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Potassium Releasing Bacteria for Unlocking Soil Potassium- A Way Forward for Judicious Use of Chemical Fertilizers

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Potassium (K) is one of the essential macronutrients required for the plants and its availability to plants is hampered due to its fixation with other ions. The Potassium Releasing Micro-organisms (KRMs) present in the soil are capable of converting the fixed form of potassium into an available

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form of K for the plants to uptake. Most commonly present potash releasing bacteria in rhizosphere soil belong to phylum Firmicutes, Proteobacteria and Actinobacteria. These microbes produce organic acids, siderophores, biofilms for converting the insoluble K into a soluble form. They also produce some of the plant growth hormones, apart from providing abiotic and biotic stress resistance which results in enhanced yield and quality traits of the crop. The use of KRMs as bio-fertilizer could decrease the level of application of chemical fertilizers and thereby reduce the excess accumulation of potassium in the soil. The presence of sufficient numbers of Potash Releasing Bacteria (KRB) in the soil would ease the potassium transformation processes.

Keywords: Potash releasing microbe; organic acids; rhizosphere; siderophore; sustainable agriculture.

1. INTRODUCTION

The marked rise in world population and increased demand in food production resulted in the use of many chemical products in agriculture for meeting the growing demand. For the proper growth and development of the plants, the essential nutrients are to be made available in adequate quantity and in available form. But many soils lack some of the essential plant nutrients in an available form. This resulted in the overuse of synthetic fertilizers for sustaining the crop yield, which in turn deteriorated the soil properties, natural fertility and caused damage to the environment.

Potassium (K) is the 7th most abundant element in earth's crust and the 3rd most essential macronutrient for plant growth and development after nitrogen (N) and Phosphorus (P). It influences the plant both directly and indirectly. It has a significant role in the growth, development, several physiological processes of the plant and also provides resistance to diseases, insects, cold and waterlogging [1]. Higher concentration of K in flag leaves could elevate the ABA (Abscisic Acid) degradation, which also contributed to higher drought tolerance [2]. Among the 0.04-3% of the reported K content in soils, only 1-2% is available for the plants [3]. According to several studies, even when K was added into the soil in the form of natural or synthetic fertilizer, only a little amount (1-2%) of this would be available for the plants as the rest would bound to other minerals and get converted into an unavailable form [4]. The different forms of K present in the soil are mineral K, exchangeable K, non-exchangeable K and solution K [5].

The soil microbial community has a major role in influencing availability of soil minerals, ion cycling, converting fixed forms of nutrients into available form for plants by decomposition, mineralisation, storage/release of nutrients and thus influencing soil fertility [6,7]. Among such microorganisms, the K releasing microorganisms finds a place in influencing the availability of soil K, thus promoting the plant growth and yield.

2. FORMS OF SOIL POTASSIUM

Potassium is a mobile element and present as mineral potassium with feldspar and mica, captured K within clay minerals, exchangeable clay and solution K. Easily available potassium containing minerals are sylvite, carnallite, kainite, langbeinite, schoenite and polyhalite. The K availability in soil depends upon clay mineral content, K-bearing minerals, soil moisture availability, soil aeration, and soil pH.

