International Journal of Research (IJR)
e-ISSN: 2348-6848, p- ISSN: 2348-795X Volume 2, Issue 11, November 2015
Available at http://internationaljournalofresearch.org

Isolation of Salt Tolerant Rhizo bacteria and their Plant Growth Promoting Activities from Sodic Soils of Haryana

Kochar, H. K.[1] & Gera, R.[2]

1. Ph.D research scholar, Deptt. of Microbiology, College of Basic Sciences and Humanities. CCSHAU, Hisar, Haryana. 125004, India.
Email Id- hrshpreet@yahoo.co.in
Contact no. 9728207460
2. Professor, Deptt. of Microbiology, CCSHAU, Hisar, Haryana. 125004, India. Contact no.9416961450

ABSTRACT

In the present investigation, 20 sodic water irrigated soil and their respective water samples were collected from different salt affected districts of Haryana. The RSC, pH and EC_{iw} of these water samples was above 2.50 me/l, 8.50 - 10.90 and 1.01 - 1.50 dS/m, respectively. Their respective soil samples were analyzed for pH, EC_e, organic C, total N and total P, which varied from 8.30 - 10.50, 1.00 - 2.40 dS/m, 0.09 - 0.46%, 0.002 - 0.040% and 625 - 701 mg P/kg soil, respectively. One hundred and twenty four morphotypes were isolated on 5 different media from different salt affected districts of Haryana. Most of these morphotypes were gram -ve rods, cocci and small rods in addition to some fraction of gram +ve small rods and cocci. All the morphotypes were assessed for plant growth promotion activities. Ammonia excretion and indole acetic acid (IAA) production was assayed spectrophotometrically using Nesseler's and Salkowaski reagent, respectively. P- solublization and siderophore production were tested qualitatively by plating the bacteria in Pikovaskaya and chrome azurol S (CAS) agar, respectively. Only 18 morphotypes were found to have all the above four characteristics. PCR amplification of the nifH region of the DNA from 86 selected morphotypes, showed the presence of nifH in 42 isolates. Out of these, 15% of the isolates were obtained using Jensen's medium; 14 and 20% of the isolates were obtained using malate and soil extract medium, respectively. On the basis of biochemical characters and nifH activity, six promising sodicityity tolerant morphotypes *i.e., KtK569, KtJ571, KrK564, KrS530, KtP390 and KrS546 were screened out to check their performance in pot house under induced level of sodicity, i.e. RSC 10 and 15 me/l.*

Key words: EC; pH; sodic soil; screening; plant growth promotion

INTRODUCTION

Salt stress is a major vulnerability to crop growth and yield. These stresses decrease yields of crops and correspond to barriers to the introduction of crop plants in areas that are not suitable for crop cultivation. Sodic soils are often referred to as "black alkali" or "slick spots" because of the dissolved organic matter in the soil solution. Sodic soils have an EC less than 4 dS/m while ESP more than 15, RSC more than 2.5 milli equivalents/liter (me/l) and pH more than 8.5. The

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exchangeable sodium causes soil particles to disperse, resulting in decreased pore space within the soil and increased soil crusting. The loss of permeability due to less pore space can severely restrict water movement into the root zone resulting in plant stress from lack of water (Ogle 2010). As the salt content of the soil increases, it becomes more hard for plants to take up water. A salt which is most abundantly available in the soil, which competes with the a range of nutrients at diverse levels of crop growth and development resulting in nutrient deficiency and ion toxicity by definite elements. In arid and semi-arid regions of the world, including India, the use of high RSC water for irrigation resulted in decline of crop yield and deterioration of soil physical and chemical properties.

