Discussion
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PGPR inhabit the roots of plant and the area adjoining the roots to augment plant growth and development through myriad of mechanisms. Nevertheless, the precise mechanism by which PGPR kindle plant growth is not yet clearly understood, although several processes like production of phytohormones, suppression of phytopathogenic fungi, activation of phosphate solubilization and promotion of the mineral nutrient uptake have so far been thought to be the reasons behind plant growth promotion (Lalande et al., 1989; Glick, 1995). In the present study, plant beneficial bacteria were isolated from rhizosphere of Jatropha. Isolated bacteria were screened for different plant growth promotional activities and characterized by biochemical tests. Phosphorus is one of the most sought after nutrients for plant development, second only to nitrogen in requirement by plants. Phosphorus is majorly present in the soil in the form of insoluble phosphates and therefore, is not readily available to the plants. The ability of the bacteria to solubilize mineral phosphates has been postulated by agriculturists across the globe, as a possible underlying mechanism for enhancing plant growth. Although all the six rhizobacterial isolates demonstrated activity of phosphate solubilisation, isolate BJJ-5a (Klebsiella pneumoniae) showed highest phosphate solubilisation activity (Table 9). It has been reported that higher population of phosphate-solubilising bacteria are majorly localised in the rhizospheric soil in comparison to non-rhizospheric soil (Reyes et al., 2007). Phosphate solubilising bacteria also promote plant growth in soils with large amount of water holding capacity.

IAA is one of the most crucial phytohormones and functions as significant signal molecule in the regulation of plant development. It has been postulated that IAA production by rhizobacteria can differ among various species and strains, and also subjective to culture conditions.
conditions, growth stage and substrate availability (Sajjad Mirza et al., 2001). In the current study, three isolates namely, BJJ-5a, SJPB-2a and BJJ-4 were positive for IAA production (Table 9). Earlier studies have demonstrated that IAA biosynthesis is subjective to L-Trp precursor. L-Trp is a chief precursor for formation of IAA in many microorganism. In present study it was observed that on supplementation of tryptophan in the medium, the amount of IAA produced considerably increased. BJJ-5a showed maximum IAA production among six rhizobacteria both in presence and absence of tryptophan.

Another important trait of PGPR is production of siderophore. Siderophore is a biocontrol mechanism belonging to PGPRs groups under iron limiting conditions. PGPR produces a range of siderophore which have kinship towards iron. Therefore, the availability of iron would overpower the growth of pathogen organisms including plant pathogenic fungi. Iron is a limiting bioactive metal in soil and essential for growth of soil microorganisms. The iron concentration in the soil is exceptionally low ($10^{-7}$M) enough to hinder the growth of soil microorganism ($10^{-8}$-$10^{-6}$M) (Guerinot, 1994). Rhizobacteria are equipped with some strategies to acquire iron. An important tactic is the production of siderophores. The rhizobacteria that can produce siderophores compete for iron with soil borne pathogens. Siderophore producing bacteria are crucial in plant growth promotion. All the six rhizobacterial isolates were found to be siderophore producing. Among the six isolates, BJJ-4 and BJJ-7 demonstrated maximal siderophore production (Table 9).

PGPR are specially designed by nature to harbor growth promotional benefits for host plant. Colonization of roots by PGPR is a potential mechanism for successful plant-microbe interaction. In certain associations of microbes with plants, exopolysaccharides (EPS) have a major role that help bacteria to inhabit the root surface through specific adhesion, leading to
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root colonization that eventually results in biofilm formation (Ramey et al., 2004; Matthysse et al., 2005). Our study demonstrated robust EPS production by all the six rhizobacterial isolates, with SJPB, SJPB-2a and SJPB-2b exhibiting maximum EPS production (Table 9), which suggest the propensity of these isolates to colonize the roots of host plants efficiently.

Furthermore, rhizobacteria BJJ-5a and BJJ-4 for ammonia production, BJJ-5a and SJPB-2a for catalase activity and BJJ-7 for HCN production (Table 9) demonstrated maximal activity which suggests potential for plant growth promotion, stress tolerance and antagonistic activity against phytopathogens, respectively.

A number of studies suggest that PGPR enhances the growth, seed emergence, crop yield, and contribute to the protection of plants against certain pathogens and pests (Dey et al., 2004; Kloeper et al., 2004; Kokalis-Burelle et al., 2006; Herman et al., 2008). Recently, a study reported successful isolation and identification of PGPRs associated with maize (*Zea mays* L.) from twenty sites of Himalayan region of Hajira-Rawalakot, Azad Jammu and Kashmir (AJK), Pakistan (Zahid et al., 2015). A total of 100 isolates were isolated from these sites, out of which eight (HJR1, HJR2, HJR3, HJR4, HJR5, MR6, HJR7, HJR8) were selected *in vitro* for their plant growth promoting ability (PGPA) including phosphorus solubilization, indole-3-acetic acid (IAA) production and N2 fixation (Zahid et al., 2015). All the eight isolates were reported with the potential to produce IAA in the range of 0.9-5.39 μg mL⁻¹ and promote plant growth (Zahid et al., 2015). Results from their subsequent pot experiment indicated PGPRs distinctly increased maize shoot and root length, shoot and root dry weight, root surface area, leaf surface area, shoot and root N and P contents (Zahid et al., 2015). The aforesaid data is confirmatory to my studies.
In the present study, isolate BJJ-5a (*Klebsiella pneumoniae*) was found to be the most efficient PGPR which solubilised insoluble phosphorus, produced IAA, exopolysaccharide, ammonia, HCN and demonstrated catalase activity. Present study, thus, paves a path for potential use of soil rhizobacteria as inoculants or biofertilizers which may help to substitute the use of environmentally harmful chemical fertilizers.