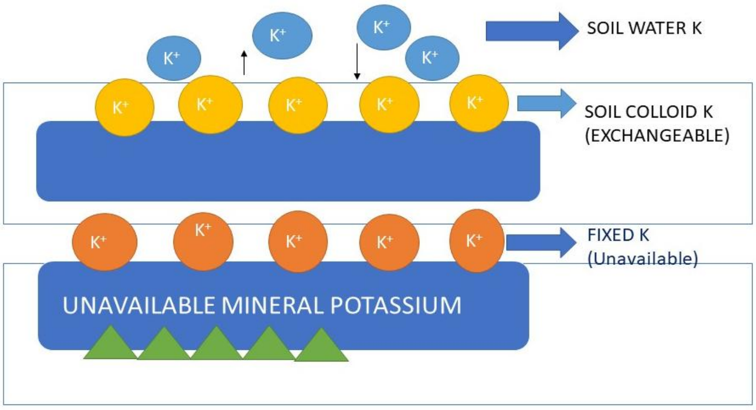

Fig. 1. Forms of soil potassium

3. IMPORTANCE OF POTASSIUM NUTRITION TO CROPS

Potassium plays a major part in the fundamental physiological and biochemical activities of the plants and has a crucial role in plant growth as it aids in the activation of enzymes, protein synthesis, photosynthesis and enhancement of quality traits of crop. It triggers around 60 different enzymes that act as a catalyst in several biochemical reactions which are involved in the plant growth and production. The amount of potassium present in the soil determines the number of enzymes that are activated. Potassium also determines the physical nature of the enzyme molecule and reveals the chemically suitable sites for reaction [8]. Specific enzymes like vacuolar PPAse isoforms and enzymes that are involved in the carbon metabolism such as pyruvate kinase, phosphofructokinase, ADP glucose and starch synthase are mainly dependent on potassium for its activation [9]. The organic and inorganic ions in the plant cells are neutralized by potassium thereby it stabilizes the pH of the plant cell wall between 7 to 8 which provides a favourable condition for many enzymatic reactions [10]. The stomatal opening and closing, water transport, nutrient uptake and plant cooling are regulated by the potassium element present in the plants. The water molecules are absorbed by the roots due to the gradient of osmotic pressure created by the upsurge of potassium ions in the roots of plants. The lack of potassium ions might lead to lower water absorption and stress conditions [11]. The insufficiency of potassium in plants would result in declined ATP generation and reduced photosynthetic rate and other cellular activities. The decline in ATP production due to the deficiency of potassium would hamper the phloem transport system. The transcription of genetic code in the plants to produce proteins and enzymes is not feasible without sufficient potassium in plants [12]. Plants with potassium deficiency and abundance of nitrogen, might use nitrates as the percussor for protein accumulation instead of amino acids and amides [13]. In potassium insufficient plants, the synthesis and accumulation of low molecular compound such as amino acids, soluble sugars, organic acids and amides is a common phenomenon and these compounds provide a favourable environment for the disease and insect infestation whereas presence of sufficient potassium enhances the accumulation of high molecular compounds such as protein, starch and cellulose thus decreases the accumulation of low molecular compounds [79]. Potassium sufficient plants are found to have tolerance against abiotic stress like cold stress, drought stress, waterlogging stress and salinity [14,15]. González et al. [16] observed the effects of water stress in sunflower and olive trees and reported that the plants with inadequate potassium could prevent the water stress induced stomatal closure by ethylene synthesis which would inhibit the action of abscisic acid on stomata and delay the stomatal closure thereby reduce water use efficiency during drought stress condition. From the long-term experiment conducted on the rice – wheat cropping system, it has shown significant decline in the yields of rice than wheat mainly due to the depletion of potassium in the soils [17]. Thus, potassium, the essential macronutrient, greatly influences yield and other overall quality parameters.

