Introduction

Biofilms are the common life strategy for bacteria in natural environments. Biofilms are composed of populations or communities of microorganisms embedded in self-produced polymeric matrix (mainly extracellular polysaccharides) that have adhered to environmental surfaces in which sufficient moisture is present (Costerton et al., 1995). These three-dimensional microbial communities may be formed in all environments colonized by bacteria, such as on solid substrates in contact with moisture or on tissue surfaces in living organisms. The mutualistic association between microbial communities and plant roots, the so-called rhizosphere, form an environment that fulfills the requisites for biofilm formation: sufficient moisture and a supply of nutrients, which are provided by the plant. Most researchers working with rhizospheric bacteria have not described the formation of biofilms on plant roots. In the past, however, different reports
have indicated that rhizospheric bacteria (such as Rhizobium, Azospirillum and Pseudomonas) associated with root surfaces are embedded in the root mucigel and might also be encased in a self-produced extracellular matrix.

Transmission electron microscopy has shown the presence of fibrillar material around rhizobia attached to the root surface (Fujishige et al., 2006). These observations further support the proposal that root colonizing bacteria are capable of forming biofilms, it is reasonable to suppose that the molecular mechanisms operating in bacterial attachment to roots also might be relevant for biofilm development. The dynamic processes that characterize relationships between plants and microbial communities are complex. Soil microorganisms have an important influence on soil fertility and plant growth (Andrade et al., 1997; Miransari, 2011). A recent study showed that biofilm formation of rhizobia with common soil fungi is a plausible strategy for the survival (Seneviratne and Jayasinghearachchi, 2003). These biofilms can be used to successfully introduce bacterial inoculants into soil because they can protect the inoculants against adverse environmental conditions and the competition by native soil populations.

This study on zinc solubilization by bacteria has an immense importance in zinc nutrition to plants in the world. The rhizospheric microorganisms play a pivotal role in the enhancement of crop production by the solubilization of unavailable form of metal into available form. This metal solubilization was due to the production of organic acids and pH drop by organisms.

For optimal nutrition of a crop, the replenishment of a K depleted soil solution is affected predominantly by the release of exchangeable K from clay minerals. Consequently, for maximal crop growth, soil solution and exchangeable K need to be replenished continually with K through the release of non-exchangeable K through the weathering of K reserves (i.e. micas and feldspars) (Sparks and Huang, 1985) or the addition of K fertilizers. Many microorganisms in the soil are able to solubilize ‘unavailable’ forms of K-bearing minerals, such as micas, illite and orthoclases, by excreting organic acids which either directly dissolve rock K or chelate silicon ions to bring the K into solution (Groudev, 1987; Friedrich et al., 1991; Ullman et al., 1996; Bennett et al., 1998). Biofilm formation of this zinc solubilizers and potassium releasers has an immense importance in agriculture.

Materials and Methods

Soil sampling

In order to isolate ZnSB, KSB a total of fifteen rhizospheric soil samples were collected at a depth of 10-30 cm, from different sites near Rajendranagar, Hyderabad, Telangana, India. From each site, three subsamples were collected from adjacent plants and well mixed to form a composite sample. All tools used in soil sampling were surface disinfected using 70% ethanol and soils were placed in sterile sample bags, stored at 4 °C and processed within a week. Each sample was homogenized in sterile saline (0.85 % NaCl, w/v), serially diluted and used.

Screening of isolates for zinc solubilizing and potassium releasing ability

The isolates were inoculated into modified TRIS medium (ingredients g L⁻¹), (Glucose-10.0 g; Zinc phosphate- 1 g; Ammonium sulphate- 0.5 g; Potassium chloride- 0.2 g; Yeast extract- 0.5 g; Ferrous sulphate- 0.01 g; Manganese sulphate- 0.01 g; Di-potassium
hydrogen phosphate- 0.25 g; Agar- 20 g and Double distilled water- 1000 ml) containing 0.1 % insoluble zinc compound (ZnPO₄). The test organisms were inoculated on these media and incubated at 28 ± 2 °C for 48-72 h. Subsequently, isolates were inoculated on the modified Alexondrov’s medium (Glucose- 5 g; Magnesium sulphate- 0.5 g; Ferric chloride- 0.005 g; Calcium carbonate- 0.1 g; Tri-calcium phosphate- 2 g; Potassium alumino silicate- 2 g; Double distilled water-1000 ml) containing 0.2 % potassium alumino silicate as a potassium source.

