSS-II were also observed with respect to plant growth biometric data. The positive effect might be attributed to the synthesis of IAA as well as phosphate solubilization characteristics of the PGPR isolates. Coriander seed yield is in accordance with the Kauim *et al*. (2015) but variation in present investigation may be due to varietal difference as well as agro-ecological effect. Besides PGPR isolates, some plant factors are also responsible for the growth-promoting effect.

In coriander, plant height, number of primary branches, number of umbels/plant and number of umbellets per umbel were significantly more in treatment with 100% N in combination with *Azospirillum*, PSB and FYM @ 5 tonnes/ha (66.4 cm, 6.2 and 15.4 respectively) than control. More number of secondary branches were recorded with *Azotobacter*, PSB and FYM @ 5 tonnes/ha (15.4) which is significantly superior to control (8.7) and 100% N alone (10.2). Maximum number of umbels/plant was recorded in 100 % N in combination with *Azospirillum*, PSB and FYM @ 5 t/ha (26.9) which was significantly superior to 100% N alone (Kalidasu *et al*. 2008).

Chlorophyll and carotenoids content are good biochemical parameters to assess the effect of PGPR on plant growth promotion. The maximum total chlorophyll content was assayed with *B. subtilis* NRCSS-I which was 1.38 mg/g f. wt. and 1.30 mg/g f wt at 45 and 90 DAS respectively. The total carotenoids contents did not change significantly with growth stage of coriander from 45 to 90 DAS. These findings are comparable to that reported by Agrawal *et al*. (2013) in fenugreek leaves at different growth stages.

Peroxidase enzyme (Pox) activity was assayed to evaluate the plant defence potential, as peroxidase enzymes help plants in enhancing their vitality and suppressing of pathogen growth. Peroxidase activity in coriander roots and shoots was assayed at 45 and 90 DAS. It was observed that Pox activity increased with increase in growth period irrespective of PGPR treatments. However, Pox activity was higher in shoot tissues than in root tissues, both at 45 and 90 DAS. Within the PGPR strains, the maximum Pox activity was observed in roots treated with *B. megaterium* ISB28 followed with *A. vinelandii* ISB5 at 45 DAS. Similarly, in root tissues at 90 DAS, the maximum Pox

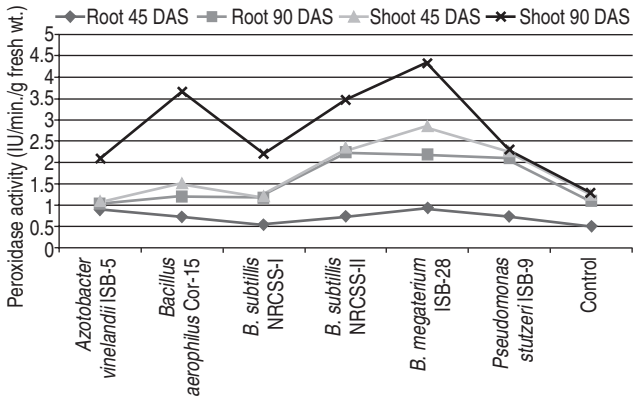

Fig 2 Effect of PGPR on peroxidase activity of coriander roots and shoots (DAS-Days after sowing)

activity was recorded in the coriander plant treated with *B. subtilis* NRCSSII (2.25 IU/min/g) which was at par with *B. megaterium* ISB28. The highest Pox activity was recorded with *B. megaterium* ISB28 (4.31 IU/min/g) in coriander shoot tissues at 90 DAS followed by *B. aerophilus* cor-15. However, the minimum peroxidase activity in root as well as shoot on both 45 and 90 DAS was assayed for the control treatment (Fig 2). Though, the control showed at par peroxidase activity with some PGPR isolates, the variation may be due to molecular signaling as a result of plant -microbe interaction in the rhizosphere (Grover *et al*. 2009, Mishra *et al*. 2010) of coriander plants. This may be also a physiological expression pattern of the coriander plants. These findings of peroxidase activity in coriander root and shoot tissues are in accordance with Kumar *et al*. (2013).