4. ROLE AND MECHANISMS OF MICROBES IN RELEASING SOIL POTASSIUM

Potassium is one of the major essential macronutrients which play a major role in the growth and development of plants followed by nitrogen and phosphorous. From the research conducted on the fertility status of the Indian agricultural soil, it has been proved that 21% of Indian soil were low in potassium, 51% were medium and 28% were high in potassium [18]. Aleksandrov et al. [19] and Bennet et al. [20] stated that the potassium in the soil was either complexed or chelated to insoluble form as in mica or illite which could be solubilized by potassium releasing bacteria by the secretion of organic acids and convert the insoluble potassium(K) into a soluble form which can be readily available to the plants. Potassium (K) exists as mineral K, exchange K, non-exchange K, dissolved/solution K (K+ ions) [21]. Direct uptake of K by plants is by solution K which is about 2% in Indian soils and the rest 98% are found in mineral form such as vermiculite, muscovite, feldspar, biotite and mica [22]. The potassium releasing microorganisms were found to use a mechanism such as an acidolysis, siderophore production, exchangeable reactions, chelation (complex formation) Si^{4+}, Al^{3+}, Fe^{2+} associated with K minerals, production of organic and inorganic acids, polysaccharide (extracellular and capsular) production, complex lysis or ligand formation and biofilm formation for the conversation of insoluble potassium to soluble potassium [5,23]. Major mechanisms recorded were acidolysis (production of protons) and production of organic and inorganic acids [7,10,24-28]. Different types of organic acids reported were 2-Ketogluconic acid, tartaric acid, citric acid, gluconic acid, succinic acid, malic acid, lactic acid, glycolic acid, propionic acid, fumaric acid, malonic acid, etc. [4,29-34]. Different organic acids were produced by different KRBs and the most prominent were tartaric acid, oxalic acid, citric acid, Alpha-Ketogluconic acid and succinic acid [10]. Wang et al. [35], found that the organic acid production helped in the mobilization of potassium (K). Liu et al. [36] found the relationship between bacterial polysaccharides and potassium solubilization. He observed that the bacterium, *Bacillus mucilaginous* released K^+ ions from mica, but not from feldspar due to its cross-linked structure. He noticed polysaccharide production by the bacteria and concluded that polysaccharides and minerals formed a complex. The polysaccharide adsorbed organic acids on its surface and elevated its concentration near the minerals. This caused the metal to degrade partially. He also observed that, polysaccharide absorbed SiO_2. This caused a variation in concentration and affected the equilibrium, and thus lead to degradation making increased availability of potassium. The filamentous fungi such as, *Cladosporium cladosporoides*, *Penicillium* sp., produced notable number of organic acids like citric acid, oxalic acid, gluconic acid that deteriorated clay silicates, mica and feldspar in broth culture which showed that weathering of rocks by fungus is due to organic acids produced by them [37]. Maurya et al. [24] found that, organic acids caused potassium solubilization with increased period of incubation rather than in contact with the microbial cells. The increased incubation period could result in slow release of potassium. He also observed a variation in K solubilization efficiency by microbial isolates obtained from same type of soil. The surface of potassium feldspar was severely corroded when *Bacillus aryabhattai* (SK1-7) was inoculated. Chen et al. [38] inferred that dissolution was due to the production of secondary metabolites like organic acids and capsular polysaccharides. *Bacillus altitudinal* strain was found to produce organic acids to dissolve K-feldspar and release more Si, Al, Fr [39].

Saha *et al.* [40] isolated 7 efficient strains of KRBs from rhizosphere of rice, wheat, banana, maize and sorghum, which could solubilize waste biotite. He observed that, KRBs produced several organic acids which solubilized the mica structure to satisfy their Si^{4+} requirements. This brought the ions into the solution and consequently reduced the pH. Prajapati and Modi [41] isolated 5 efficient strains as KSB 1, KSB 3, KSB 7, KSB 8 and KSB 11, which could solubilize feldspar through the production of organic acids like oxalic acids, citric acid, malic acid, succinic acid and tartaric acid. K solubilization from K-feldspar by KRBs by the release of organic acids were reported in soil samples of forest soil and rubber plantation soils in Myanmar [42]. The KRBs isolated from tobacco rhizosphere were found to release auxin and secreted organic acids which increased the K concentration in soil by dissolving slow-release K compounds and increased nutrient uptake by plants thereby promoted plant growth [43]. In a study conducted in paddy rhizosphere, 7 bacterial isolates could solubilize feldspar with organic acids, and this enhanced the cation exchange between H^+ and K^+ ions [44]. Solubilization by these bacteria also resulted in the formation of a secondary mineral, Kaolinite [45]. From the research conducted on selection of high efficiency KRB from apple orchards, Chen et al. [46], reported *Paenibacillus mucilaginosus* JGK strain as the most efficient strain which solubilized potassium with the release of organic acids such as oxalic acid, citric acid, malic acid, acetic and succinic acid resulted in reduced pH of the surrounding environment and chelation with K and acid hydrolysis of the bacterial surface. Verma et al. [47] obtained potash releasing bacterial isolates *viz*. MPS1C2, MPS2C5, MPS2C4, MPS5C1, UPS1C1, UPS2C1 and UPS3C1 from different rhizospheric soils. They analysed that the optimum temperature and pH for potassium solubilization was 28±2°C and pH 7, respectively. It was evident from another research that, the mechanism of potassium solubilization of 14 bacterial strains isolated from the common kharif crops (maize, banana, sugarcane, potato, pigeon pea, tobacco) was associated with production of oxalic acid, acetic acid, gluconic acid, fumaric acid, tartaric acid and citric acid. The secretion of these acids lowered the pH and disintegrated the waste mica source and thereby released Si^{4+} and K^+ ions [25]. When trachyte was used as a potassium source, 6 isolates from the sugarcane rhizosphere showed a positive correlation between organic acid production and potassium solubilization. The higher the total organic acids produced, greater the K originated from trachyte. Metabolic activities of microbes caused the production of aromatic organic acids like ferulic acid, syringic acid, and coumaric acid and aliphatic acids like citric and malic acids [48].