One approach to solve the salt stress problem is the use of plant growth-promoting bacteria (PGPB). Many Gram-positive and negative PGPB have been reported to colonize the plant rhizosphere and grant beneficial effects by various direct and indirect mechanisms (Glick 1995). Investigations on the interaction of PGPB with other microbes and their effect on the physiological response of crop plants under different salt effected regimes are still at an incipient stage (Singh et al., 2011). The most suitable solution in such conditions is to make use of salt tolerant bacterial inoculants that may prove constructive in developing strategies to help plant growth in sodic soils (Mayak et al., 2004). Salt-tolerant bacteria that have managed to survive under adverse environmental factors could greatly help in harnessing them for their beneficial properties in such environments in which other microorganisms hardly survive (Mayak et al., 2004). Some of them may be capable to boost plant growth, increase the rate of seed germination, improve seedling emergence and responses to external stress factors, and protect plants from disease (Lugtenberg et al., 2001). In view of this, the present investigation was planned to isolate salt tolerant isolates from sodic water irrigated rhizosphere soil, which further also has potential to be developed as multifunctional biofertilizer in agriculture, particularly fields with sodic soils.

Material and methods

Research Sites

A total of 20 sodic water irrigated soils along with their respective water samples were collected from different districts of Haryana. Sodic soils along with their respective water samples were collected from farmer's fields of different villages of Hisar (29° 10' N, 75° 46'E), Karnal (29° 42' N, 77° 02' E) Kaithal (29° 48' N, 78° 26' E) and Mahendergarh (28° 27' N, 76° 14' E) districts. About 100 g of rhizospheric soil sample, about 15 to 30cm deep, was collected from the four corners and the center of each field which were thoroughly mixed and pooled making up a total of 500 g. The pooled sample from each field represented one rhizospheric soil sample. The top layer of the soil was removed prior to collecting samples, as the microorganisms present around the rhizosphere and rhizoplane would be helpful in crop improvement. The samples were transported to the laboratory in the sterile plastic bags and held in reserve at 4 °C for further analyses. About 250 ml of water used for irrigation in respective fields were collected in sterilized bottles and were also kept at 4°C for further analyses.

Soil chemical and physical analysis

The soil samples were analyzed for EC and pH was checked by Rowell's method (1994). The sample dried at 20^0C to 25^0C (Jackson 1958). The

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organic C in the soil was determined by the method of Kalembessa & Jenkinson (1973). Total nitrogen (%) was measured using Kjeldahl's method while total P was determined by John's method (1970).

Water analysis

Water sample was collected in a sterilized glass or plastic container. The probe of electrical conductivity meter was submerged into the sample and waited until the reading on the meter was stabilized and EC was measured. Similarly, the probe of pH meter was submerged into the sample and waited until the pH reading on the meter was stabilized and pH was measured.

Soil Microbiological Analyses

For the enumeration and isolation of total viable counts in the soil samples, the different growth media were used for different bacteria, as soil extract agar medium (Subba Rao 1977); Jensen's medium (Jensen 1951) and malate medium (Sadasivan & Neyr 1985) for N_2 fixers; Pikovskaya's medium (Pikovskaya 1948) for phosphate solubilising bacteria and King's B medium (King, Ward & Raney 1954) for *Pseudomonas* species. To estimate the number of soil microflora, counts were calculated on the basis of serial 10 fold dilutions in duplicate, using the spread plate (Johnson & Curl 1972). All petri dishes (90 mm diameter) contained 25 ml medium, and plate were incubated at 30±2^{o}C. Colony forming units (CFU) were recorded after 48 hour as; CFU = Bacterial plate count × dilution factor/ weight of soil (grams) Single morphotypes were picked from the petri dishes and purified by re-streaking on fresh plate. The purified isolates were maintained on media slants at 4°C.

Plant Growth Promoting Mechanisms

Ammonia excretion

Bacterial isolates were screened for the production of ammonia in peptone water. Freshly grown culture were inoculated in 10 ml peptone water in each tube and incubated for 48-72 h at 28±2°C. Nessler's reagent (0.5 ml) was added in each tube. Development of brown to yellow colour was a positive for ammonia production (Cappucino & Sherman 1992).

Indole acetic acid production

IAA was quantified by the method of Patten & Glick (1996). The presence of IAA was determined by the development of pink color and the IAA concentration was measured spectroscopically at 520 nm.