Total microbial population under the root zone of coriander plants were estimated by using soil serial dilution technique and pour plating on selective growth media for bacterial and fungal colony count. There were significantly higher bacterial population all PGPR treatments than control except *P. stutzeri* ISB-9 and maximum bacterial population was recorded with *B. subtilis* NRCSS-II. However, maximum fungal population was recorded with *P. stutzeri* ISB-9 and that of minimum was found in control (Table 3). Salantur *et al.* (2006) also showed the effect of PGPR in terms of enhancement of plant height and productivity by synthesizing phytohormones, increasing the availability of nutrients, facilitating the uptake of nutrients by the plants, and antagonizing plant pathogens in wheat crop.

An important factor to consider during evaluation of new PGPR isolates is their activity in the range of environments/soil types wherein they would be expected to be used (Ross *et al*. 2000). In our investigation, the bacterial isolates increased plant growth parameters as compared with uninoculated plants. The growth parameters, root length, shoot length, root weight and shoot weight increased significantly due to PGPR inoculants. The higher seed yield and essential oil yield response to all inoculants compared to controls clearly showed the beneficial role of these PGPR, which might be attributed to IAA production, phosphorus solubilization, nitrogen-fixing capacity of bacteria and any other PGPR activity in favour of plant growth response. All the selected PGPRs had promising positive effects on the plant growth parameters of coriander under semi-arid conditions of Rajasthan, India.

Table 3 Effect of PGPR application on bacterial and fungal population under coriander rhizosphere.

Rhizobacterial isolate	Bacterial count (log cfu/g)	Fungal count (log cfu/g)
Azotobacter vinelandii ISB-5	5.26	6.42
Bacillus aerophilus Cor-15	7.02	5.00
B. subtilis NRCSS-I	7.06	4.80
B. subtilis NRCSS-II	7.24	5.04
B. megaterium ISB-28	6.90	4.96
Pseudomonas stutzeri ISB-9	4.23	6.83
Control	5.66	4.72
SEm±	0.087	0.022
CD (P = 0.05)	0.261	NS

It may be concluded that the isolated and identified native PGPR species have capability to promote the plant growth and yield of coriander crop. Maximum enhancement in root and shoot weight and plant height was recorded by only two isolates (*B. aerophilus* Cor-15, and *B. megaterium* ISB-28) among the six bacterial isolates. These PGPR isolates also increased the seed yield as well as essential oil yield as compared to control. Our data shown that *B. aerophilus* cor-15 and *Bacillus megaterium* ISB-28 have potential to be used as a plant growth promoting rhizobacteria, particularly for organic cultivation of *C. sativum* L. cv Acr1 in the state of Rajasthan, India.

REFERENCES

Agrawal K B, Ranjan J K, Rathore S S, Saxena S N and Mishra B K. 2013. Change in physical and biochemical properties of fenugreek (*Trigonella* sp.). *International Journal of Seed Spices* **3**: 31–35.

Annonymous. 2014. Indian Horticulture Database-2014. National Horticulture Board, Ministry of Agriculture, Government of India, Gurgaon, pp 16–7.

Burt S. 2004. Essential oil: their antibacterial properties and potential applications in foods. *International Journal of Food Microbiology* **94**: 223–53.

Garg V K, Singh P K, Katiyar R S. 2004. Yield, mineral composition and quality of coriander (*Coriandrum sativum*) and fennel (*Foeniculum vulgare*) grown in sodic soil. *Indian Journal of Agricultural Sciences* **74**: 221–3.

Glick B R. 1995. The enhancement of plant growth by free living bacteria. *Canadian Journal of Microbiology* **41**: 109–14.

Grover M, Pandey A K, Mishra B K, Lata and Roy R C. 2009. *Sugarcane Crops: Plant Growth Promoting Bacteria in Growth, Yield and Productivity*. (*In*) *Sugar Beet Crops: Growth, fertilization and Yield*, pp 135–51. Hertsburg Claus T (Eds). Nova Science Publishers Inc., New York.

Jackson M L. 1973. *Soil Chemical Analysis*. Prentice-Hall of India Pvt Ltd, New Delhi.

Jeffries S, Gianinazzi S, Perotto S, Turnau K, Barea J M. 2003.

The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology and Fertility of Soils* **37**: 1–16.

Kaium A, Islam M, Sultana S, Hossain E, Shovon S C and Mahjuba A. 2015. Yield and yield contributes of coriander (*Coriandrum sativum* L.) as influenced by spacing and variety. *International Journal of Scientific Research Publication* **5**: 1–5.

