Effect of bacterial consortia on growth and yield of maize grown in *Fusarium* infested soil

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Abstract

Soil borne pathogens are responsible for considerable yield losses in field crops. Healthy growth and ultimate yield of the crop depends upon the efficient supply of water, nutrients and absence of biotic and abiotic stress. Under biotic stress plant growth promoting rhizobacteria (PGPR) and compost inhabiting bacteria (CIB) can help the plant to function normally by suppressing the pathogen. A pot experiment was conducted to determine the effect of PGPR and CIB on growth and yield of maize, grown in fungus infested soil. Two strains, each of PGPR (Mb4 and Mb7) and CIB (Cb4 and Cb9) were evaluated to improve the growth and yield of maize crop. Maize seeds were sterilized and inoculated with bacterial strains before sowing along with un-inoculated control for comparison. Recommended dose of fertilizers (180, 140, 90 NPK kg ha⁻¹) was applied at sowing and pots were arranged in completely randomized design. Results showed that inoculation with selected strains of bacteria, exhibited percent increase in yield of fresh cob (up to 52.69%) and dry cob (40.87%), cob length (51.42%), grain yield (up to 55.34%), 1000-grain weight (up to 37.27%), K contents in grains and straw (1.756 and 0.793, respectively), %N in grains and straw (up to 2.675 and 0.997%, respectively) and %P in grains and straw (up to 1.756 and 0.793%, respectively) compared to uninoculated control. Keeping in view the higher yield parameters of inoculated treatments compared to un-inoculated control, it was concluded that inoculation of maize seeds with bacterial consortia suppressed the adverse effect of fungal pathogen and enhanced the growth and yield of maize crop.

Keywords: Bacterial consortia, PGPR, CIB, *Fusarium oxysporum*, maize

Introduction

Microbes are everywhere on the earth but the largest number of microbes reside in the rhizosphere (Carmen and Roberto, 2011). Among this microbial population, bacteria and fungi cover the highest proportion (Morgan et al., 2005). They compete with each other for food and space and differ from the microbes residing in the bulk soil (Chaparro et al., 2013). Rhizospheric bacteria are very important for proper development of plants under stressed conditions. They can be plant specific and their number can vary with age of plant, type of soil and environmental conditions (Hryniewicz et al., 2010; Bouffaud et al., 2012). Their effect on plants may be detrimental, beneficial or neutral (Katarzyna and Christel, 2011). Detrimental microbes may be major plant pathogens and/or minor parasites while favorable bacteria help plants to grow successfully (Bulgarelli et al., 2013).

Seedling blight in maize crops is due to soil born fungus *Fusarium oxysporum*. Different *Fusarium* species cause seedling blight, crown rot and scab of wheat and barley, stalk, cob and crown rot of maize (Khan et al., 2006). Seed infected with *Fusarium*, exhibited reduced germination, seedling emergence and caused post emergence death of wheat seedling and ear rot of maize (Charles et al., 2007).

Seed treatment with pesticide could be effective for control of pathogens but more severe problems may arise due to lethal residues of fungicides (Cardoso et al., 2010). The continuous use of pesticides is not only deteriorating the environment but also has increased the resistance in the pests (Gassmann et al., 2011). Extensive use of pesticide might cause soil and air pollution which might have adverse effects on the human, animals and plants health. The persistent nature of many pesticide/fungicides further aggravated the problem. Sometimes pesticides may activate into more harmful by-products that might cause more serious health problems due to their uptake by plant and ultimately by entering into the food chain (Wasim et al., 2009). Therefore, biocontrol may be the best alternative of chemical control for plant diseases (Killani et al., 2011) being economical and environment friendly (Lugtenberg and Kamilova, 2009).

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Beneficial bacteria (PGPR, CIB) colonize the plant root surface and increase nutrient uptake (Jing et al., 2007), release organic compounds (Shukla et al., 2011; Drogue et al., 2013) and suppress the diseases (Tarkka et al., 2008) resultantly improve the growth of plants. They produce antimicrobial metabolites and induce systemic resistance in plants (Falahian et al., 2007; Erdogan and Benlioglu, 2010). Plant growth promoting rhizobacteria help plants by modifying the chemical composition of root cell wall (El Zemrany et al., 2007) and by amplifying the lignin deposition in epidermal tissues of inoculated plants under diseased condition (Niranjan et al., 2012).