The test organisms were inoculated on the media and incubated at 28 ± 2 °C for 48-72 h. The diameter of the colony and clearing zones around the colonies were measured.

To standardize the procedures for biofilm formation of efficient Zinc (Zn) solubilizing and Potassium (K) releasing bacteria and fungi

Biofilm formation involves in the selection of efficient zinc solubilizers and potassium releasers based on qualitative data along with fungal partner to use as a substrate. For this initially compatibility between the pure isolates of fungi and bacterial isolates checked on the common media (TRIS-minimal medium). After that the pure isolates of fungi and bacterial isolates were inoculated aseptically in the common 500 ml broth which contains both insoluble zinc and potassium sources.

The broth was then kept in the incubator at 28 ± 2 °C for 15 days without disturbing it along with control. In between after 7 days of inoculation pH of the broth and counts of both bacterial and fungal spores were taken, fluctuation (acidic) in the pH was corrected with addition of a pinch of CaCO₃ to the medium.

Microscopic observation of biofilms

**Compound microscope**

The biofilms were observed for every 2 days interval by visual and microscopical observations at 100X magnification. After harvesting, the biofilm was washed with sterile water to remove the non adherent cells on biofilm. A loopful of biofilm was spread on the slide, air dried and heat fixed. Two drops of Lactophenol cotton blue stain was added and after 1 min washed and then safranine was added. After 1 min, the slide was washed and covered with cover slip and observed under microscope at 10, 40 and 100X objectives (oil immersion). Microscopical pictures were taken.

**In vitro screening of biofilms**

Initially all the individual isolates were screened biochemically characterized thereafter finally biofilms were confirmed by using same biochemical tests. Biochemical tests like starch hydrolysis, IMVIC tests, catalase and oxidase were used for screening (Table 1).

**Results and Discussion**

**Zinc solubilizing capacity**

The isolates evaluated for their efficiency of zinc solubilization on TRIS minimal medium. Results revealed that the isolate ZnSF-4 has showed the maximum solubilization zone of 54 mm and least solubilization zone observed in ZnSB-8 (7 mm). No solubilization was observed in KSB-2, KSB-3 and KSF-1. The solubilization efficiency ranges from a maximum of 315 % to a minimum of 10 %. The maximum solubilization efficiency was observed with ZnSF-4 having 315 % whereas minimum solubilization efficiency was found in ZnSF-3 (10 %). So far, only bacterial
species belong with species of *Bacillus* spp and *Pseudomonas* spp were reported to be zinc solubilizer as they form a clear halo zone (Simine et al., 1998 and Saravanan et al., 2003) (Table 3).

**Potassium releasing capacity**

All isolates were screened for their potassium releasing ability. The isolated potassium releasing bacteria and fungi had showed solubilization zone ranging from a maximum of 58 to a minimum of 8 mm. The isolate KSF-2 had shown the maximum solubilization zone of 58 mm followed by KSF-1 (43 mm), KSB-1 (12 mm), KSB-4 (12 mm), KSB-3 (11 mm), KSB-5 (10 mm) and least solubilization zone was observed in ZnSB-7 (5 mm). The maximum solubilization efficiency was showed by KSB-1 with the efficiency of 150 % followed by KSB-4 (140 %), KSB-3 (120 %), KSB-1 (100 %), KSB-2 (60 %), KSF-1 (34 %) and with minimum solubilization efficiency in KSF-2 (28 %). The solubilization process of minerals may be due to the production of various organic acids such as acetic, formic, gluconic, oxalic and succinic acids Lal (2002). Adeleke et al., (2010) have reported the ability of ectomycorrhizal fungi in mobilization of P and K sources from insoluble ore. Greater release of K from muscovite has been recorded in *B. mucilaginosus* (Sugumaran and Janarthanam, 2007) (Table 4).

**Biofilm formation of efficient zinc solubilizing and potassium releasing bacteria and fungi**

**Compatibility of bacteria with fungi for biofilms formation**

Compatibility deals with the degrees of intimacy that are exhibited between the two partners (Bacteria and Fungi) in terms of their different physical associations. The physical association between them was highly specific symbiotic associations of fungal hyphae and bacterial cells. This colonization in biofilms differs from consortium or dual cultures.