KRBs produced biofilms on aluminosilicate minerals that enhanced its weathering process by increasing the residence time of water on mineral surface [5]. Biofilm production also increased the release of K, Al and Si from the mineral surface by promoting corrosion of K- rich shale [49]. Siderophore production was found to be associated with actinobacterial strains (P18, BC3, BC10, BC11) from Morocco desert soils, that dissolved mica [50]. It is concluded that change in pH, chelation, weathering due to acid production, biofilm formation, siderophore production and polysaccharides are in general, the mechanism behind solubilization of potassium by microbes.

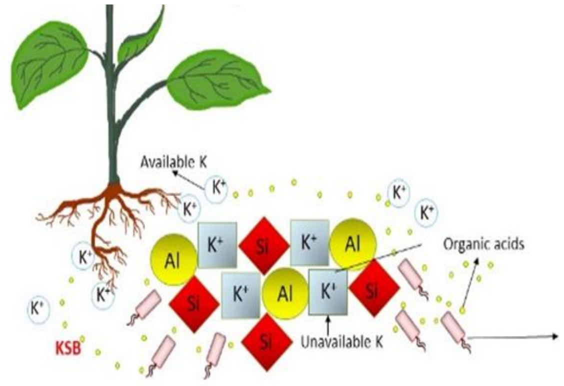

Fig. 2. Mechanism of potassium release by microbes

5. DIVERSITY OF POTASSIUM RELEASING BACTERIA

Amidst the fact that, potassium is an abundant mineral in the earth's crust, its availability to plants is a question of fact. As it becomes chelates and complexes, its availability is reduced and this is where KSB comes to play. Various microbes associated with rhizosphere increases the availability of potassium to the plants. The presence of KRBs was higher in rhizosphere region than non-rhizosphere region [51]. From the data collected, it was evident that soil bacteria efficiently converted soil potassium to their available form to plants [25,41,52]. Among the microbial population studied, KRBs belonged mostly to phylum Firmicutes, followed by Proteobacteria, Actinobacteria *etc*. *Bacillus* sp. and *Pseudomonas* sp. were found to be dominant in rhizosphere region and were most widely studied [53]. Besides these microbes, *Enterobacter hormaechei* was isolated from ceramic industry soil [41], *Agrobacterium tumefaciens* from waste mica [25], *Klebsiella variicola* from tobacco rhizosphere [53]. Asb 1, Asb 4, Prj 1, Prj 2, Sbr 3, Sbr 4 were the strains isolated from sugarcane rhizosphere by Setiawati and Mutmainnah [48]. Strain LJK2 isolated from paddy rhizosphere also proved to be an effective KRB [44]. *Micrococcus varians* and *Corynebacterium kutscheri* [47] possessed potash solubilizing ability. Studies also proved that fungi belonging to phylum Ascomycota such as *Aspergillus* sp. and *Penicillium* sp. [54] could effectively solubilize potassium. Chen et al. [38] isolated *Bacillus aryabhattai* (SK1-7), from the soil collected from the rhizosphere of *Populus alba*, that severely corroded the surface of mica. Saha et al. [40], isolated 7 efficient potash solubilizing strains from rhizosphere of rice, banana, sorghum, maize and wheat like *B. licheniformis, P. azotoformans, P. sabulinigri etc*. which dissolved potassium from waste biotite. All the strains produced slime as well as auxins. *Streptomyces alboviridis, S. griseorubens, Nocardiopsis alba* were the actinobacterial strains isolated from desert soils of Morocco that solubilized potassium [50]. KI_{11} and KA_{51} Gram-positive rod-shaped bacteria isolated from wheat and maize rhizosphere respectively, showed highest solubilization of waste mica [24]. Chen et al. [46] reported *Paenibacillus mucilaginosus* as an efficient KRB for apple seedlings. *Mesorhizobium* sp., *Paenibacillus* sp., and *Arthrobacter* sp. were identified as KRBs from Rape rhizosphere [55]. *Leclercia adecarboxylata* (GZ 18), *Burkholderia diffusa* (HZ 18), *Burkholderia stabilis* (SZ 5) were KRBs obtained from rhizosphere of *Mikania micrantha* [56].