Inoculation of field crops with compatible strains showed better results than single inoculation (Figueiredo et al., 2010). Inoculation with PGPR and arbuscular mycorrhizal fungi enhanced the yield of sorghum (Kumar et al., 2012). Inoculation with a consortium of two PGPR and one mycorrhizal strain exhibited enhanced growth of root in maize crop (Walker et al., 2012). In the present study bacterial strains were characterized for siderophore and chitinase production, biofilm formation and antagonism assay and the efficient strains were used to evaluate the potential of bacterial consortia for yield and growth promotion of maize crop in fungus infested soil.

Materials and Methods

Isolation of bacteria

Bacteria were isolated using standard dilution-plating procedure as described by Pugliese et al. (2008). Ten gram of the sample (Compost/rhizosphere soil) was mixed with 90 mL of sterile distilled water in conical flask, shaken vigorously on a vortex mixer for 10 minutes and serially diluted up to 10⁶. An aliquot (0.1 mL) of these suspensions was spread on the plates of Luria-Bertani (LB) agar medium (Luria and Burrous, 1995). Inoculated plates were incubated at 26 ± 2 ºC for 48 h and were purified by repeated streaking on the same medium until pure colonies were established.

Cross check of pathogen

The pathogen (Fusarium oxysporum) was collected from Department of Plant Pathology, Ayub Agricultural Research Institute, Faisalabad, isolated by tissue segment method and identified by using colony morphology and microscopic features. Pathogenicity was tested on live plant by cut stem method (Singh et al., 1991). The mycelial suspension of the isolates was produced in broth medium of 250 mL in conical flasks. The mycelium of the isolate was filtered through the cheesecloth by gentle pressing to remove excess liquid and blending for 30 seconds in blender at the rate of 5 g of mycelium per liter of sterile deionized water. The resulting suspension was used as inoculum. The inoculum was freshly prepared before the applications. Three weeks old seedlings of maize, grown in sterilized potted soil were inoculated with the mycelial suspension of the fungal isolate. The pathogen was re-isolated from the infected plants and identified using colony morphology and microscopic features (Singh et al., 1991) and compared the characteristics with the initial isolates.

Characterizations of bacterial isolates

Seventy five strains of each PGPR and CIB were isolated from maize rhizosphere and compost, respectively. Twenty five strains were selected for preliminary tests (in vitro disease suppression assay), and two each of PGPR (Mb1 to Mb25) and CIB (Cb1 to Cb25) were selected for further evaluation under pot condition. The selected strains were further characterized for beneficial plant growth promoting traits following standard methods as mentioned in Bergey’s Manual of Systematic Bacteriology (Krieg and Holt, 1984). Bacterial strains (Mb4, Mb7, Cb4 and Cb9) were characterized for siderophore production and chitinase activities, by following the protocols described by Clark and Bavoil (1994) and Chernin et al. (1998) respectively. Biofilm formation was carried out by following the procedure adopted by Peeters et al. (2008).

Antagonism assay

The target pathogen was inoculated on PDA at four equidistant peripheral points while compost inhabiting bacteria were inoculated at the center of Petri plates. In another set, the target pathogens were inoculated at the center and CIB at four equidistant peripheral points of Petri plates. Same was repeated for the PGPR in place of compost inhabiting bacteria. The experiment was replicated thrice and incubated at 28± 1 ºC. Inhibition of pathogens was observed after every 12 h. The means of the three measurements were recorded for each pathogen. Inhibition of pathogen (%) over control was calculated by using the following formula (Vincent, 1947),

\[ \text{Percent Inhibition of mycelium (I)} = \frac{c - t}{c} \times 100 \]

Where ‘I’ is percent inhibition of mycelium, ‘C’ is growth of mycelium in control and ‘T’ is growth of mycelium in inoculated treatment.

Preparation of inoculum and seed inoculation

Inocula of selected strains of PGPR (Mb4 and Mb7) and CIB (Cb4 and Cb9) were prepared separately in 250 mL conical flask having 100 mL LB broth. The inoculated culture was incubated at 28±1º C in the orbital shaking incubator at 100 rpm for 48 hours. An optical density of
0.5, recorded with an optical density meter at wavelength of 535 nm was achieved by dilution to maintain uniform cell density (10^8–10^9 CFU mL^{-1}) prior to seed inoculation. A consortium was prepared by mixing bacterial strains cultures in 1:1 ratio. The seeds of maize were inoculated by coating with peat-based slurry containing 2-days old inocula of respective strains and sugar solution (10%). Whereas the seeds for control were treated with peat containing sterilized broth and solution of sugar (Yadav et al., 2010). Inoculated seeds were air dried under shade before sowing. *Fusarium oxysporum* culture was prepared in 250 mL flak contain potato dextrose broth (PDB)

