DOI : 10.5958/0974-0112.2017.00041.X
Indian J. Hort. 74(2), June 2017: 189-197

Effect of consortia of potassium solubilizing bacteria and fungi on growth, nutrient uptake and yield of banana

Nileema S. Gore[*] and Annasaheb M. Navale[**]
MGM's Institute of Biosciences and Technology, N-6, CIDCO, Aurangabad 431003, Maharashtra

ABSTRACT

In the present study, three potassium solubilizing bacteria (KSB) *Pseudomonas* sp. (KSB 49, 239.75 mgl^{-1}; KSB 43, 228.25 mgl^{-1} and KSB 47, 205.75 mgl^{-1}) and three potassium solubilizing fungi (KSF) *Aspergillus* sp. (KSF 3, 334.66 mgl^{-1}; KSF 13, 310.16 mgl^{-1} and KSF 31, 297.66 mgl^{-1}) were found to be efficient to release potassium from mica as compared with the commercial potassium solubilizing bacterial (CKSB) strain *Frateuria aurantia* (CKSB1, 221.25 mgl^{-1}). Based on the compatibility test, the consortia of efficient potassium solubilizers were designed separately. The liquid bio-formulation for KSB consortium and talc powder for KSF consortium was found to be effective delivery system in banana field. For their influence on growth, nutrient uptake and yield of banana under field conditions with 13 treatments including KSB and KSF consortia with the application of graded levels of K_2O (50, 75 and 100% RDF). The fungal consortium + 75% K_2O treatment showed higher potential followed by bacterial consortium + 75% K_2O treatment. The application of KSF consortium along with 75% K_2O (T_6) recorded the highest marketable number of hands per bunch, fingers per hand, bunch weight and total yield (9.22, 16.22, 28.55 kg and 126.87 t/ha, respectively). The maximum total potassium uptake of 1198.17 kg/ha was recorded by KSF consortium + 75% K_2O (T_6), which was at par with KSB consortium + 75% K_2O (T_3) (1177.21 kg/ ha). These findings clearly indicated that addition of KSF and KSB in the nutrient schedule, 25% savings of the potassium fertilizers, *i.e.*, 222.22 K_2O kg/ha was possible.

Key words: Potassium solubilization, *Pseudomonas* sp., *Aspergillus* sp., banana.

INTRODUCTION

Banana is globally fourth most important fruit crop and India is the largest producer. Potassium (K^+) plays an important role in growth and development of plant and most abundant cations in the tissues of banana often up to 3 to 4 per cent of dry weight. One tonne of banana is estimated to remove 17 to 20 kg potassium (Bhalerao, 5). Potassium is one of the major nutrients limiting plant growth and nutrient balance sheets in most of the Indian soils have been negative. In India, most of the farmers have mainly focused on the application of nitrogen (N) and phosphorus (P) for crop production. The bio-intervention of waste mica with potassium solubilizing microorganisms could be another alternative to solubilize insoluble K in mica into plant available pool and used efficiently as a source of K fertilizer for sustaining crop production and maintaining soil potassium. A wide range of bacteria, namely, *Pseudomonas*, *Burkholderia*, *Acidothiobacillus ferrooxidans*, *Bacillus mucilaginosus*, *Bacillus edaphicus*, *B. circulans* and *Paenibacillus* sp. have been reported to release potassium in accessible form from potassium bearing minerals in soils (Liu *et al.*, 22). *Aspergillus niger* (KF 1) has showed highest potassium solubilization and acid production by utilizing feldspar and potassium aluminium silicate as an insoluble source of potassium (Prajapati *et al.*, 15). In India, there is no reserve of K-bearing minerals for manufacturing of K fertilizers and the whole consumption of K fertilizers are imported, which leads to a huge amount of foreign exchange. Therefore, the application of potassium solubilizing microorganism is a promising approach for increasing K availability in soils. In the present study, efficient potassium solubilizers were subjected to release potassium from potassic mineral (mica). The three most efficient potassium solubilizing isolates of bacteria (*Pseudomonas* sp.) and fungi (*Aspergillus* sp.) were selected for development of consortium as delivery in the form of liquid /carrier bio-formulations in the banana.

MATERIALS AND METHODS

A total of 42 potassium solubilizing bacterial (KSB) and 30 potassium solubilizing fungal (KSF) isolates were isolated from rhizosphere soil samples of banana, sugarcane, cabbage, potato, guava collected from 10 districts of western and northern Maharashtra, *viz*., Pune, Kolhapur, Sangali, Satara, Solapur, Ahmednagar, Nasik, Jalgaon, Nandurbar and Dhule in the year 2014-15. All the bacteria and

*Corresponding author's E-mail: goreneel@gmail.com
**Department of Plant Pathology & Agricultural Microbiology, MPKV, Rahuri 413 722, Maharashtra

fungi were isolated on Aleksandrov's agar medium Hu *et al.* (9) and Glucose-yeast extract-$CaCO_3$ agar medium Lisdiyanti *et al.* (11). From that, three efficient *Pseudomonas* sp. and three efficient *Aspergillus* sp. from rhizosphere soils of banana were selected for formation of consortia and field study. These isolates were identified using standard cultural, morphological and biochemical methodology. The bacterial and fungal isolates were examined for their ability to release K from Aleksandrov's broth (supplemented with 1% Muscovite mica). One ml of overnight culture of each of isolate was inoculated in to 25 ml of Aleksandrov's broth Hu *et al.* (9) and available K content was determined by flame photometry.