Observation of the effects of fungi on bacterial development is clear that fungi can promote distinct differences in bacterial development by contributing to a distinctive ecological niche, within which bacteria exhibit physiological differences, such as resistance to antibiotics, stress, etc, the observations were clear that the compatibility between the bacteria and fungi was very high in *in vitro* conditions of biofilms (Table 2).

Wide range of microorganisms found considerable variation in their ability to form a biofilm. The bacterial and fungal organisms synergistically associated and play key role in persistence and show good compatibility. These bacterial-fungal interactions often result in changes to the nutritional influence of one or both partners towards plants. They can also result in unique contributions to biogeochemical cycles and biotechnological processes. Microorganisms occupying such structures typically showed enhanced resistance and record best results towards plants when inoculated.

Among all isolates the most compatible combinations found to be ZnSF-2 with ZnSB-2; ZnSF-4 with ZnSB-8; KSF-2 with ZnSB-2, moderately compatible combinations are ZnSF-2 with ZnSB-8, ZnSB-10 and KSB-4; ZnSF-4 with ZnSB-2; KSF-2 with ZnSB-8 and weakly compatible combinations were ZnSF-2 with ZnSB-9 and KSB-2; ZnSF-4 withZnSB-6, KSB-2 and KSB-4; KSF-2 with ZnSB-3, ZnSB-6, ZnSB-10, KSB-2 and KSB-3.

The best combinations ZnSF-2 with ZnSB-2 and ZnSB-2 with KSF-2 is selected for biofilm formation based on their solubilization as well as compatibility data.
**In vitro development of biofilms**

Microorganisms are capable of growing in both a freely (planktonic) or as biofilms attached to solid surfaces. Biofilms in distinct settings form different structures comprising different microbial consortia dictated by biological and environmental parameters. The conditions were provided for in vitro development of biofilms for 15 days in TRIS minimal broth with the best screened isolates (ZnSF-4 + ZnSB-2 and ZnSB-2 + KSF-2). Successfully the biofilm mats were developed with different microbial consortium (Patel et al., 2013).

Salma et al., (2015) reported the best PSB strongly attached to the hyphae of Ri-26 isolates belonged to *Burkholderia spp.* and one was identified as *Rhizobium miluonense.* Triveni et al., (2015) reported that *Trichoderma* based biofilms with *Azatobacter chroococcum*, *P. fluorescens* and *B. subtilis.* While *A. torulosa* biofilms were prepared by using *B. subtilis* and *Trichoderma.* Heleen et al., (2014) discussed the three mechanisms that play an important role in biofilm survival. The process of cellular chaining, the biomass stickiness also strongly hinders the reorganization of cells within the biofilm. Radha et al., (2014) reported that the *Anabaena -T. viride* biofilmed formulations proved to be the most promising for Soybean, recording 12–25 % enhanced yield and microbial activity.

| S. No | Isolates | Indole production | Oxidase test | Catalase test | Starch hydrolysis | MR test | VP test | Citrate utilization | Gelatin liquefaction |
|-------|----------|------------------|--------------|---------------|-------------------|--------|--------|-------------------|---------------------|
| 1     | ZnSB-1   | +                | +            | +             | -                 | -      | +      | -                 | +                   |
| 2     | ZnSB-2   | -                | +            | +             | -                 | -      | +      | +                 | +                   |
| 3     | ZnSB-3   | -                | +            | +             | -                 | -      | +      | +                 | -                   |
| 4     | ZnSB-4   | -                | +            | +             | -                 | -      | +      | +                 | +                   |
| 5     | ZnSB-5   | +                | +            | -             | -                 | +      | +      | +                 | +                   |
| 6     | ZnSB-6   | -                | +            | +             | +                 | -      | +      | +                 | +                   |
| 7     | ZnSB-7   | +                | +            | +             | -                 | -      | +      | -                 | -                   |
| 8     | ZnSB-8   | -                | +            | +             | -                 | -      | +      | +                 | +                   |
| 9     | ZnSB-9   | -                | +            | +             | -                 | -      | +      | -                 | +                   |
| 10    | ZnSB-10  | -                | +            | +             | -                 | +      | -      | +                 | +                   |
| 11    | ZnSF-1   | -                | +            | +             | -                 | -      | +      | +                 | +                   |
| 12    | ZnSF-2   | -                | +            | +             | -                 | -      | +      | +                 | -                   |
| 13    | ZnSF-3   | -                | +            | +             | +                 | -      | +      | +                 | +                   |
| 14    | ZnSF-4   | -                | +            | +             | -                 | -      | +      | +                 | +                   |
| 15    | ZnSF-5   | -                | +            | +             | +                 | -      | -      | +                 | +                   |
| 16    | KSB-1    | -                | +            | +             | +                 | -      | +      | -                 | +                   |
| 17    | KSB-2    | -                | +            | +             | -                 | +      | +      | -                 | +                   |
| 18    | KSB-3    | +                | +            | +             | -                 | -      | -      | +                 | -                   |
| 19    | KSB-4    | -                | +            | +             | +                 | -      | +      | +                 | -                   |
| 20    | KSB-5    | -                | +            | +             | -                 | -      | -      | +                 | +                   |
| 21    | KSF-1    | -                | +            | +             | -                 | -      | -      | +                 | +                   |
| 22    | KSF-2    | -                | +            | +             | -                 | -      | +      | -                 | -                   |