**Pot experiment**

Pot experiment was carried out in sandy clay loam soil having pH 7.9; EC, 1.4 dS m^{-1}; nitrogen, 0.030%; available phosphorus, 7.2 mg kg^{-1} and extractable K 120 mg kg^{-1} at wire house of Soil Bacteriology Section, Agriculture Biotechnology Research Institute, AARI, Faisalabad. Each pot contained 12 kg soil. Recommended dose of NPK fertilizers (180, 140, 90 NPK kg ha^{-1}) was applied as urea, single super phosphate, and sulphate of potash). The whole P and K were supplemented as basal dose whereas N was added in two splits (Once after germination and then at tasseling stage). Equal volume of fungus (*Fusarium oxysporum*) inoculum (10^6 spores mL^{-1}) was added at the time of pot filling by mixing manually into soil. Surface disinfected maize seeds were inoculated by peat based inocula/slurry (consist of peat, sugar and bacterial culture, multiplied on LB broth media) while control was treated with slurry prepared with peat, sugar and LB broth without bacteria cells (un-inoculated). Seed of each treatment was sown at the depth of 3.81 cm. Each treatment was replicated thrice and arranged according to completely randomized design. Good quality canal water [EC = 0.7 dS m^{-1}, SAR = 0.5 (mmol L^{-1})1/2 and RSC = 0.05 mmolc L^{-1}] meeting the irrigation quality criteria for crops (Ayers and Westcot 1985) was used for irrigation. Data regarding disease suppression and growth promotion was collected during the growth period while yield data was collected at harvest.

Grains and straw samples were digested using tri-acid mixture (nitric acid, sulfuric acid and perchloric acid (9:2:1 (v/v)) and analyzed phosphorus and potassium following protocol given by Ryan et al. (2001). Soil and plant samples were digested with sulfuric acid and catalyst mixtures following Gunning and Hibbard’s method and for the distillation of ammonia into nitrogen, 4% boric acid was utilized using macro Kjeldhal’s apparatus (Jackson, 1967) while available phosphorus was determined by Olsen method (Olsen and Sommer, 1982). Extractable potassium was determined using flame photometer Jenway PFP-7.

**Statistical analysis**

Standard errors of means of the data were computed following Steel et al. (1997) using the statistical software STATISTIX v8.1 whilst means were compared by means of Duncan’s Multiple Range Test (Duncan, 1955).

| Table1: Characterization of PGPR and CIB isolates |
|-----------------------------------------------|
| **Treatment** | **Siderophore production** | **Chitinase** | **Antagonism (I %)** | **Biofilm formation Absorbance** |
| Mb4 | ++ | ++ | 84 | 4.095 |
| Mb5 | - | - | 84 | 2.018 |
| Mb6 | ++ | - | 82 | 2.508 |
| Mb7 | ++ | ++ | 81 | 3.314 |
| Cb1 | - | ++ | 86 | 2.341 |
| Cb 4 | ++ | ++ | 86 | 3.210 |
| Cb 8 | - | ++ | 88 | 2.117 |
| Cb 9 | ++ | ++ | 86 | 4.081 |

Mb4= *Bacillus megaterium*, Mb7= *Pseudomonas aeruginosa*, Cb4= *Serratia spp.*, Cb9= *Pseudomonas fluorescens*

**Results**

**Characterization of PGPR and CIB**

All the isolates (Mb4, Mb7, Cb4, and Cb9) were characterized for siderophore production, chitinase production, antagonistic effect against *Fusarium oxysporum* and biofilm formation (Table 1). Four strains i.e. Mb4, Mb7, Cb4, Cb9 were proficient siderophore producers and showed efficient chitinase activity. Percent antagonism by Mb4 and Mb7 ranged from 82 to 84% and it varied from 86 to 88% by Cb4 and Cb9. Biofilm formation at absorbance of 595 and 600 nm was observed and results showed that Mb4 (4.095, 2.971 nm), Mb7 (3.14, 2.860 nm), Cb4 (3.210, 2.78 nm) and Cb9 (4.081, 2.54 nm) were efficient for biofilm formation at both the wavelengths while Cb9 was the most effective strain for biofilm formation.
Effect of bacterial consortia on growth parameters of maize