The tested microorganism, *viz.*, bacteria with bacteria, fungi with fungi and bacteria with fungi were inoculated in 25 ml glucose-yeast extract-$CaCO_3$ broth (dual culture) as per 21 combinations and incubated at 28 ± 2°C for 3-4 days. The compatibility test was carried out for the development of consortium of three selected efficient isolates of KSB (*Pseudomonas* sp.) and KSF (*Aspergillus* sp.). On the basis of compatibility test, the bioformulations of bacterial and fungal consortia were prepared separately. The three most efficient *Pseudomonas* sp. were grown on five test media for finding out the most suitable medium for mass multiplication of KSB consortium. For the preparation of suitable medium and to increase the shelf-life of *Pseudomonas* sp. the base material which contains emulsifier, dispersant, cell protectant, moisturizer and humectants *etc*. were used in different concentrations (Chandra, 7). Sterilized glucose-yeast extract-$CaCO_3$ broth was inoculated with a loopful of efficient isolates of KSB cultures and kept for incubation at 28 ± 2°C for 48 h in a shaker BOD at 130 rpm/ min. After attending the full growth (10^9 cfu/ ml), the bioinoculant was transferred separately into each of the sterilized test media at 1:3 ratio and kept for incubation at 28 ± 2°C for 72 h in shaker BOD at 130 rpm/ min. The formulations were stored in sterile plastic bottles after taking initial count.

The most efficient three *Aspergillus* sp. were multiplied on potato dextrose broth culture. The inocula thus obtained, were harvested and used for preparation of talc (adding with carboxymethyl cellulose) based and lignite based formulations Singh *et al.* (18). Initial population count was taken and packed in polypropylene bag and it was used for field experiment. The liquid (KSB)/ carrier (KSF) based inoculum was further tested for its shelf-life by recording cfu count at monthly interval for six months by serial dilution technique Warcup (33) on Glucose-yeast extract-$CaCO_3$ agar medium plates. The colonies were counted with the help of the colony counter after 48 and 72 h of incubation and expressed in terms of cfu/g or cfu/ml of bio-formulation. The survival percentage of potassium solubilizers in different bio-formulations were calculated as survival (%) is equal to population count at 180 days/ maximum population count × 100.

A field experiment was conducted at the Research Farm of Deptt. of Plant Pathology and Agricultural Microbiology in the year 2012-13 using bacterial (three efficient *Pseudomonas* sp.) and fungal (three efficient *Aspergillus* sp.) consortia bio-formulations in comparison with commercial formulation, KEMOFER *i.e.* potassium mobilizing potassium bio-fertilizer, Coimbatore, Tamil Nadu, to study their performance in enhancing the growth, K uptake and yield of banana cv. Grand Naine. The soil type was sandy loam in texture. The soil pH was 7.9, EC (0.15 dS m^{-1}), available nitrogen (209.05 kg ha^{-1}), available phosphorus (18 kg ha^{-1}), available potassium (408.66 kg ha^{-1}) and population of KSB (6.66 × 10^3 cfu /g) and KSF (2.33 × 10^2 cfu /g). The field was uniformly levelled and pits were dug at 1.5 m × 1.5 m spacing. The experiment was laid out in Randomized Block Design with three replications and 13 treatments including recommended dose of fertilizers (200 g N + 40 g P_2O_5 + 200 g K_2O + 10 Kg FYM $plant^{-1}$). Bacterial consortium with 50, 75 and 100% K_2O, fungal consortium with 50, 75 and 100% K_2O, bacterial + fungal consortia with 50, 75 and 100% K_2O, commercial formulation with 50, 75 and 100% K_2O. The experiment was conducted under irrigated conditions. Bacterial consortium and fungal consortium were applied through seedling dip treatment and through soil at monthly interval four times as per the application of K_2O. Nitrogen and potassium were applied through the soil at monthly interval in seven and four splits, respectively (Bhalerao, 5). Phosphorus was applied as basal dose with FYM and bio-formulations through soil at the time of planting. Both consortia (3 ml or 3 g) were mixed with 3 kg FYM and then applied to soil.

Representative surface and subsurface soil samples were collected from each plot before planting, shooting and at harvest of the main banana plot for microbial population dynamics study and soil available NPK analysis. A known quantity (0.2 g) of the fine powdered plant and fruit samples were digested with 1:1 mixture of concentrated H_2SO_4 and H_2O_2 (for 30 min.) and this acid extract was used for the determination of N (microKjeldhal), P (vanado-molybdate yellow colour in nitric acid system) and K (flame photometry).

The statistical analysis of the data was carried out by employing completely randomized design (CRD) and randomized block design (RBD). Wherever

F tests was significant and interpretation of the results was carried out in accordance with Panse and Sukhatme (14).