Phosphorus solubilization

Isolates exhibiting clear zone on Pikovaskya's agar after 6-7 days of incubation at 28±2ºC in a BOD incubator, were considered as positive.Then the ability of PSM to solubilize the insoluble phosphate was studied by the determination of solubilization index (SI) (Edi- Premono 1996).

SI = Colony diameter + Halozone diameter / Colony diameter

Siderophore production

It was assayed according to Schwyne & Neilands (1987). Isolates exhibiting an orange halo zone on Chromeazurol S agar after 6-7days of incubation at 28±2ºC in a BOD incubator were considered as positive.

Extraction of genomic DNA, quantification, and amplification of the *nif*H gene

The bacterial isolates were grown in 25 ml Jensen's, malate and soil extract broth. The log phase cells were harvested and total genomic DNA was extracted by using CTAB method (Ausubel et al., 2001). Finally, the DNA was quantified and stored at -20°C. The isolated DNA was resolved on 0.8 % agarose gel. The degenerative *nif*H primers, *nif*H for (5′TAY GGN AAR GGN GGH ATY GGY ATC 3′) and *nif*H rev (5′ATR TTRTTN GCN GCRTAVABB GCC ATC AT 3′) (Sarita et al., 2008) were used for the

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amplification of *nif*H gene sequences present in genomic DNA of the morphotypes by polymerase chain reaction using a thermal cycler. The conditions for PCR included an initial denaturation at 94 °C for 3 min; denaturation at 94 °C for 45 s, annealing at 52.4 °C for 30 s, extension at 72 °C for 1 min, with 40 cycles; and final extension at 72 °C for 10 min. The amplified product was separated by electrophoresis at 100 V for 1.5–2.25 h in 1.5% (w/v) agarose gels in TBE buffer (0.089 M Tris-borate, 0.002 M EDTA, 0.089 M boric acid). The gels were stained with ethidium bromide (1 mg ml^{-1}) and photographed under UV illumination with Gel Doc (DNR Bio-Imaging Systems).

Results and discussion

Rhizosphere is a rich habitat of microorganisms and ideal for obtaining potential PGPR, which can be useful in developing bioinoculants for enhancement of crop growth and yield. A total of 20 sodic water irrigated rhizospheric soil along with their respective water samples were collected from Hisar, Karnal, Kaithal and Mahendergarh districts of Haryana state. The RSC, pH and EC_{iw} of these water samples varied from 2.50 me/l, 8.50 - 10.90 and 1.01 - 1.50 dS/m respectively (Table 1). Soil samples were oven dried at 20-25 ^{o}C for 24 hours. 1:5 soil: water suspensions were analysed for pH and EC. Their respective soil samples were analyzed for pH varied from 8.30 - 10.50 and EC_e varied from 1.00 - 2.40. The organic C, total N and total P ranged from 0.09 - 0.46%, 0.002 - 0.040% and 625 - 701 mg P/kg soil, respectively. Water sample KrA used for irrigation in fields of Ardhana village of Karnal district was having maximum RSC i.e.12.00 me/l, followed by water samples, KrG and KrT, collected from Karnal district, which showed RSC of 10.00 and 5.80 me/l, respectively. The soil sample KrA collected from Karnal district was having maximum organic C (0.46%), while soil sample MBj2 collected from Mahendergarh district was having maximum total N (0.040%). The maximum amount of total P (701 mg P/kg of soil) was observed in soil sample MBh, collected from Mahendergarh district

Table 1:Viable counts of bacteria in sodic soils collected from different districts of Haryana