Leaf size is related to photosynthesis of the plant, so health of the crop is affected by leaf area. Leaf length was positively affected by bacterial inoculation. Increase in leaf area was higher by single inoculation but combination of two and three strains of Mb and Cb gave better result while maximum leaf length was recorded with consortium of all the four strains (88.40 cm) compared to control (62.2 cm). All the inoculated treatments showed leaf width, significantly higher than control. Maximum leaf width was recorded with consortium of four (7.9 cm) followed by Mb4 + Cb4 + Cb9 (7.87 cm), Mb7 + Cb4 + Cb9 (7.7 cm) and Cb9 + Mb4 + Mb7 (7.5 cm) which were significantly higher than control (3.9 cm). Inoculated treatments gave

Table 2: Effect of consortium of bacterial strains on leaf length, leaf width and intermodal distance of maize grown in fungus infested soil

| Treatment                      | Leaf length (cm) | Leaf width (cm) | Leaf area (cm²) | Inter-nodal distance (cm) |
|--------------------------------|------------------|-----------------|-----------------|--------------------------|
| Control                        | 62.20 h          | 3.90 k          | 242.18 h        | 10.20 c                  |
| Mb4                             | 78.50 efg        | 5.70 j          | 447.15 g        | 13.50 ab                 |
| Mb7                             | 75.30 g          | 6.00 ij         | 452.00 g        | 13.40 abc                |
| Cb4                             | 78.03 fg         | 6.6 fgoh        | 514.8 ef        | 12.20 bc                 |
| Cb9                             | 79.90 ef         | 6.27 hi         | 529 def         | 12.90 abc                |
| Mb4+Cb4                         | 80.90 def        | 7.13 cde        | 576.89 bc       | 12.90 abc                |
| Mb4+Cb9                         | 82.00 cde        | 6.73 efg        | 552.27 cde      | 13.00 abc                |
| Mb7+Cb4                         | 81.90 cde        | 6.63 fgh        | 543.67 c-f      | 12.50 abc                |
| Mb7+Cb9                         | 81.7 cdef        | 6.6 fgh         | 536 c-f         | 13.70 ab                 |
| Mb4+Cb4+Cb9                     | 86.00 ab         | 7.87 ab         | 663.00 a        | 14.60 ab                 |
| Mb7+Cb4+Cb9                     | 85.30 abc        | 7.70 ab         | 656.81 a        | 15.0 ab                  |
| Cb4+Mb4+Cb9                     | 84.44 cd         | 7.43 bcd        | 594.26 b        | 13.70 ab                 |
| Cb9+Mb4+Mb7                     | 85.50 bc         | 7.50 abc        | 675.45 a        | 14.40 ab                 |
| Consortium of all the four strains | 88.40 a          | 7.90 a          | 676.82 a        | 15.50 a                  |
| LSD                             | 3.8250           | 0.4347          | 41.736          | 3.2027                   |

Means sharing the same letter are not significantly different from each other (data is the mean of three repeats)

Mb4= *Bacillus megaterium*, Mb7= *Pseudomonas aeruginosa*, Cb4= *Serratia* spp., Cb9= *Pseudomonas fluorescens*

Table 3: Effect of consortium of bacterial strains on stem diameter, plant height, root length and shoot dry weight of maize grown in fungus infested soil

| Treatment                      | Stem diameter (mm) | Plant height (cm) | Root length (cm) | Shoot dry Weight (g pt⁻¹) |
|--------------------------------|--------------------|-------------------|------------------|---------------------------|
| Control                        | 8.40 i             | 131.2 hi          | 65.00f           | 41.50 ef                  |
| Mb4                             | 9.30 h             | 137.7 efg         | 69.00def         | 44.44 de                  |
| Mb7                             | 9.50 gh            | 135.9 gh          | 70.33def         | 44.17de                   |
| Cb4                             | 9.70 fg            | 136.7 fg          | 67.00 ef         | 45.51de                   |
| Cb9                             | 9.90 f             | 137.4 fg          | 70.67 de         | 45.61de                   |
| Mb4+Cb4                         | 10.47 d            | 140.0 defg        | 71.34cde         | 47.45cd                   |
| Mb4+Cb9                         | 10.50 d            | 142.5 cde         | 73.67 bcd        | 48.70 bcd                 |
| Mb7+Cb4                         | 10.30 de           | 137.3 fg          | 73.65bcd         | 48.23 bcd                 |
| Mb7+Cb9                         | 9.93 ef            | 140.7 def         | 76.67bc          | 49.00 bcd                 |
| Mb4+Cb4+Cb9                     | 11.70 bc           | 143.7 cd          | 77.67b           | 52.32 ab                  |
| Mb7+Cb4+Cb9                     | 12.40 b            | 147.4 abc         | 86.65a           | 54.74 a                   |
| Cb4+Mb4+Mb7                     | 12.50 b            | 145.7 bc          | 85.33 a          | 54.80 a                   |
| Cb9+Mb4+Mb7                     | 12.27 b            | 150.7 a           | 83.55 a          | 54.83 a                   |
| Consortium of all the four strains | 13.30 a           | 149.4ab           | 87.00 a          | 55.55a                    |
| LSD                             | 0.3964             | 4.8463            | 5.6166           | 5.2626                    |