RESULTS AND DISCUSSION

The amount of potassium released from Muscovite mica by the potassium solubilizing bacterial isolates in Aleksandrov's broth was estimated at 8 days after incubation (DAI) and for KSF isolates 10 days after incubation. The isolates KSB 49 released maximum amount of potassium from mica 239.75 mgl^{-1} followed by KSB 43 (228.25 mgl^{-1}), KSB 47 (205.75 mgl^{-1}) and control showed 42.81 mgl^{-1}. However, isolate KSB 49 recorded the highest potassium solubilisation than commercially used KSB as reference strain (CKSB1) (221.25 mgl^{-1}). They were further selected for development of bacterial consortium. The isolate KSF 3 recorded the highest potassium solubilisation (334.66 mgl^{-1}) than all other isolates, followed by KSF 13 (310.16 mgl^{-1}), KSF 31 (297.66 mgl^{-1}) and control showed 42.80 mgl^{-1}. They were selected for the development of fungal consortium. The decrease in pH of Aleksandrov's broth from initially adjusted pH of 7.0 was also noted at 8 days after incubation for KSB isolates and 10 days after incubation for KSF isolates. A reduction in pH of the medium, *i.e.* pH 5.65 was recorded by KSB 49 isolate followed by KSB 43, CKSB 1 (*F. aurantia*), and KSB 47, which reduced the pH of the medium to 5.71, 5.85 and 5.94, respectively. A reduction in pH of medium was recorded by KSF 3 (3.80) followed by KSF 13 (3.81) and KSF 31 (3.76). The positive relation of decrease in pH of the medium with increasing amounts of potassium solubilization was observed. These findings are in agreement with the findings of Girgis *et al.* (8) who showed that inoculation with selected strains of *Bacillus* sp. UBFBc1 and UBFBa7 released high concentrations of soluble K (236.2 and 195.3 mgl^{-1}, respectively) in MA-f (Feldspar) and MA-m (Mica) culture media. In support of the current study, Lopes-Assad (12) also studied two strains (CCT4355 and CCT911) of *Aspergillus niger.* The soluble K, titratable acidity and pH were analyzed and the solubilisation rate (SR) was calculated relative to the total K in the rock powder (2.921 mmolc/l). K-solubilizing capacities of strains KNP413, KNP414 and AS1.153 (*Bacillus mucilaginosus*) were monitored up to 5 days in Aleksandrov medium at 30°C. This lowered the medium pH from 7.5 to 5.12 at 4 days post-incubation; thereafter, pH of the medium remained stable. *Aspergillus terreus* solubilized (KF 2) insoluble potassium well in a liquid medium supplemented with Feldspar and caused a remarkable drop in pH (2.2 at 7 days of incubation) of culture medium. *Aspergillus niger* (KF 1) also showed remarkable drop in pH 2.7 at 7 days of incubation (Prajapati *et al.*, 15).

Three potassium solubilizing bacterial isolates (*Pseudomonas* sp.) were compatible with each other and three potassium solubilizing fungal isolates (*Aspergillus* sp.) were compatible with each other, but KSB and KSF were not compatible with each other. As per the results, a consortium of *Pseudomonas* sp. and a consortium of *Aspergillus* sp. were developed separately in the form of bio-formulations. Compatibility of the inoculants *Rhizobium* sp., *Bacillus megaterium* and *Pseudomonas fluorescens* tested through cross streak plate assay. The inoculants were found to be compatible with each other and were able to grow simultaneously without any inhibition in growth Anandaraj (2).

At 60 days, the test Medium 3 showed highest population 24.6 × 10^8 cfu/ ml of formulation. After the second month, the population of test media 3, 4 and 5 decreased, but test Medium 3 showed maximum population (8.3 × 10^8 cfu/ ml) at 180 days (Fig. 1). Out of all five test media, the survival percentage in test Medium 3 was highest (33%) among all the tested media. Hence, the test Medium 3 was selected as the excellent liquid bio-formulation for KSB consortium for efficient delivery in the field. Further, the population in test medium 3 up to 360 days period was carried out. At 210 to 360 days, the population decreased from 7.1 to 0.1 × 10^8 cfu/ ml of formulation. The survival percentage (at cfu count, × 10^8 cfu/ ml) for 0 to 360 days was 0.40%. Similar results were also obtained by Chandra (7) who studied the shelf-life of liquid inoculum *vs* carrier based inoculum of potassium mobilizing bacteria (KMB). KMB solid medium maintained the shelf-life up to 6 months but in suggested case of liquid formulations in KMB survived up to two years. This suggested the superiority of liquid formulation over carrier base formulations. The PMB and KMB bacteria retained their population up to 10^8/ ml up to 12 months. The survivability of KSF 3, KSF 13 and KSF 31 was studied in two carriers, *i.e.*, talc and lignite. The shelf-life of different test carriers was carried out for 0-180 days (Fig. 2). In case of carrier based bio-formulations, the test medium talc powder showed highest population of 7.3 × 10^7 cfu/ ml at 8 days period and decreased later up to six months 2.0 × 10^7 cfu/ ml of formulation. The survival percentage was 27% in talc powder test medium as compared to the lignite (8.0%) (Fig. 2). Therefore, the talc powder was found to be an excellent bio-formulation of KSF consortium for efficient delivery in the field. In support of these findings, talc-based bio-formulation was found to be the best material to retain maximum number of viable propagules, *i.e.*, 29.7 × 10^6 cfu/g at 180 days of storage. It has also been found that the isolates can retain their viability up to 120 days in all the cases (Shahid *et al.*, 16). The strains of *A. niger* fungus have high potential of K solubilization and could be used as alternative to chemical fertilizers (Lopes-Assad, 12). However, work available on the application of potassium solubilizing fungi (*Aspergillus* sp.) under field conditions is very scanty.