Sr. No.	Sample No.	WATER ANALYSIS			SOIL ANALYSIS				
		RSC (me/l)	pH	EC_{iw} (dS/m)	pH	EC_e (dS/m)	Organic Carbon (%)	Total Nitrogen (%)	Total Phosphorous (mg P/kg soil)
1	HHF3	3.20	8.60	1.01	8.50	2.10	0.19	0.016	670
2	HHF4	2.60	8.60	1.18	8.81	2.00	0.18	0.022	647
3	MBs0	3.80	8.70	1.08	8.51	2.10	0.10	0.008	652
4	MBs1	4.60	9.00	1.05	8.53	1.60	0.09	0.002	657
5	MBs2	4.20	8.50	1.50	8.55	1.10	0.22	0.016	665
6	MBs3	2.80	8.60	1.15	8.58	1.00	0.20	0.017	632
7	MBh	2.80	8.60	1.07	8.60	1.00	0.15	0.012	701
8	MBj1	3.00	8.50	1.14	8.60	2.00	0.15	0.012	635
9	MBj2	3.00	8.50	1.35	8.60	1.80	0.31	0.040	625
10	MBj3	3.00	8.50	1.14	8.60	1.40	0.29	0.038	644

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11	KrA	12.00	10.90	1.01	10.50	2.40	0.46	0.032	679
12	KrG	10.00	9.70	1.04	8.70	2.40	0.37	0.025	661
13	KrT	5.80	9.30	1.06	8.30	2.30	0.35	0.025	650
14	KrP1	2.80	9.50	1.19	8.50	1.00	0.38	0.031	647
15	KrP2	2.80	9.50	1.19	9.80	2.10	0.40	0.031	669
16	KrP3	2.80	9.50	1.19	8.64	1.30	0.35	0.036	645
17	KtKm1	4.90	8.70	1.32	8.60	1.40	0.29	0.030	664
18	KtKm2	4.70	8.90	1.16	8.52	2.10	0.20	0.018	673
19	KtN1	2.50	8.60	1.17	8.80	1.20	0.19	0.020	674
20	KtN2	4.80	8.90	1.17	9.10	2.00	0.30	0.028	646

The total bacterial counts of different soil samples on Jensen's, malate, Pikovaskaya's, King's B and soil extract agar media varied as shown in table 2. A total of 124 bacterial isolates were collected and sorted out into pure different colonies, exhibiting morphological and staining characteristics. It was also observed that microbial population was decreased with increase in salt stress due to less accumulation of organic matter which further lowers down the microbial activity in salt-affected soils (Mallouhi & Jacquin 1985; Pankhurst et al., 2001; Ramadoss et al., 2013), but in these soils, the organic C contents were on the very low side; therefore, no such correlation could be observed in the present study. The possibility of increasing salt contents under the condition of low organic C contents could be detrimental to the bacterial population.

Table 2. Viable counts of bacteria in sodic soils collected from different districts of Haryana

Sr. No.	Sample No.	RSC of water (me/l)	EC_e of the soil (dS/m)	Viable counts (log cfu g^{-1} soil)				
				Jensen's Media	Malate Media	Pikovaskaya's Media	King's B media	Soil extract Media
1	MBs3	2.80	1.00	6.23	6.44	5.31	5.01	8.00
2	MBh	2.80	1.00	5.84	6.27	4.45	3.47	7.91
3	MBs2	4.20	1.10	4.10	5.39	5.44	5.50	7.50
4	KrP1	2.80	1.19	4.42	4.65	5.12	5.45	7.85
5	KtN1	2.50	1.20	4.57	4.60	3.81	3.26	6.00
6	KrP3	2.80	1.30	4.19	5.36	5.36	5.77	7.49
7	MBj3	3.00	1.40	5.20	5.69	5.45	5.97	7.38
8	KtKm1	4.90	1.40	3.44	4.67	4.65	5.95	7.50
9	MBs1	4.60	1.60	5.94	6.00	4.74	4.31	6.25
10	MBj2	3.00	1.80	5.86	6.04	5.13	4.78	6.11
11	HHF4	2.60	2.00	5.74	4.91	4.54	4.00	6.01
12	MBj1	3.00	2.00	5.55	5.85	4.14	4.51	6.14
13	KtN2	4.80	2.00	4.47	4.47	3.77	6.06	5.85
14	KrP2	2.80	2.10	5.17	4.17	4.39	4.47	6.69