Kalidasu G, Sarada C and Yellamanda Reddy T. 2008. Efficacy of biofertilizers on the performance of rainfed coriander (*Coriandrum sativum*) in vertisols. *Journal of Spices and Aromatic Crops* **17**: 98–102.

Kaushik B D, Saxena A K and Prasanna R. 2004. Techniques in Microbiology: A laboratory manual for post graduate students. Indian Agricultural Research Institute, New Delhi, India, 60 p.

Kumar M, Prasanna R, Bidyarani N, Babu S, Mishra B K, Kumar A, Adak A, Jauhari S, Yadav Kuldeep, Singh Rajendra, Saxena A K. 2013. Evaluating the plant growth promoting ability of thermotolerant bacteria and cyanobacteria and their interactions with seed spice crops. *Scientia Horticulturae* **164**: 94–101.

Mahendra P and Bisht S. 2011. *Coriandrum sativum*: a daily use spice with great medicinal effect. *Pharmacognosy Journal* **3**: 84–88.

Malhotra S K and Vashishtha B B. 2007. *Production Technology for Seed Spices Crops*. National Research Centre on Seed Spices, Tabiji, Ajmer, India.

Mandal S and Mandal M. 2015. Coriander (*Coriandrum sativum* L.) essential oil: chemistry and biological activity. *Asian Pacific Journal of Tropical Biomedicine* **5**:421–8.

Mishra B K, Khandelwal S K, and Joshi A. 2010. *Plant growth promoting rhizobacteria for biocontrol of plant diseases*. (*In*) *Organic Farming: An Overview*, pp 129–35. Archana Singh (Ed). Pointer Publication, Jaipur, India.

Mishra B K, Sharma A, Aishwath O P, Sharma Y K, Kant K, Vishal M K, Saxena S N and Ranjan J K. 2013. Microbiological profile of coriander (*Coriandrum sativum* L.) crop rhizosphere in Rajasthan and screening for auxin producing rhizobacteria. *International Journal of Seed Spices* **3**: 59–64.

Moghaddam M, Khaleghi S N, Pirbalouti A G, Mehdizadeh L and Ghaderi Y. 2015. Variation in essential oil composition and antioxidant activity of cumin (*Cuminum cyminum* L.) fruits during stages of maturity. *Industrial Crops and Products* **70**: 163–9.

Olsen S R I, Cole C V, Wantanable F S and Dean L A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 10: 939.

Ozcan M and Chalchat J C. 2006 Chemical composition and antifungal effect of anise (*Pimpinella anisum* L.) fruit oil at ripening stage. *Annals of Microbiology* **56**: 353–8.

Qureshi M A, Ahmad Z A, Akhtar N, Iqbal A, Mujeeb F and Shakir M A. 2012. Role of phosphate solubilizing bacteria (psb) in enhancing P availability and promoting cotton growth. *Journal of Animal and Plant Sciences* **22**: 204–10.

Rana A, Saharan B, Joshi M, Prasanna R, Kumar K and Nain L. 2011. Identification of multi-trait PGPR isolates and evaluating their potential as inoculants for wheat. *Annals of Microbiolology* **61**: 893–900.

Rathore S S, Saxena S N and Singh B. 2013. Potential health benefits of major seed spices. *International Journal of Seed Spices* **3**: 1–12

Ross I L, Alami Y, Harvey P R, Achouak W, Ryder M H. 2000. Genetic diversity and biological control activity of novel species of closely related Pseudomonads isolated from wheat field soils in South Australia. *Applied Environmental Microbiology* **66**: 1 609–16.

Sahay R and Patra D D. 2014. Identification and performance of sodicity tolerant phosphate solubilizing bacterial isolates on *Ocimum basilicum* in sodic soil. *Ecological Engineering* **71**: 639–43.

Salantur A, Ozturk A and Akten S. 2006. Growth and yield response of spring wheat (*Triticum aestivum* L.) to inoculation with rhizobacteria. *Plant and Soil Environment* **52**: 111–8.

Subbiah B V and Asija G L. 1956. A rapid procedure for the estimation of available nitrogen in soil. *Current Science* **25**: 259–60.

Tiwari R J and Banafar R N S. 1995. Application of nitrogen and phosphorus increases seed yield and essential oil of coriander. *Indian Journal of Cocoa, Arecanut and Spices* **19**: 51–5.

Wellburn A R. 1994. The spectral determination of chlorophyll a and chlorophyll b, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. *Journal of Plant Physiology* **144**: 307–13.