Based on the highest efficiency of K solubilization of selected three *Pseudomonas* sp. and three *Aspergillus* sp., developed as liquid bio-formulation of KSB consortium and talc formulation of KSF consortium were further examined for their performance to enhance growth, nutrient uptake and yield of banana. The number of leaves was more at the shooting stage. Among the treatments highest number of leaves were recorded with treatment having fungal consortium (KSF) with 75% K_2O (T_6) (16.00 and 13.33 leaves/ plant, at shooting and harvesting stages, respectively) followed by treatment with bacterial (KSB) consortium with 75% K_2O (T_3) (14.33 and 12.66 leaves/ plant) at both the stages as compared to commercial formulation and RDF (T_1). The application of 75% K_2O showed higher No. of leaves than application of 100 and 50% K_2O at both the stages. The pseudostem height and girth increased rapidly up to shooting stage and later on marginally up to harvest. The application of KSB consortium + 75% K_2O (T_3) recorded the highest pseudostem height of 197.77 and 226.55 cm at both stages respectively, which was at par with the treatment of KSF consortium + 75% K_2O (T_6) (197.33 and 224.55 cm, respectively). The pseudostem girth was significantly influenced by the application of potash level. The application of KSF consortium with 75% K_2O (T_6) recorded maximum pseudostem girth of 59.33 and 68.77 cm at shooting and at harvest stage respectively, and it was at par with the treatment of KSB consortium with 75% K_2O (T_3) (57.77 and 64.66 cm, respectively). The pseudostem height and girth of both the treatments were highest as compared with the application of commercial formulation and RDF (T_1). The lowest pseudostem height and girth were recorded in the treatment with combined application of KSB consortium and KSF consortium with 50% K_2O (T_8) at both the stages, but in case of pseudostem, the height was lowest in treatment with commercial formulation and 50% K_2O (T_{11}) at the

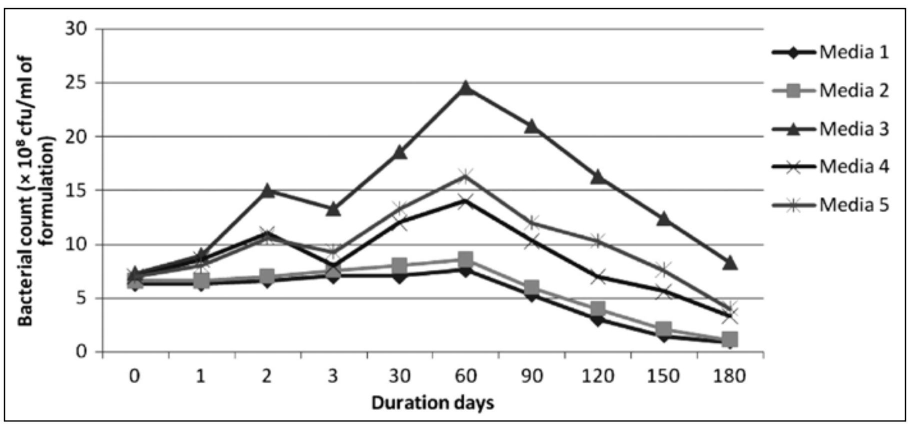

Fig. 1. Population of potassium solubilising bacteria (KSB) in liquid bio-formulations.

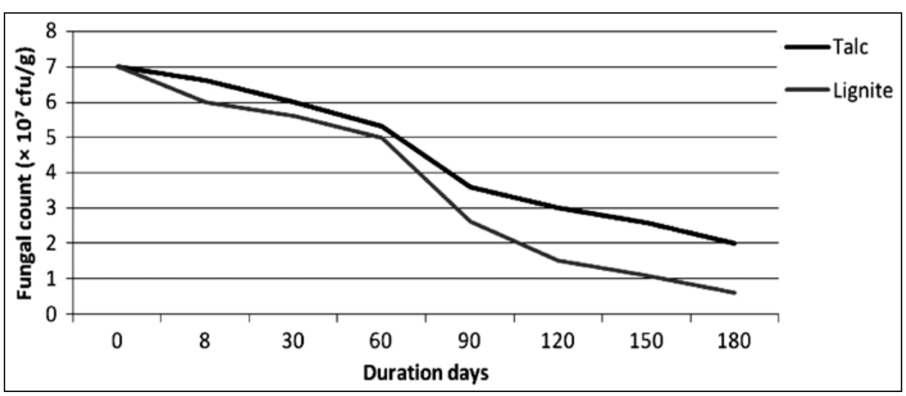

Fig. 2. Population of potassium solubilising bacteria (KSB) in carrier based bio-formulations.

shooting stage (175.11 cm) (Table 1). In the present study, the results obtained related to plant growth (Table 2) are comparable with the results of Sheng (17) who reported that silicate dissolving bacteria could improve soil P, K, Si reserves and promote plant growth. Similar observations on growth by KSB have been reported by several workers (Abou-el-Seoud and Abdel-Megeed,1; Badr, 4). Potassium solubilizing bacteria (*Bacillus* and *Pseudomonas*) were examined for the production of IAA and GA. All the isolates produced IAA and GA in the range of 1.10 to 16.50 and 0.60 to 3.29 µg/ 25 ml broth, respectively Archana *et al.* (3). Evidences exist which indicate that some *A. niger* isolates also produce IAA and other phytohormones Mostafa and Yovssef (13), which significantly increased the growth and yield.