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15	HHF3	3.20	2.10	5.78	5.45	5.26	5.35	6.41
16	MBs0	3.80	2.10	5.30	4.21	4.30	4.41	6.71
17	KtKm2	4.70	2.10	5.60	4.61	4.83	4.11	6.36
18	KrT	5.80	2.30	5.87	5.04	4.54	4.24	6.77
19	KrG	10.00	2.40	5.47	4.69	4.65	4.00	6.39
20	KrA	12.00	2.40	5.65	4.84	4.90	4.69	6.77

From 124 morphotypes, soil extract showed maximum, i.e. 35 morphotypes (Table 3). Soil extract medium from the source sediments contains the complex mixture of nutrients which endorse the development of indigenous bacteria and therefore, boost the revival of culturable bacteria (Anderson & Davis, 2013). Gram's staining of all these morphotypes revealed both gram positive and gram negative bacteria having rod or cocci in shape.

Table 3: Viable counts and morphotypes obtained on different media from sodic soils

Media	Viable count (log cfu g^{-1} soil)	Morphotypes from sodic soil
Jensen's	4.16- 6.23	23
Malate	4.07 - 6.44	35
Pikovaskaya's	3.77 -5.45	16
King's B	3.10- 6.06	22
Soil Extract	4.65- 8.00	28
Total		124

PGPR traits

A total of 124 isolates were further screened for PGPR traits like ammonia, IAA, siderophore and phosphate solublization. Ammonia excretion by the morphotypes ranged from 0.022 - 2.516 µg ml^{-1}, respectively. Out of 124 morphotypes obtained, 8 morphotypes were high ammonia excreters, and the isolate KrK564 excreted maximum amount of ammonia, i.e 2.516 µg ml^{-1}. Bacterial IAA stimulates the development of the host plant root system. The advantage for root linked bacteria is a rich supply of nutrients. The property of synthesizing IAA is an effective tool for screening the beneficial microorganisms as there are many reports that reported that such bacteria has a profound effect on plant growth. Out of the total, 3 morphotypes showed high IAA production. KrS530 isolate produced maximum IAA, i.e 7.335 µg ml^{-1}. Most of the morphotypes obtained from sodic soils were able to produce IAA and excrete ammonia. Out of 124 morphotypes isolated from sodic soil, 7 morphotypes were able to produce high siderophore. The P- solublization index by the morphotypes ranged between 1.01 to 3.20. The morphotype KtP390 was found to be best P- solublizer, having a P-solublization index of 3.20. The potential to produce siderophores by microorganisms in improving iron availability to plants was also reported by some workers (Bar-Nes et al., 1992; Rroco et al., 2003; Sharma et al., 2003). The ability to produce siderophore was limited to few morphotypes only. Phosphate solubilization by *Bacillus* sp. isolated from the salt stressed environment had been observed by earlier researchers (Son et al., 2006). Some of the bacteria are known to improve the solubilization of the fixed soil phosphorous and applied phosphates, resulting in higher yields, even under stress conditions (Banerjee et al., 2010).