Means sharing the same letter are not significantly different from each other (data is the mean of three repeats)

Mb4= *Bacillus megaterium*, Mb7= *Pseudomonas aeruginosa*, Cb4= *Serratia* spp., Cb9= *Pseudomonas fluorescens*
higher leaf surface area than un-inoculated control (242.18 cm²). Inter-nodal distance, stem diameter and plant height was higher by inoculated treatments, however effect of single inoculation was less than the consortium of two and three strains while maximum increase was observed with consortium of all the four strains.

Root length is related to healthy growth of the plant because it anchors the plant and enables it to uptake required amount of water and nutrients. Root length was increased by inoculation with bacterial consortia compared to un-inoculated control. Longest root was observed by inoculation with consortium of all the four strains (87 cm), medium length was with consortium of Mb7 with Cb4 and Cb9 and smaller with single inoculation however all the inoculated treatments showed longer root than control (65 cm). Shoot dry weight was also higher by inoculation with bacterial consortium of all the four strains (55.55 g plant⁻¹) which was statistically at par with consortium of Cb9 with Mb4 and Mb7 and significantly better than single strain inoculation.

**Effect of bacterial consortia on yield parameters of maize**

Cob weight was affected by inoculation with bacterial consortia. Fresh cob weight was higher by inoculation with consortium of four strains (107.45 g cob⁻¹) which were statistically at par with consortium of Cb4 and Cb9 with Mb4 and Mb7 showing 52.69, 49.4 and 47.98% increase respectively over control. Eminent increase in cob weight was also observed by inoculation with consortium of two and three strains which were significantly higher than single treatments. Consortium of all the four strains showed 40.87% increase in cob weight followed by consortium of Cb9 with Mb4 and Mb7 which showed 39.78% increase over control. Percent increase in dry cob weight ranged from 39.78% by consortium of triple strains to 28.29% by consortium of two strains while single strain inoculation showed increase up to 22.06% (Cb9). Highest cob length was observed with consortium of four which showed 51.42% increase over control. Cob length ranged from 15 to 17.33 cm by consortium of three strains while cob length with consortium of two strains ranged from 13.34 to 14.67 cm and was significantly higher than control (12.33 cm).

Grain yield is the ultimate capitulate and of actual interest. Grain yield was higher by all the inoculated treatments than control. Significantly higher grain yield 55.77 g cob⁻¹ was perceived by inoculation with consortium of all the four strains which showed 55.34% increase in grain yield while 37.27% increase in thousand grain weight over control. Other prominent values for thousand grain weight were 156, 153.5, and 153.34 g, with consortium of different combination of three strains which was significantly higher than control (120.44 g).

**Effect of bacterial consortia on NPK contents of grain and straw of maize**

Inoculation positively affected the chemical composition of maize, grown in fungus infested soil. Percent nitrogen in grain (2.675%), percent nitrogen of straw (0.997%), phosphorus percentage in grain and straw.