At shooting stage, the rhizosphere population of potassium solubilizing bacteria (KSB) (21.66 × 10^5 cfu/ g soil) was significantly higher when KSB consortium + 50% K_2O (T_2) was applied, followed by KSB consortium + 75% K_2O (T_3) (18.00 × 10^5 cfu/ g soil), which were at par with each other. The KSB population increased rapidly up to shooting stage and later on marginally up to harvest (Table 2). At shooting, the rhizosphere population of potassium solubilising fungi (8.33 × 10^4 cfu/g soil) was significantly higher with application of KSF consortium + 50% K_2O (T_5), followed by fungal consortium + 75% potassium (T_6) (7.33 × 10^4 cfu/g soil), which was at par with each other. At harvest, the rhizosphere population of potassium solubilising fungi (5.33 × 10^3 cfu/g soil) was significantly higher when fungal consortium + 50% K_2O (T_5) given, followed by KSF consortium + 75% K_2O (T_6) and 100% K_2O (T_7). The application of bacterial consortium, commercial consortium and combination of bacterial and fungal consortium and RDF did not differ with each other (Table 2). These results could be mainly due to production of growth hormones and may be due to release of organic acids. The total number of bacteria increased due to inoculation of *B. mucilaginosus* (KSB) from 8.4×10^3 to 9.6 ×10^6 cfu/ g, respectively compared to uninoculated control in the experiment of groundnut plant. *Pseudomonas* has ability to colonize rhizosphere of a wide variety of crops including cereals, pulses, oilseeds and vegetables (Chambel *et al.*, 6).

At shooting, the available N, P and K in soil (312.17, 25.80 and 593.60 kg/ha, respectively) were significantly higher when KSF consortium + 75% K_2O (T_6) were given, followed by KSB consortium + 75% K_2O (T_3) (310.85, 25.40 and 582.40 kg/ha, respectively), which was at par with each other for

Table 1. Effect of soil application of microbial (KSB and KSF) consortia under graded levels of potassic fertilizer on growth and duration of banana.

Treatment	No. of leaves/ plant		Height (cm)		Pseudostem girth (cm)		No. of days for shooting	No. of days for maturation
	Shooting	Harvest	Shooting	Harvest	Shooting	Harvest		
T_1	11.11	11.00	179.89	197.33	49.00	57.77	242.55	347.33
T_2	12.67	10.33	184.67	210.00	50.77	58.55	237.00	346.11
T_3	14.33	12.66	197.77	226.55	57.77	64.66	230.67	333.33
T_4	13.55	11.78	190.33	217.67	55.99	63.66	234.11	339.77
T_5	12.22	10.89	187.33	208.55	52.44	59.99	236.67	347.22
T_6	16.00	13.33	197.33	224.55	59.33	68.77	230.00	330.44
T_7	13.33	11.89	193.44	219.22	56.81	63.44	233.67	337.88
T_8	11.00	10.55	177.77	192.89	45.00	53.11	239.78	346.44
T_9	11.00	10.66	176.88	195.77	48.22	56.77	241.00	347.11
T_{10}	12.11	11.44	186.22	205.33	49.90	59.88	234.89	346.89
T_{11}	11.33	10.67	175.11	194.44	46.00	54.77	238.33	347.44
T_{12}	12.66	10.89	181.44	200.40	49.44	56.44	238.22	346.66
T_{13}	13.45	11.33	187.88	212.77	54.77	61.67	234.00	344.77
CD at 5%	2.77	1.65	2.15	2.92	1.41	1.22	2.26	5.11

T_1 = Recommended dose of fertilizer (RDF) (200 g N + 40 g P_2O_5 + 200 g K_2O g $plant^{-1}$); T_2 = Bacterial (KSB) consortium + 50% K_2O; T_3 = Bacterial (KSB) consortium + 75% K_2O; T_4 = Bacterial (KSB) consortium + 100% K_2O; T_5 = Fungal (KSF) consortium + 50% K_2O; T_6 = Fungal (KSF) consortium + 75% K_2O; T_7 = Fungal (KSF) consortium + 100% K_2O; T_8 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 50% K_2O; T_9 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 75% K_2O; T_{10}- Bacterial (KSB) consortium + Fungal (KSF) consortium + 100% K2O; T_{11} = Commercial formulation + 50% K_2O; T_{12} = Commercial formulation + 75% K_2O; T13 = Commercial formulation + 100% K_2O.

Table 2. Effect of soil applications of microbial (KSB and KSF) consortia under graded levels of potassic fertilizers on available N, P and K in soil and population dynamics of KSB and KSF in the rhizosphere.

Treatment	Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)		KSB Population (10^5 cfu/g soil)		KSF Population (10^4 cfu/g soil)	
	Shooting	Harvest	Shooting	Harvest	Shooting	Harvest	Shooting	Harvest	Shooting	Harvest
T_1	284.30	183.33	22.80	18.64	526.46	294.96	6.66	1.66	0.73	0.53
T_2	294.06	192.32	23.46	19.00	548.80	306.18	21.66	14.00	1.33	1.10
T_3	310.85	206.25	25.40	20.48	582.40	332.27	18.00	11.33	0.90	1.66
T_4	307.99	200.68	24.60	19.62	578.66	321.07	15.00	9.33	0.86	0.73
T_5	296.85	196.50	23.80	19.22	560.00	309.89	3.33	2.33	8.33	5.33
T_6	312.17	207.65	25.80	20.64	593.60	339.46	3.00	3.33	7.33	3.66
T_7	303.73	204.86	25.00	20.03	574.93	328.53	2.66	2.66	5.66	2.33
T_8	275.94	181.17	21.60	18.10	522.66	291.20	2.33	3.33	4.33	1.66
T_9	278.72	186.74	22.33	18.24	526.40	302.47	4.66	5.66	2.60	1.33
T_{10}	291.19	193.71	23.00	19.24	556.26	309.89	3.33	4.66	2.33	0.96
T_{11}	281.51	182.56	22.53	18.48	537.60	294.96	16.33	11.00	0.10	0.80
T_{12}	288.48	188.14	22.71	18.70	545.06	305.18	13.33	12.66	1.33	0.63
T_{13}	301.03	199.00	24.10	19.42	569.77	313.63	10.33	7.33	0.86	0.60
CD at 5%	5.00	2.61	0.40	0.35	10.80	12.30	4.60	2.40	1.82	1.22