**Table.1** Biochemical characters of all Zinc solubilizing and Potassium releasing isolates
Table 2 Compatibility study of Zinc solubilizing bacteria and Potassium releasing bacteria for biofilm preparation

| S.No | Bacterial isolates | Zinc solubilizing fungal isolates | Potassium releasing fungal isolates |
|------|--------------------|----------------------------------|------------------------------------|
|      |                    | ZnSF-1  | ZnSF-2  | ZnSF-3  | ZnSF-4  | ZnSF-5  | KSF-1  | KSF-2  |
| 1.   | ZnSB-1             | -       | -       | -       | -       | -       | -       | -       |
| 2.   | ZnSB-2             | -       | +++     | -       | ++      | -       | -       | +++     |
| 3.   | ZnSB-3             | -       | -       | -       | -       | -       | -       | +       |
| 4.   | ZnSB-4             | -       | -       | -       | -       | -       | -       | -       |
| 5.   | ZnSB-5             | -       | -       | -       | -       | -       | -       | -       |
| 6.   | ZnSB-6             | -       | -       | +       | -       | -       | -       | +       |
| 7.   | ZnSB-7             | -       | -       | -       | -       | -       | -       | -       |
| 8.   | ZnSB-8             | -       | ++      | -       | +++     | -       | -       | ++      |
| 9.   | ZnSB-9             | -       | +       | -       | -       | -       | -       | -       |
| 10.  | ZnSB-10            | -       | ++      | -       | -       | -       | -       | +       |
| 11.  | KSB-1              | -       | -       | -       | -       | -       | -       | -       |
| 12.  | KSB-2              | -       | +       | -       | +       | -       | -       | +       |
| 13.  | KSB-3              | -       | -       | -       | -       | -       | -       | -       |
| 14.  | KSB-4              | -       | ++      | -       | +       | -       | -       | +       |
| 15.  | KSB-5              | -       | -       | -       | -       | -       | -       | -       |

+ Weakly Compatible  ++ Moderately Compatible  +++ Highly Compatible  - Not Compatible
**Table 3** Zinc solubilization by isolates

| Isolates | Solubilization zone (mm) | Solubilization efficiency (%) |
|----------|--------------------------|-------------------------------|
| ZnSB-1   | 0                        | 0                             |
| ZnSB-2   | 0                        | 0                             |
| ZnSB-3   | 0                        | 0                             |
| ZnSB-4   | 0                        | 0                             |
| ZnSB-5   | 0                        | 0                             |
| ZnSB-6   | 6                        | 50                            |
| ZnSB-7   | 5                        | 66                            |
| ZnSB-8   | 6                        | 100                           |
| ZnSB-9   | 0                        | 0                             |
| ZnSB-10  | 0                        | 0                             |
| ZnSF-1   | 0                        | 0                             |
| ZnSF-2   | 0                        | 0                             |
| ZnSF-3   | 0                        | 0                             |
| ZnSF-4   | 0                        | 0                             |
| ZnSF-5   | 0                        | 0                             |
| KSB-1    | 12                       | 100                           |
| KSB-2    | 8                        | 60                            |
| KSB-3    | 11                       | 120                           |
| KSB-4    | 12                       | 140                           |
| KSB-5    | 10                       | 150                           |
| KSF-1    | 43                       | 34.3                          |
| KSF-2    | 58                       | 28.8                          |
Table 4 Potassium released by the isolates