### Table 4: Effect of consortium of bacterial strains on yield parameters of maize

| Treatment       | Fresh cob yield (g cob⁻¹) | Air dried cob yield (g cob⁻¹) | Cob length (cm) | Grain yield (g cob⁻¹) | 1000 Grain weight (g) |
|-----------------|---------------------------|-------------------------------|----------------|----------------------|----------------------|
| Control         | 70.37 i                   | 45.60 h                       | 12.33b         | 35.90f               | 120.44g              |
| Mb4             | 91.5 fg                   | 53.45 fg                      | 14.33ab        | 40.43ef              | 132.1de              |
| Mb7             | 89.76fg                  | 54.53efg                      | 13.45b         | 42.33def             | 126.45ef             |
| Cb4             | 81.00 h                   | 50.31gh                       | 13.33b         | 42.01def             | 126.6ef              |
| Cb9             | 90.98 fg                  | 55.66 d-g                     | 13.77ab        | 40.37ef              | 126.33ef             |
| Mb4 +Cb4        | 97.77cde                 | 58.50 b-f                     | 14.44ab        | 45.43cde             | 135.23d              |
| Mb4 +Cb9        | 97.98 cde                 | 58.99 a-e                     | 14.51b         | 44.55def             | 132.34d              |
| Mb7 + Cb4       | 94.79 ef                  | 57.55 c-f                     | 14.67b         | 44.14def             | 141.1c               |
| Mb7 + Cb9       | 97.28 de                  | 55.34 d-g                     | 13.34b         | 47.31 bcd            | 137.0 cd              |
| Mb4 +Cb4 + Cb9  | 100.44 bcd                | 60.54a-d                      | 15.00 ab       | 52.44 ab             | 150.7 b               |
| Mb7 +Cb4 + Cb9  | 102.85abc                | 62.64abc                      | 17.33ab        | 50.05bc              | 156.0 b               |
| Cb4 + Mb4 +Mb7  | 105.13ab                 | 62.54abc                      | 16.54ab        | 50.44 bc             | 153.34 b              |
| Cb9 + MB4 +Mb7  | 104.14 ab                 | 63.74 ab                      | 16.67ab        | 51.41 ab             | 153.5 b               |
| Consortium of all the four strains | 107.45a | 64.24 a | 18.67a | 55.77a | 165.34a |
| LSD             | 5.2163                    | 5.4738                        | 5.1064         | 5.3289               | 5.5473               |

Means sharing the same letter are not significantly different from each other (data is the mean of three repeats).

Mb4 = *Bacillus megaterium*, Mb7 = *Pseudomonas aeruginosa*, Cb4 = *Serratia* spp., Cb9 = *Pseudomonas fluorescens*
(1.411 and 0.793% respectively) and maximum potassium in grain (1.756%) and straw (1.064%) (Table 6) was recorded with the treatments, inoculated with consortium of all the four strains (Mb4, Mb7, Cb4 and Cb9). Medium concentration of N, P and K was observed in treatments, inoculated with consortium of three and lower with single inoculation. All the inoculated treatments showed higher phosphorus and potassium by grain and straw of maize was also higher in treatments, inoculated with consortium of four strains of bacteria (Table 5).

### Discussion

Seedling blight suppresses the growth by blocking the vascular tissues of the plant. Plant growth promoting percentage of NPK than control. Uptake of nitrogen, rhizobacteria and CIB compete with pathogen to colonize

### Table 5: Effect of consortium of bacterial strains on chemical composition of grain and straw of maize

| Treatment          | % N in grains | % P in grain | % K in grain | % N in straw | % P in straw | % K in straw |
|--------------------|---------------|--------------|--------------|--------------|--------------|--------------|
| Control            | 1.69 j        | 0.677 k      | 0.937 k      | 0.483 m      | 1.27 l       | 0.822 m      |
| Mb4                | 1.945 g       | 0.753 i      | 1.079 i      | 0.607 j      | 1.497 j      | 0.932 k      |
| Mb7                | 1.92 h        | 0.747 j      | 1.117 h      | 0.553 l      | 1.43 k       | 0.933 k      |
| Cb4                | 1.877 i       | 0.767 h      | 1.067 j      | 0.58 k       | 1.44 jk      | 0.893 l      |
| Cb9                | 1.897 i       | 0.753 i      | 1.127 gh     | 0.62 i       | 1.51 i       | 0.95 j       |
| Mb4 + Cb4          | 1.997 f       | 0.797 f      | 1.203 e      | 0.673 f      | 1.63 e       | 1.007 h      |
| Mb4 + Cb9          | 2.017 f       | 0.776 g      | 1.177 f      | 0.654 h      | 1.532 h      | 0.96 i       |
| Mb7 + Cb4          | 2.11 d        | 0.77 h       | 1.134 g      | 0.667 h      | 1.563 g      | 1.017 g      |
| Mb7 + Cb9          | 2.08 e        | 0.827 e      | 1.239 d      | 0.667 g      | 1.607 f      | 1.027 f      |
| Mb4 + Cb4 + Mb9    | 2.12 cd       | 0.843 d      | 1.297 c      | 0.788 b      | 1.67 d       | 1.059 b      |
| Mb7 + Cb4 + Cb9    | 2.565 b       | 0.987 b      | 1.354 b      | 0.777 c      | 1.734 b      | 1.034 e      |
| Cb4 + Mb4 + Mb7    | 2.170 d       | 0.847 d      | 1.23 d       | 0.766 d      | 1.673 d      | 1.043 d      |
| Cb9 + Mb4 + Mb7    | 2.675 a       | 0.997 a      | 1.411a       | 0.793 a      | 1.756 a      | 1.064 a      |
| LSD                | 0.0204        | 4.856E 03    | 0.0141       | 4.580E 03    | 0.014        | 3.948 E03    |