T_1 = Recommended dose of fertilizer (RDF) (200 g N + 40 g P_2O_5 + 200 g K_2O g plant^{-1}); T_2 = Bacterial (KSB) consortium + 50% K_2O; T_3 = Bacterial (KSB) consortium + 75% K_2O; T_4 = Bacterial (KSB) consortium + 100% K_2O; T_5 = Fungal (KSF) consortium + 50% K_2O; T_6 = Fungal (KSF) consortium + 75% K_2O; T_7 = Fungal (KSF) consortium + 100% K_2O; T_8 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 50% K_2O; T_9 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 75% K_2O; T_{10}- Bacterial (KSB) consortium + Fungal (KSF) consortium + 100% K2O; T_{11} = Commercial formulation + 50% K_2O; T_{12} = Commercial formulation + 75% K_2O; T13 = Commercial formulation + 100% K_2O.

available N and P but on par for available K_2O. Among 100% K_2O application treatments, the application of KSF consortium + 100% K_2O (T_4) for available N and K (307.99 and 578.66 kg/ha, respectively) had a better effect as compared to others and RDF (T_1). The lowest soil available N, P and K (181.17, 18.10 and 291.20 kg/ha, respectively) were recorded in the treatment of combined application of bacterial and fungal consortia + 50% K_2O (T_8) (Table 2).

In support of these findings Badr (4) reported inoculation of KSB and PSB in conjunction with amendment of its respective rock P or K materials that increased the availability of P and K in soil. Applied together, mixed inoculation and rock P and K materials, resulted in the highest availability of P and K in the soil increased about 25% of P and 15% of K as compared to the untreated control. Increasing the bioavailability of P and K in the soils with the inoculation of PGPR or with combined inoculation and rock materials have been reported by Lin *et al.* (10). Total N, P and K uptake were influenced by the application of 75% K_2O along with a KSF consortium (T_6) (Table 3). The uptake of nitrogen increased linearly with all the treatments at harvest stage. Plant nitrogen uptake was the highest as compared with fruit nitrogen uptake. The application of KSB consortium + 75% K_2O (T_3) (651.83 kg/ ha) was recorded second highest treatment after T_6 (661.47 kg/ ha) for total nitrogen uptake, which was at par with each other. In case of total nitrogen uptake, among the 100% K_2O and 50% K_2O application treatments, the application of 100% K_2O had a better result than 50% K_2O. A similar trend was observed in case of plant and fruit nitrogen uptake (Table 3). Plant P uptake was more as compared with the fruit P uptake. Total uptake of P was influenced significantly (80.52 kg/ ha) by the application of 75% K_2O + KSF consortium (T_6) among all the treatments followed by KSB consortium + 75% K_2O (T_3) (75.73 kg /ha), which were at par with each other (Table 3). The total uptake of potassium increased constantly till harvest in all the treatments. The uptake by banana at harvest was significantly influenced by different potash levels. The maximum total potassium uptake of 1198.17 kg/ha was recorded by KSF consortium + 75% K_2O (T_6), which was at par with KSB consortium + 75% K_2O (T_3) (1177.21 kg/ha). Among the 50 and 100% K_2O application treatments for total potassium uptake of banana, the application of 100% K_2O had better result than 50% K_2O. In case of 100% K_2O application treatments, KSF

Table 3. Effect of soil applications of microbial (KSB and KSF) consortia under graded levels of potassic fertilizers on N, P and K uptake by banana plant.

Treatment	Plant N uptake (kg/ha)	Fruit N uptake (kg/ha)	Total plant N uptake (kg/ha)	Plant P uptake (kg/ha)	Fruit P uptake (kg/ha)	Total plant P uptake (kg/ha)	Plant K uptake (kg/ha)	Fruit K uptake (kg/ha)	Total plant K uptake (kg/ha)
T_1	305.41	261.35	566.76	45.51	16.57	62.08	482.88	462.15	945.03
T_2	319.99	280.48	600.47	46.86	17.84	64.70	509.16	466.93	976.09
T_3	345.85	305.98	651.83	53.33	22.40	75.73	689.55	487.66	1177.21
T_4	336.96	296.42	633.38	50.90	20.71	71.61	678.78	476.50	1155.28
T_5	327.26	286.86	614.12	48.48	16.57	65.05	590.45	469.81	1060.26
T_6	352.31	309.16	661.47	55.75	24.77	80.52	700.32	497.85	1198.17
T_7	340.19	299.60	639.80	51.71	19.12	70.83	680.16	479.69	1159.85
T_8	298.17	254.98	553.15	43.63	14.97	58.60	427.37	457.37	884.74
T_9	308.67	267.70	576.37	43.63	15.60	59.23	441.70	457.37	899.07
T_{10}	321.60	286.86	608.46	48.48	16.25	64.73	529.53	465.23	994.76
T_{11}	307.80	264.54	572.34	44.57	15.93	60.50	453.20	458.97	912.17
T_{12}	315.00	277.26	592.26	46.46	16.25	62.71	497.13	462.10	959.23
T_{13}	334.45	293.23	627.68	50.09	18.40	68.49	661.87	474.90	1136.77
CD at 5%	9.05	6.65	11.70	2.17	1.81	5.01	18.50	7.13	27.16