| Isolates | Solubilization zone (mm) | Solubilization efficiency (%) |
|----------|--------------------------|------------------------------|
| ZnSB-1   | 10                       | 42                           |
| ZnSB-2   | 9                        | 50                           |
| ZnSB-3   | 9                        | 28                           |
| ZnSB-4   | 12                       | 33                           |
| ZnSB-5   | 15                       | 25                           |
| ZnSB-6   | 11                       | 37.5                         |
| ZnSB-7   | 8                        | 33.3                         |
| ZnSB-8   | 7                        | 16                           |
| ZnSB-9   | 15                       | 50                           |
| ZnSB-10  | 13                       | 62.5                         |
| ZnSF-1   | 36                       | 63                           |
| ZnSF-2   | 30                       | 66.6                         |
| ZnSF-3   | 21                       | 10.5                         |
| ZnSF-4   | 54                       | 315                          |
| ZnSF-5   | 42                       | 162                          |
| KSB-1    | 12                       | 300                          |
| KSB-2    | 0                        | 0                            |
| KSB-3    | 0                        | 0                            |
| KSB-4    | 9                        | 125                          |
| KSB-5    | 9                        | 28                           |
| KSF-1    | 0                        | 0                            |
| KSF-2    | 43                       | 138.8                        |

Attempts were made by Nissi et al., (2014) to improve the crop production and disease control in chickpea. Isolated 15 bacterial cultures and characterized developed biofilms in vitro. Four biofilms and 4 coinoculations were used as biofertilizers in chickpea crop. The results revealed that T_8 (T. viride + R. leguminosarum + P. fluorescence + B. subtilis (Biofilm)) showed best results in all aspects like protein content, PGP activity, yield and yield attributes etc., followed by T_2 (Trichoderma viride + Rhizobium leguminosarum- Biofilm). Karivaradharajan et al., (2013) reported Anabaenae-Pseudomonas biofilm showed highest P uptake, illustrating the interrelationships of nitrogen fixation with increased P uptake by plant. Triveni et al., (2013) highlighted that compost and vermiculite (1:1) was a suitable carrier for the novel biofilm biofertilizers. Triveni et al., (2012) recorded Trichoderma - Azatobacte r biofilm was recorded the highest nitrogenase activity.
and ACC deaminase activity. Xuan et al., (2012) reported maximum concentration of soluble phosphorus (P) was determined in the mixed culture of *P. chlororaphis* and *A. pascens*. Seneviratne et al., (2011) reported the combined application significantly increased soil organic C by ca. 20 %, and reduced leaf transpiration by ca. 40 %. Prasanna et al., (2011) reported the *Allocasurina torulosa* - *A. chroococcum* and *A. torulosa* – *Mesorhizobium ciceri* biofilms were able to utilize new saccharides as compared to the individual cultures. Kokare et al., (2008) studied on biofilm importance and application. Thomas and Clay (2007) revealed on biofilm formation by plant-associated bacteria. Shrout et al., (2006) conducted investigation in associations with QS mechanism. Bronwyn et al., (2004) reviewed on surface properties of the plant tissue. Prakash et al., (2003) studied on biofilms a survival strategy of bacteria. Webb et al., (2003) reported that microbial biofilms are communities of microorganisms adhering to abiotic/ biotic surfaces and embedded in an organic matrix of biological origin which provides structure and stability to the community.

**Biochemical characterization of biofilms**

*In vitro* formed biofilms (ZnSF-4 + ZnSB-2 and ZnSB-2 + KSF-2) were confirmed for their biofilm formation by following biochemical screening. Biofilm (ZnSF-4 + ZnSB-2) was confirmed based on the positive result for Vogues Proskuers test and biofilm (ZnSB-2 + KSF-2) was confirmed based on the positive result for gelatin liquefaction. (Triveni et al., 2012)

**Screening of biofilms for zinc solubilization and potassium releasing characters**

Biofilms were screened further for their efficacy in zinc solubilization as well as potassium releasing ability in order to compare over the individual cultures. The *in vitro* formed biofilms were shown comparatively higher amount of zinc solubilization and potassium releasing ability as compared to individual cultures. Zinc solubilization was 35 % and Potassium releasing ability was found to be 23 % more than the individual cultures (when both the individual isolates taken i.e combined value is less than the biofilm value). This is indicating that biofilms has an added advantage over individual isolates. Seneviratne and Jayasinghearachchi (2005) reported that biofilms increased N and P mineralizations of the soil and showed a high nitrogenase activity even under a very high NO3 concentration in the soil, compared to its member microbes. Salma et al., (2015) trapped phosphate solubilizing bacteria (PSB) on the hyphae of the arbuscular mycorrhizal fungus (AMF) *Rhizophagus irregularis* (Ri). Results showed that increased P solubilization and P mobilization considerably than individual isolates.