Means sharing the same letter are not significantly different from each other (data is the mean of three repeats)

Mb4 = *Bacillus megaterium*, Mb7 = *Pseudomonas aeruginosa*, Cb4 = *Serratia* spp., Cb9 = *Pseudomonas fluorescens*

### Table 6: Effect of consortium of bacterial strains on uptake of NPK by grains and straw of maize grown in pots

| Treatment          | N uptake grain (mg pot$^{-1}$) | N uptake straw (mg pot$^{-1}$) | P uptake grain (mg pot$^{-1}$) | P uptake straw (mg pot$^{-1}$) | K uptake grain (mg pot$^{-1}$) | K uptake straw (mg pot$^{-1}$) |
|--------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Control            | 606.71                        | 280.955                       | 336.383                       | 200.445                       | 455.93                        | 341.13                        |
| Mb4                | 786.365                       | 334.6332                      | 443.5171                      | 269.7508                      | 586.11371                     | 414.1808                      |
| Mb7                | 812.736                       | 329.9949                      | 472.8261                      | 244.2601                      | 605.319                       | 412.1061                      |
| Cb4                | 792.7287                      | 349.0617                      | 448.2467                      | 263.958                       | 604.944                       | 406.4043                      |
| Cb9                | 765.8189                      | 343.4433                      | 454.9699                      | 282.782                      | 609.587                       | 435.5755                      |
| Mb4+Cb4            | 907.2371                      | 378.1765                      | 546.5229                      | 319.3385                      | 740.509                       | 477.8215                      |
| Mb4+Cb9            | 894.1185                      | 377.912                       | 524.3535                      | 318.498                       | 682.506                       | 467.52                        |
| Mb7+Cb4            | 931.354                       | 371.371                       | 500.5476                      | 331.3401                      | 689.9082                      | 490.4991                      |
| Mb7+Cb9            | 984.048                       | 405.23                        | 586.1709                      | 326.83                        | 760.2717                      | 503.23                        |
| Mb4+Cb4+Cb9        | 1111.728                      | 448.6446                      | 680.1468                      | 419.3736                      | 875.748                       | 563.5998                      |
| Mb7+Cb4+Cb9        | 1283.783                      | 540.2838                      | 677.677                       | 425.3298                      | 867.867                       | 566.0116                      |
| Cb4+Mb4+Mb7        | 1062.771                      | 464.156                       | 620.412                       | 419.768                       | 843.8612                      | 571.564                       |
| Cb9+Mb4+Mb7        | 1103.773                      | 480.8591                      | 661.6467                      | 420.5461                      | 884.252                       | 577.9082                      |
| Consortium of all the four strains | 1491.848 | 553.8335 | 786.9147 | 440.5115 | 979.3212 | 591.052 |

Mb4 = *Bacillus megaterium*, Mb7 = *Pseudomonas aeruginosa*, Cb4 = *Serratia* spp., Cb9 = *Pseudomonas fluorescens*
the root, thus restrain the pathogen and help plant to grow successfully in fungus infested soil. Fungal pathogen stunted the growth and sometime fully destroyed the developmental activities of plant. Inoculation with selected strains of PGPR and CIB help plant to grow, survive and positively influence the ultimate yield of maize in infested soil. Healthy growth of the crop is responsible for better yield. Biotic stress stunted the growth which leads to the poor yield of the crop.

Under biotic stress, different mechanisms were adopted by bacteria to promote growth of the plant. They provide relief to the plant by improving nutrition (Peralta et al., 2013), producing requisite hormone to suppress the pathogens (Saharan and Nehra, 2011) and by releasing siderophore (Arruda et al., 2013). Siderophore production by bacteria is very important with respect to pathogen control. It chelates the micronutrients, necessary for growth and pathogenicity of the pathogens and creates famine of these nutrients for pathogens to kill them. It was also endorsed by other scientists who observed that siderophore producers support the plant against disease attack (Wani et al., 2007) and enable to bear biotic and abiotic stress (Usha et al., 2011).