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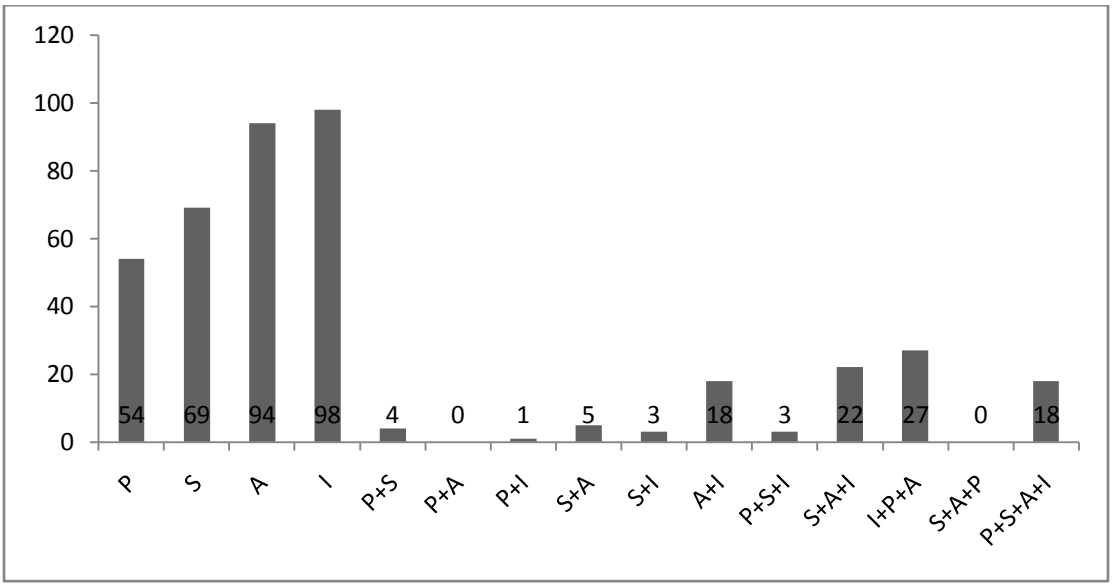
Phosphate solubilisation is considered to be most important attribute of plant growth promoting rhizobacteria (Kloepper et al., 1989). Only 18 out of 124 morphotypes were found to have all the four characteristics, i.e. ammonia excretion, IAA production, P- solublization and siderophore production, while 52 morphotypes possesses any of these three characteristics (Fig 1), indicating important isolates of sodic soils. These results were supported by the findings of Woo et al., (2010) that isolated PSB strains from the rhizosphere of Chinese cabbage were found to solubilize P in the media and besides this, they were able to produce IAA and siderophores.

The combination of IAA production ability (Goldstein 1995), phosphorous solubilization (Gyaneshwar et al., 1998) and siderophore production (Duffy 1994) of bacteria aid the plant rhizosphere in enhancing the nutrient absorption potential under sodic environment for enabling economic production of commercial horticultural crops (Damodaran et al., 2013). These results indicate that the tested isolates could exhibit two or three plant growth promoting (PGPR) traits, which may promote plant growth synergistically or individually. They have good prospects to improve plant growth, especially in soil which is affected by salts. Even, multi-strain inoculant biofertilisers may be particularly beneficial. There are prospects for utilizing this multi-strain inoculant biofertiliser technology in the Australian rice industry (Williams & Kennedy 2002). Other multi-strain inoculants for rice currently being applied in the field at the National Institute for Biotechnology and Genetic Engineering in Faisalabad, Pakistan (Malik et al., 2002) and similarly in Egypt (Hegazi et al., 1998). These inoculants are claimed to give similar yield increases on rice farms of around 20%.



(P- P- solubluizers**; S-** Siderophore producers**; A-** Ammonia excreters**; I-**Indole acetic acid producers**)**

Fig 1. Characterization of the morphotypes obtained from sodic soil Isolation of Genomic DNA and Amplification of *nif*H sequences

DNA was isolated from all the morphotypes by using the CTAB method for the amplification of *nif*H gene. The amount of DNA isolated from each morphotype was approximately 70 to100 ng μl^{-1}. The

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isolated DNA was resolved on 0.8 % agarose gel. Genomic DNA of few morphotypes has been shown in fig 2.