T_1 = Recommended dose of fertilizer (RDF) (200 g N + 40 g P_2O_5 + 200 g K_2O g plant^{-1}); T_2 = Bacterial (KSB) consortium + 50% K_2O; T_3 = Bacterial (KSB) consortium + 75% K_2O; T_4 = Bacterial (KSB) consortium + 100% K_2O; T_5 = Fungal (KSF) consortium + 50% K_2O; T_6 = Fungal (KSF) consortium + 75% K_2O; T_7 = Fungal (KSF) consortium + 100% K_2O; T_8 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 50% K_2O; T_9 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 75% K_2O; T_{10}- Bacterial (KSB) consortium + Fungal (KSF) consortium + 100% K2O; T_{11} = Commercial formulation + 50% K_2O; T_{12} = Commercial formulation + 75% K_2O; T13 = Commercial formulation + 100% K_2O.

consortium + 100% K (T_7) (1159.85 kg/ ha) was higher than others, followed by T_4 (1155.28 kg/ ha) and T_{13} (1136.77 kg/ ha), which were at par with each other. The lowest total uptake of potassium of 884.74 kg/ ha was recorded due to the combined application of KSB and KSF consortium + 50% K_2O (T_8), which was at par with the combined application of KSB and KSF consortium + 75% K_2O (T_9) (899.07 kg /ha). A similar trend was observed in case of plant and fruit uptake (Table 3). The results are comparable with the findings of Badr (4) who reported that inoculation of KSB and PSB in conjunction with amendment of its respective rock P or the minerals increased the availability of P and K in soil, enhanced N, P and K uptake and promoted the growth of egg plant. Similarly, the dynamics of K release from waste mica inoculated with potassium solubilizing microorganism (*Bacillus mucilaginosus*) and to investigate its effectiveness as potassic-fertilizer using Sudan grass (*Sorghum vulgare* Pers.) var. *sudanensis* as test crop grown under two Alfisols.

The maximum length and girth of banana fruit (22.88 and 13.96 cm) was recorded by the application of fungal consortium + 75% K_2O (T_6). It was followed by the bacterial consortium + 75% K_2O (T_3) (22.22 and 13.90 cm), which were at par with each other. The treatment of commercial formulation (T_{11}, T_{12} and T_{13}) and RDF (T_1) were significantly lower than the above treatment (T_6) (Table 4). The application of KSF consortium along with 75% K_2O (T_6) recorded the maximum marketable number of hands per bunch, fingers per hand, bunch weight and total yield (9.22, 16.22, 28.55 kg and 126.87 t/ha, respectively) followed by KSB consortium + 75% K_2O (T_3) (9.00, 16.11, 27.88 kg and 123.89 t/ha, respectively). These treatments were significantly superior to treatments with commercial formulation and RDF (T_1). The lowest number of hands per bunch (7.44) and fingers per hand (13.67) were recorded by the combined application of bacterial and fungal consortia along with 50% K_2O (T_8), which was at par with treatments, T_9 (7.55 and 14.00), T_{11} (7.33 and 13.90), T_{12} (7.88 and 14.99) and RDF (T_1) (7.67 and 14.77) (Table 4). Similar findings were also noticed by Mostafa and Yovssef (13) using K solubilizing bacteria (*Bacillus* sp.) as compared to the reference strain (*Frateuria aurantia*) for their influence on growth, K uptake and yield of maize plants under glass house conditions. All the inoculated treatments with bacteria (*Bacillus* sp. KSB 11 recorded the highest yield 51.33 g/ plant)

Table 4. Effect of soil applications of microbial (KSB and KSF) consortia under graded levels of potassic fertilizers on grade of the fruit, bunch characteristics and yield of banana.

Treatment	Fruit length (cm)	Fruit girth (cm)	No. of hands/ bunch	No. of fingers/ hand	Bunch wt. (kg)	Yield (t/ha)
T_1	20.88	12.44	7.67	14.77	21.55	95.76
T_2	21.00	13.11	8.22	15.67	24.11	107.14
T_3	22.22	13.90	9.00	16.11	27.88	123.89
T_4	22.00	13.55	8.66	16.11	26.44	117.49
T_5	21.77	13.22	8.26	15.81	24.67	109.63
T_6	22.88	13.96	9.22	16.22	28.55	126.87
T_7	22.11	13.77	8.88	16.11	26.77	118.96
T_8	20.22	12.00	7.44	13.67	20.00	88.88
T_9	20.22	12.11	7.55	14.00	20.00	88.88
T_{10}	21.00	13.00	8.00	15.66	23.77	105.63
T_{11}	20.55	12.22	7.33	13.90	20.11	89.36
T_{12}	20.77	12.55	7.88	14.99	22.00	97.76
T_{13}	22.00	13.44	8.55	16.00	25.77	114.52
CD at 5%	0.73	0.41	0.58	0.70	2.71	12.28

T_1 = Recommended dose of fertilizer (RDF) (200 g N + 40 g P_2O_5 + 200 g K_2O g plant^{-1}); T_2 = Bacterial (KSB) consortium + 50% K_2O; T_3 = Bacterial (KSB) consortium + 75% K_2O; T_4 = Bacterial (KSB) consortium + 100% K_2O; T_5 = Fungal (KSF) consortium + 50% K_2O; T_6 = Fungal (KSF) consortium + 75% K_2O; T_7 = Fungal (KSF) consortium + 100% K_2O; T_8 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 50% K_2O; T_9 = Bacterial (KSB) consortium + Fungal (KSF) consortium + 75% K_2O; T_{10}- Bacterial (KSB) consortium + Fungal (KSF) consortium + 100% K2O; T_{11} = Commercial formulation + 50% K_2O; T_{12} = Commercial formulation + 75% K_2O; T13 = Commercial formulation + 100% K_2O.

and was found to increase growth parameters and yield components compared to absolute control and 25 per cent of RDK control.