In conclusion formation of biofilms has considerably increased the zinc solubilization and potassium releasing as compared to individual isolates. Biofilms also enhances the chances of survival in the soil for long time, both these factors will begin a new era for the biofertilizers production. This is clear that there is no havoc to environment too.

**Acknowledgments**

The authors would like to thank Mr. Damodarachari, Mr. G. Thirumal, Mis. K. Bhavya for continuous support during research and we would like to thank, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad, India for giving financial support in order to complete research successfully.

**References**

Adeleke, R.A., Cloete, T.E., Bertr, A. and Khasa, D.P. 2010. Mobilization of potassium and phosphorus from iron ore by ecto mycorrhizal fungi. *World J. Microbial Biotechnol.*, 26: 1901-1912.

Andrade, G., Mihara, K.L., Linderman, R.G and Bethlenfalvay, G.J. 1997. Bacteria from rhizosphere and hyphosphere soils of
different arbuscular-mycorrhizal fungi. *Plant and Soil*, 192: 71–79.

Bennett, P.C., Choi, W.J and Rogera, J.R. 1998. Microbial destruction of feldspars. *Miner. Manage.*, 8(6): 149–150.

Bronwyn, E.R., Maria, K., Susanne, B. Band Clay, F. 2004. Biofilm formation in plant–microbe associations. *Curr. Opinion in Microbiol.*, 7: 602-609.

Costerton, J.W., Lewandowski, Z., Caldwell, D.E., Korber, D.R and Lappin, S.H.M. 1995. Microbial biofilms. *Ann. Rev. Microbiol.*, 49: 711–745.

Friedrich, S., Platonova, N.P., Karavaiko, G.I., Stichel, E and Glombitza, F. 1991. Chemical and microbiological solubilization of silicates. *Acta. Biotech.*, 11: 187–196.

Fujishige, N.A., Kapadia, N.K and Hirsh, A.M. 2006. A feeling for the micro-organism: structure on a small scale. Biofilms on plant roots, *Bot. J. Linn. Soc.*, 150: 79–88.

Groudev, S.N. 1987. Use of heterotrophic microorganisms in mineral biotechnology. *Acta Biotech.*, 7: 299–306.

Heleen, V.A., Patrick, V.D and Tom, C. 2014. Molecular mechanisms of antimicrobial tolerance and resistance in bacterial and fungal biofilms. *Trends in Microbiol.*, 22(6).

Karivaradharajan, S., Radha, P., Arun, K., Sasmita, P., Kalyana, C., Yashbir, S.S., Rajendra, S and Saxena, A.K. 2013. Evaluating the influence of novel cyanobacterial biofilm ed biofertilizers on soil fertility and plant nutrition in Wheat. *European J. Soil Biol.*, 55: 107–116.

Kokare, C.R., Chakraborty, S., Khopade, A.N and Mahadik K.R. 2008. Biofilm: importance and application. *Indian J. Biotechnol.*, 8: 159-168.

Lal, R. 2002. Soil carbon sequestration in China through agricultural intensification, and restoration of degraded and desertified ecosystems. *Land Degradation and Develop.*, 13: 469-478.

Miransari, M. 2011. Interactions between arbuscular mycorrhizal fungi and soil bacteria. *Appl. Microbiol. Biotechnol.*, 89: 917-930.

Nissi, P.M., Triveni, S., Subhash, R.R. and Sridevi, D. 2014. Evaluation and screening of *Trichoderma* based biofilms against *Fusarium oxysporum* f. spp. *Ciceris*. *Progressive Res.*, 9: 887-890.

Prakash, B., Veeregowda, B. M and Krishnappa, G. 2003. Biofilms: A survival strategy of bacteria. *Curr. Sci.*, 85(9): 10.

Prasanna, R., Pattnayak, S., Sugitha, T.C.K., Nain, L. and Saxena, A.K. 2011. Development of cyanobacterium based biofilms and their in vitro evaluation for agriculturally useful traits. *Folia Microbiol.*, 56: 49–58.

Radha, P., Triveni, S., Bidyarani, N., Santosh, B., Kuldeep, Y., Anurup, A., Sangeeta, K., Madan, P., Yashbir, S.S and Anil, K.S. 2014. Evaluating the efficacy of cyanobacterial formulations and biofilm ed inoculants for leguminous crops. *Arch. Agron. Soil Sci.*, 60: 349-366.