Another way to control pathogen is the ability to produce antifungal enzymes. Therefore chitinase producing bacterial strains have better antifungal activities. Our selected strains were good chitinase producers and it was observed that better chitinase and siderophore producing strains helped plants to survive and produced higher biomass in fungus infested soil. These strains antagonized the pathogens up to 86% which was due to production of antifungal metabolites. It was observed previously that PGPR act as defensive mediators against soil-borne plant pathogens (Lowe et al., 2012) due to the production of antifungal enzymes (Laslo et al., 2012). Compost inhabiting bacteria, particularly fluorescent pseudomonads and certain Bacillus spp effectively controlled the root diseases (fungal and bacterial) of agricultural crops (Ahmadzadeh et al., 2004).

In fungus infested soil, consortium of bacterial strains helps plant to function normally by contending the pathogen. They compete with pathogen for food and space by root colonization and by producing various antibiotic compounds. They have multiple functions in the rhizosphere and approaching towards plant growth promotion. Suppression of pathogen through competition for food and space enables the bacteria to support the better growth and yield of the crop in fungus infested soil. Root colonization is important criteria to suppress the pathogen and biofilm is the measure of root colonizing ability of microbes. It is the biological response to compete for root niches and nutrients and inducing systemic resistance in host plants (Haas and Défago, 2005). In the current study, selected bacterial strains showed higher values for biofilm formation. Biofilm formation is important for plant microbe interaction to control the pathogen (Timmusk, 2005). It is a bio barrier on the roots against pathogens (Morikawa et al., 2006). Root length significantly increased by inoculation with consortium of beneficial bacteria. Our study exhibited that seed inoculation with consortia resulted in developed and improved root architecture due to which uptake of nutrients (N, P, and K) is enhanced. The increased uptake of nitrogen, phosphorus and potassium was due to solubilization of nutrients (Ranjan et al., 2013), production of siderophore (Sayyed et al., 2010) and well developed root system (Karnwal, 2009) due to inoculation with consortium of bacteria strains (Figueiredo et al., 2010).

Results also showed the increase in root and shoot biomass by inoculation with bacterial consortia. PGPR has the capability to promote plant growth and productivity through synthesizing phytohormone, increasing the nutrient availability, antagonizing phytopathogens and decreasing metal toxicity (Burd et al., 2000). The improving effect of seed inoculation with bacterial consortia on shoot dry weight and yield of maize was reported by Shahraroona et al. (2006). Such an enhancement might be due to the ability of bacteria to fix nitrogen, solubilize the phosphate and production of growth regulators (Salantur et al., 2006). Consortium inoculation increased the leaf area responsible for efficient photosynthesis and finally the yield of the crop. It is due to well-developed root system, efficient root colonization and resultantly the uptake of water for photosynthesis. Elkoca et al. (2008) determined that dry matter, grain yield and phosphorus uptake was significantly higher by co-inoculation than single inoculated treatments in legumes. Other scientists also observed the increase in plant height and leaf area by inoculation with bacterial consortia (Govindappa et al., 2011). Increased growth was also observed in wheat (Salantur et al., 2006), tomato (Gravel et al., 2007), chickpea (Verma et al., 2010), fodder galega (Egamberdieva et al., 2010) and maize (Paçôme et al., 2013) due to co-inoculation. Under diseased condition it may be due to the production of siderophore, antifungal compounds, auxin biosynthesis and efficient root colonization. Biocontrol strategy depends on the nutrient management, better root colonization (biofilm formation) and production of siderophore and chitinase. Present study exhibited that selected strains of bacteria (Mb4, Mb7, Cb4 and Cb9) possessed these characteristics, therefore had suppressive effect on the pathogen which cause seedling blight in maize. Their combined activity showed higher efficiency for growth promotion in fungus infested soil than...
the single inoculation but consortium of all the four strains showed the best in results this contest.

**Conclusion**

Beneficial bacterial population played important role in growth and yield promotion through different mechanisms. They suppressed the pathogen through competition for food and space on root, production of antifungal metabolites and by inducing systemic resistance in plant. They promoted growth through solubilizing the nutrients and making it available to plant. However their efficiency may vary under different conditions. The selected bacterial strains suppressed the pathogen because they were screened against the *Fusarium oxysporum* which caused seedling blight in maize and their efficiency may vary with change in causal organism or disease. Their effectiveness in other crops may also be different. To avoid the harmful effect of pesticide the bacterial consortia may be extended in other crops under stressful condition. The selected strains may be tested under abiotic stresses because the characteristics described above, enabled them to promote growth under stressful condition. Nevertheless the given consortium of bacterial strains can effectively be used to increase the growth of maize in *Fusarium* infested soil.

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