In conclusion, the present study resulted in potassium solubilizing bacteria *Pseudomonas* species and fungi *Aspergillus* species, which proved better than the reference strain (*Frateuria aurantia*). The best delivery system for banana is an excellent potassium solubilizing ability of *Aspergillus* consortium with talc formulation and *Pseudomonas* consortium with liquid bio-formulation. These findings clearly indicated 25% savings of potassic fertilizers, *i.e.*, 222.22 K_2O kg/ ha.

ACKNOWLEDGMENTS

The first author gratefully acknowledges the funding support rendered by the DST, New Delhi for the INSPIRE Fellowship. The authors are also thankful to the Head, Department of Plant Pathology and Agricultural Microbiology, MPKV, Rahuri, Maharashtra.

REFERENCES

1. Abou-el-Seoud and Abdel-Megeed, A. 2012. Impact of rock materials and biofertilization on P and K availability for maize (*Zea mays*) under calcareous soil conditions. *Saudi J. Biol. Sci.* **19**: 55-63.
2. Anandaraj, B. and Leema Rose Delapierre, A. 2010. Studies on influence of bioinoculants (*Pseudomonas fluorescens, Rhizobium* sp., *Bacillus megaterium*) in green gram. *J. Biosci. Tech.* **1**: 95-99.
3. Archana D.S., Savalgi, V.P. and Alagawadi, A.R. 2008. Effect of potassium solubilizing bacteria on growth and yield of maize. *Soil Biol. Ecol.* **28**: 9-18.
4. Badr, M.A. 2006. Efficiency of K-feldspar combined with organic materials and silicate dissolving bacteria on tomato yield. *J. App. Sci. Res.* **2**: 1191-98.
5. Bhalerao, V.P. 2009. Integrated nutrient management for banana. **In**: *Proceeding of National Conference on Banana*, Pune (MS, India). 16-17 Jan, 2009, pp. 49-53.
6. Chambel, L., Cantinubo, C. and Palminha, J. 1992. Isolation, identification and characterization of fluorescent *Pseudomonas* rhizobacteria. *Bulletin OILB–SROP.* **15**: 100-2.

7. Chandra, K. 2009. *NPK- Liquid Biofertilizer* (*PolyCulture*), Regional Center of Organic Farming, Bengaluru, India.

8. Girgis, M.G.Z., Khalil Heba, M.A. and Sharaf, M.S. 2008. *In vitro* evaluation of rock phosphate and potassium solubilizing potential of some *Bacillus* strains. *Australian J. Basic Appl. Sci.* **2**: 68-81.

9. Hu, X., Chen, J. and Guo, J. 2006. Two phosphate- and potassium-solubilizing bacteria isolated from Tianmu Mountain, Zhejiang, China. *World J. Microbiol. Biotech.* **22**: 983-90.

10. Lin, Q.M., Rao, Z.H., Sun, Y.X., Yao, J. and Xing, L.J. 2002. Identification and practical application of silicate-dissolving bacteria. *Agric. Sci. China*, **1**: 81-85.

11. Lisdiyanti, P., Yamada, Y., Uchimura, T. and Lisdiyanti, K.K. 2003. Identification of *Frateuria aurantia* strains isolated from Indonesian sources. *Microbiol. Cult. Collection*, **19**: 81-90.

12. Lopes-Assad, M.L., Avansini, S.H., Greice Erler Rosa, M.M., Jose Ruy Porto de, C. and Ceccato-Antonini, S.R. 2010. The solubilization of potassium-bearing rock powder by *Aspergillus niger* in small-scale batch fermentations. *Canadian J. Microbiol*. **56**: 598-605.

13. Mostafa, M.A. and Yovssef, Y.A. 1962. Studies on peritrophie mycorrhiza between *Tropaeolum majus* L. and two associated rhizosphere fungi. III. Effect of fungal metabolites on relative growth vigour of *Tropaeoliem mains* L. *Egyptian J. Bot*. **111**: 137-51.

14. Panse, V.S. and Sukhatme, P.V. 1985. *Statistical Methods for Agricultural Workers*, ICAR, New Delhi, India, pp. 152-55.

15. Prajapati, K., Sharma, M.C. and Modi, J.A. 2012. Isolation of two potassium solubilizing fungi from ceramic industry soils. *Lifesci. Leaflet.* **5**: 71-75.

16. Shahid, M., Srivastava, M., Sharma, A., Vipul Kumar, Pandey, S. and Singh, A. 2013. Morphological, molecular identification and SSR marker analysis of a potential strain of *Trichoderma/ hypocrea* for production of a bioformulation. *J. Plant Path. Microbiol.* **4**: 10.

17. Sheng, X.F., Xia, J.J. and Chen, J. 2003. Mutagenesis of the *Bacillus edaphicus* strain NBT and its effect on growth of chilli and cotton. *Agric. Sci. China*, **2**: 400-12.

18. Singh, R.B., Singh, H.N., Singh, P. and Kaur, J. 2001. A comparison of different substrates for the mass production of *Trichoderma*. *Ann. Plant Protect. Sci.* **9**: 248-53.

Received : March, 2016; Revised : April, 2017; Accepted : May, 2017