Salma, T., Martin, T.E, Paola, M.S., Marc, S.A., Yves, P., Andre, F.J and Hani, A. 2015. Trapping of phosphate solubilizing bacteria on hyphae of the arbuscular mycorrhizal fungus *Rhizophagus irregularis*. *DAOM 197198*. *Soil Biol. Biochem.*, 90: 1-9.

Saravanan, V.S., Madhaiyan, M and Thangaraju, M. 2006. Solubilization of zinc compounds by the diazotrophic, plant growth promoting bacterium *Gluconacetobacter diazotrophicus*. *Chemosphere*, 66: 1794–1798.

Seneviratne, G., Zavahir, J.S., Bandara, W.M.M.S and Weerasekara, M.L.M.A.W. 2008. Fungal and bacterial biofilms: their development for novel biotechnological applications. *World J. Microbiol. Biotechnol.*, 24: 739-743.

Seneviratne, G. and Jayasingheearachchi, H.S. 2003. Mycelial colonization by bradyrhizobia and azorhizobia. *J. Biosci.*, 28: 243–247.

Seneviratne, G. and Jayasingheearachchi, H.S. 2005. A rhizobial biofilm with
nitrogenase activity alters nutrient availability in a soil. Soil Biology & Biochem., 37: 1975–1978.
Shrout, J.D., Chopp, D.L., Jus, C.L., Hentzer, M., Givskov, M and Parsek, M.R. 2006. The impact of quorum sensing and swarming motility on Pseudomonas aeruginosa biofilm formation is nutritionally conditional. Mol. Microbiol., 62: 1264-1277.
Simine, C.D.D., Sayer, J.A and Gadd, G.M. 1998. Solubilization of zinc phosphate by a strain of Pseudomonas fluorescens isolated from a forest. Biol. Fertility of Soils, 28: 87-94.
Sparks, D.L. and Huang, P.M. 1985. Physical chemistry of soil potassium. In: Potassium in Agriculture (ed. Munson, R.D. et al.). ASA, Madison, WI. 201–229.
Sugumaran, P. and Janarthanam, B. 2007. Solubilization of potassium containing minerals by bacteria and their effect on plant growth. World J. Agri. Sci., 3(3): 350-355.
Thomas, D. and Clay, F. 2007. Biofilm Formation by Plant-Associated Bacteria. Annual Rev. Microbiol., 61: 401-22.
Triveni, S., Prasanna, R., Arun, K., Ngangom, B., Rajendra, S and Saxena, K. 2015. Evaluating the promise of Trichoderma and Anabaena based biofilms as multifunctional agents in Macrophomina phaseli bona infected cotton crop. Biocontrol Sci. Technol., 25(6): 656-670.
Triveni, S., Ngangom, B., Kuldeep, Y., Radha, P. and Saxena, A.K. 2013. Development of formulations for Trichoderma based biofilms using different carriers. Pusa Agri. Sci., 35: 66-72.
Triveni, S., Prasanna, R., Shukla, L and Saxena, A.K. 2012. Evaluating the biochemical traits of novel Trichoderma-based biofilms for use as plant growth promoting inoculants. Annals of Microbiol., 10.
Ullman, W.J., Kirchman, D.L and Welch, S.A. 1996. Laboratory evidence for microbially mediated silicate mineral dissolution in nature. Chem. Geol., 132: 11–17.
Webb, J.S., Givskov, M and Kjelleberg, S. 2003. Bacterial biofilms: prokaryotic adventures in multicellularity. Curr. Opinion in Microbiol., 6: 578-585.
Xuan, Y., Xu, L., Tian, H.Z., Guang, H.L and Cui, M. 2012. Co-inoculation with phosphate solubilizing and nitrogen-fixing bacteria on solubilization of rock phosphate and their effect on growth promotion and nutrient uptake by walnut. European J. Soil Biol., 50: 112-117.

How to cite this article:
Nagaraju, Y., S. Triveni, R. Subhashreddy and Jhansi, P. 2017. Biofilm Formation of Zinc Solubilizing, Potassium Releasing Bacteria on the Surface of Fungi. Int.J.Curr.Microbiol.App.Sci. 6(4): 2037-2047. doi: https://doi.org/10.20546/ijcmas.2017.604.241