Furthermore, cell wall degrading enzymes were qualitatively assayed to understand the mechanisms behind the biocontrol of pathogens. Isolated PGPRs demonstrated unique ability to secrete cellulase, amylase, lipase, protease enzymes that may help to degrade the cell wall of pathogens. Furthermore, rhizobacteria BJJ-5a demonstrated maximal antagonism against fungal phytopathogens *F. oxysporum*, which suggests potential for antagonistic activity against phytopathogens. Present study, thus reflects the application of Plant Growth Promoting Rhizobacteria (PGPR), having significant antagonistic effect that may prove beneficial to the plant, additional to rhizobacteria’s plant growth promoting properties.

In earlier studies, a commercial soil amendment containing a mixture of four PGPR (*Azospirillum lipoferum, Azotobacter chroococcum, Pseudomonas fluorescence and Bacillus megaterium*) was evaluated and reported to increase germination rate and vigour index as compared with the control (Lenin and Jayanthi, 2012). Furthermore, effect of plant growth promoting rhizobacteria on seed germination, seedling growth and yield of field grown maize were demonstrated to be significantly enhanced (Gholami et al., 2009).

In the present study, pot trials were carried out to investigate plant growth properties of isolated rhizobacteria on *Cymopsis tetragonaloba*, wherein BJJ-5a treated seeds demonstrated better rooting, more number of leaves, increased root length, shoot length and dry weight as
compared to control treated seeds (Fig. 19 and 20). Compared to control, increased number of roots was also observed for SJPB treated seeds. Results suggested that the application of the rhizobacteria, in particular the BJJ-5a treatment, enhanced seed germination and plant growth. Moreover, BJJ-5a treated seeds demonstrated the maximal chlorophyll-a, chlorophyll-b and total chlorophyll content (Fig. 21).

Earlier studies have reported that the inoculation of rhizobacteria increased protein content of the test plants (Akbari et al., 2011). PGPR application has also been previously reported to induce plant defense enzyme (such as phehylamine ammonia lyase, peroxidase and polyphenoloxidase) activities in the leaf and root of *Piper betle* (Lavania et al., 2006) and *Antheraea assam* (Unni et al., 2008). Furthermore, total phenolic and flavonoid contents are one of the important secondary metabolites that present ubiquitously in plants and its products contained high amount of antioxidants (Razali et al., 2008). Previous studies have documented that phenolic compounds are the categories of antioxidant agents which help in the termination of free radicals (Shahidi and Wanasundara, 1992). Moreover, flavonoids have also demonstrated the antioxidant activity due to their scavenging and chelating process for free radicals (Prasad et al., 2013). Phenolic compounds play a yet another important role in defence mechanism against microbial pathogens depending on their toxicity and repellence to microbes and insects (Mazid et al., 2011).

Biochemical assays were performed to determine augmentation of protein, amino acids, sugar content; catalase and peroxidase activity; phenol and flavonoids content due to the treatment of *Cyamopsis tetragonoloba* seeds with isolated rhizobacteria. The highest protein, amino acid and sugar content; catalase and peroxidase activity; phenol and flavonoids content were observed in *Cyamopsis tetragonoloba* seedlings grown in BJJ-5a treatment.
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PGPRs not only enhance plant growth and development but also enhance fertility of the soil. Soil devoid in nutrients if treated with rhizobacteria can be reinvigorated. In the present study, BJJ-5a treated soil increased in organic carbon-, available phosphorus and potassium-content. Water holding capacity of the BJJ-5a treated soil was also observed to increase in comparison to pre-treated soil.

Current soil management strategies are mainly dependent on inorganic chemical-based fertilizers, which caused a serious threat to human health and environment. The exploitation of beneficial microbes as a bio fertilizer has become paramount importance in agriculture sector for their potential role in food safety and sustainable crop production. The eco-friendly approaches inspire a wide range of application of plant growth promoting rhizobacteria (PGPRs), endo- and ectomycorrhizal fungi, cyanobacteria and many other useful microscopic organisms led to improved nutrient uptake, plant growth and plant tolerance to abiotic and biotic stress. Bharadwaj et al (2015), recently reviewed and described how PGPRs assist in augmenting crops functional traits such as plant growth and productivity, nutrient profile, plant defense, with particular emphasis on various growth- and defense-related genes in signalling network of cellular pathways to cause host-cellular response and thereby crop improvement (Bhardwaj et al., 2014). Thus, it can be envisioned that introduction and exploitation of plant growth promoting rhizobacteria (PGPR) in agro-ecosystems enhancing plant-microbes interactions, may be very well considered to positively affect ecosystems sustainability, agricultural productivity, and environmental quality. Present study, corroborates and further reflects the application of Plant Growth Promoting Rhizobacteria (PGPR), having significant effect on seed germination, plant growth, enzyme activity and antioxidants contents in Cyamopsis tetragonoloba, in addition to their ability to enhance soil parameters like percentage of organic carbon, available phosphorus and potassium in the soil.
and water holding capacity (WHC). Since these cardinal parameters are associated with plant yield, it can be suggested that application of isolated PGPRs may further enhance crop yield of *Cyamopsis tetragonoloba* and may be exploited as a potential strategy to be employed as bio-fertilizers.