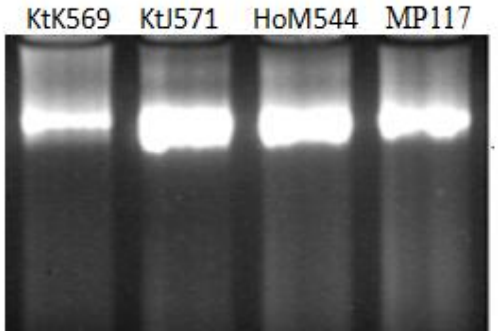

Fig2: Genomic DNA of the isolates obtained on different media using CTAB method

The genes for nitrogen fixation, called *nif* genes are found in both symbiotic and free living systems (Reed et al., 2011). Nitrogenase (*nif*) genes include structural genes, involved in activation of the Fe protein, iron molybdenum cofactor biosynthesis, electron donation, and regulatory genes required for the synthesis and function of the enzyme. Inoculation by biological nitrogen fixing plant growth promoting rhizobacteria on crop provide an integrated approach for disease management, growth promotion activity, maintain the nitrogen level in agricultural soil (Gupta et al., 2015). Thus, the highly conserved nature of *the nif*H gene makes it an ideal molecular tool to determine the potential for biological nitrogen fixation in different environments (Zehr & Capone 1996). The genomic DNA of 57 morphotypes obtained on soil extract agar, Jensen's and malate media was amplified with *nif*H gene primers, i.e *nif*H F and *nif*H R (Sarita et al., 2008), which resulted in a PCR product of 420 bp (Fig 3).

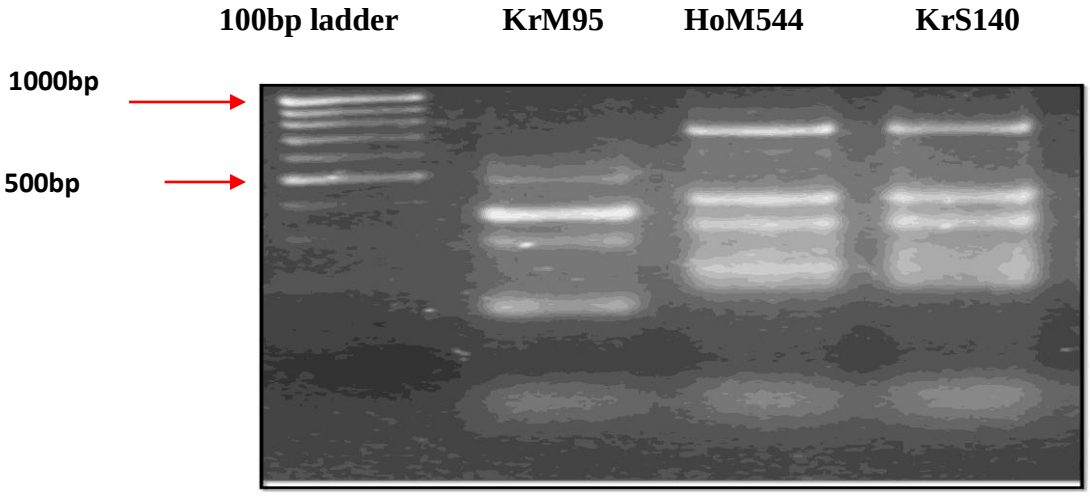

Fig3: Amplification of *nifH* gene from genomic DNA of the isolates obtained from different media

Out of 57 morphotypes isolated from sodic soil, only 28 morphotypes were *nif*H positive, which were mainly isolated from Jensen's (10), malate (6) and soil extract (12) medium. Just 49.12% of the isolates

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had potential to fix nitrogen. Further, it was observed that only one isolate, JJ355 posseses all traits. Microbial inoculants are applied to improve plant nutrition, promote plant growth by stimulating plant hormone production (Sullivan 2001). The increment in the development and yield parameters in response to inoculation endorsed the fact that biofertilizers do have one or more growth promoting mechanisms, including mobilization and efficient uptake of nutrients (Biswas et al., 2000), enhancement in stress resistance (Alami et al., 2000), solubilization of insoluble phosphates (Alikhani et al., 2006), and siderophores production (Neiland & Leong 1986). Plant growth promotion is a complex phenomenon rarely attributable to a single mechanism as most PGP microbes influence plant growth through multiple mechanisms, and in some cases their PGP effect may only occur through interactions with other microbes.

Screening of promising morphotypes from sodic soils

Six promising bacterial isolates were selected from sodic soils on the basis of different biochemical and molecular characteristics to check their efficacy in wheat under pot house conditions as shown in table 4. Many strains used as bioinoculants are effective only in normal soils, but they fail to express under salt stress conditions and the survival of the microbe are drastically affected. Only those bacteria which are adapted to such salt stressed environments, can survive in such soils. As it was reported earlier by Nia et al. (2012) that the effect of inoculation of *Azospirillum* strains isolated from salt stresses soil on yield and yield components of wheat. It was observed that inoculation with the two isolates increased salt tolerance of wheat plants; the sodic-adapted isolate significantly increased shoot dry weight and grain yield under severe water sodicity. The component of grain yield most affected by inoculation was grains per plant.

Table 4: Characteristics of selected morphotypes from sodic soils

Sr. No.	Isolate No.	EC of the soil (dS/m)	P-solubliz-ation index	Siderophore production	IAA Production (µg ml^{-1})	Ammonia Excretion (µg ml^{-1})	*nif*H^+
1	KtK569	4.00	1.61	++	0.680	1.353	N.D
2	KtJ571	3.70	1.54	+	0.770	1.883	+
3	KrK564	2.30	-	+	-	2.516	N.D
4	KrS530	1.00	-	+	7.335	-	-
5	KtP390	1.40	3.20	+	-	-	N. D
6	KrS546	1.00	-	+++	0.740	1.678	+

(- Nil, + low, ++ medium, +++ good, *N.D. Not determined)

Compatibility of promising morphotypes obtained from sodic soils

It was observed that the selected KrK564, KrS530, KtP390 and KrS546 morphotypes grew well on the nutrient agar plate and did not inhibit the growth of each other. Moreover, there was an increase in size of each colony with the increase in incubation time, showing that all the four morphotypes are compatible and can be used as consortia to check their efficacy on plant growth.

The combination of ammonia excretion, IAA production ability (Goldstein 1995), phosphorous solubilization (Gyaneshwar et al., 1998) and siderophore production (Duffy 1994) of bacteria aids the plant rhizosphere in enhancing the nutrient absorption potential under salt stress environment for enabling economic production of commercial horticultural crops (Damodaran et al., 2013). These results indicate that the tested isolates could exhibit two or three plant growth promoting (PGPR) traits, which may promote plant growth synergistically or individually. They have good prospects to improve plant growth as they have nitrogen fixing ability too, especially in soil which is affected by salts. Even, multi-strain inoculant biofertilizers may be particularly beneficial. There are prospects for utilising this multi-strain inoculant biofertilizer technology in the Australian rice industry (Williams & Kennedy 2002). Other multi-strain inoculants for rice is currently being applied in the field at the National Institute for Biotechnology and Genetic Engineering in Faisalabad, Pakistan (Malik et al., 2002) and similarly in Egypt (Hegazi et al., 1998). These inoculants are claimed to give similar yield increases on rice farms of approximately 20%. There is evidence from trials in cotton that co-inoculation with multiple PGP microbes can increase plant yield compared to single inoculums (Paul et al., 2011; Yasmin et al., 2013). Thus, six promising bacterial isolates (KtK569 and KtJ571 having all four agriculturally useful characteristics; KrK564, KrS530, KtP390 and KrS546 as consortia) can be used under induced conditions of sodicity in pot house conditions, so as to check their efficacy in wheat growth and yield.

Conclusion

It is inferred from the results that these isolates can show potential for plant growth promotion in alkaline soil regions, suggesting further studies under pot house conditions and on field trials for commercial crops grown under salt stressed conditions. However, the identification of strains is required on the basis of molecular techniques. This led to the selection of effective PGPR isolates. Their multiple PGPR traits could prove effective in improving the plant growth parameters. Such type of study is necessary as it advocates that use of PGPR as inoculants or biofertilizers is an efficient approach to replace chemical fertilizers and these PGPR isolates may be used as biofertilizers to increase the growth and productivity of plants stressed conditions. In addition to these traits, PGPR strains must be rhizospheric component, able to endure and colonize in the rhizospheric soil.

Aknowledgements

All work was done in Department of Microbiology, College of Basic Sciences and Humanities, Chaudhary Charan Singh Haryana Agricultural University, Hisar, India.

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