The diversity of KRB was even evident in stressed environmental conditions. *Bacillus* sp. was isolated from Kollam and Andaman and Nicobar Islands (acidic conditions), Sunderbans (saline), *Halomonas* from Sambar Salt Lake (saline), *Psychrobacter, Pantoea, Providencia* and *Aeromonas* from Rohtang Pass (low temperature), *Klebsiella* sp. and *Brevundimonas terrae* from Chummathang hot spring (high temperature) [52]. According to the study conducted by Verma et al. [57], plant growth promoting activities were shown by some bacteria like *Arthrobacter methylotrophus, Arthrobacter nicotinonovarans, Bacillus* sp., *Flavobacterium psychrophilum* etc. and they also aided in P and Zn solubilization apart from K solubilization. These KRBs could promote growth as it solubilized, released and mobilized K to plants.

Table 1. The strains isolated from different sources are summarized

Sl. No	Potash releasers	Phylum	Gram positive/gram negative	Habitat	Source of isolation	Authors
1.	*Agrobacterium tumefaciens* (strain GL 11)	Proteobacteria	Gram negative	China	Tobacco	[53]
2.	*Enterobacter hormaechei* (KSB 8)	Proteobacteria	Gram negative	India	Ceramic industry soils	[41]
3.	*Brevibacillus brevis*	Firmicutes	Gram positive	India	Vashist thermal spring	[52]
4.	*Planococcus psychrotoleratus* and *Planomicrobium glaciei*	Firmicutes	Gram positive	India	Sunderbans mangroves	[52]
5.	*Bacillus flexus* (BHU03)	Firmicutes	Gram positive	India	Rice	[40]
	Bacillus pumilus (BHU11)				Banana	
	Bacillus safensis (BHU12)				Maize	
	Bacillus licheniformis (BHU18)				Wheat	
	Bacillus axarquiensis (BHU27)		Gram negative		Sorghum	
	Pseudomonas sabulinigri (BHU19)	Proteobacteria			Maize	
	P. azotoformans (BHU21)				Wheat	
6.	*Bacillus licheniformis* (KSB-1)	Firmicutes	Gram positive	India	Maize	[58]
	Bacillus subtilis (KSB-3)					
	Bacillus sp. (KSB-9)	Proteobacteria	Gram negative			
	Pseudomonas sp. (KSB-17)					
	Pseudomonas sp. (KSB-20)					
7.	*Agrobacterium tumefaciens* (OPVS 11)	Proteobacteria	Gram negative	India	Maize	[25]
8.	*Paenibacillus kribensis* (CX-7)	Firmicutes	Gram positive	China	Wheat	[43]
9.	*Bacillus cereus*	Firmicutes	Gram positive	Egypt	Potato	[59]
10.	UPS1C1		Gram positive	India	Effect was studied in groundnut crop	[47]
11.	*Klebsiella variicola*	Proteobacteria	Gram negative	China	Tobacco	[53]
12.	*Rhizobium radiobacter* (CH9E)	Proteobacteria	Gram negative	Vietnam	Weathered rock	[60]
13.	*Leclercia adecarboxylata* (GZ18)	Proteobacteria	Gram negative	China	Mikania micrantha	[56]
	Burkholderia stabilis (SZ5)					
	*Burkholderia diffusa (*HZ18)					
14.	*Paenibacillus mucilaginosus* (JGK)	Firmicutes	Gram positive	China	Apple	[46]
15.	*Bacillus amyloliquefaciens* (IARI-HHS2-30)	Firmicutes	Gram positive	India	Wheat	[57]
16.	*Mesorhizobium* sp. *(*S-15)	Proteobacteria	Gram negative	China	Rape and effect were studied on Rye	[55]
	Paenibacillus sp. (S-17)	Firmicutes	Gram positive			
	Arthrobacter sp. (S-18)	Actinobacteria	Gram positive			

Sl. No	**Potash releasers**	**Phylum**	**Gram positive/gram negative**	**Habitat**	**Source of isolation**	**Authors**
17.	*Pantoea agglomerans* (KSB 37) *Rahnella aquatilis* (KSB 39) *Pseudomonas orientalis* (KSB 44)	Proteobacteria	Gram negative	Iran	Rice	[61]
18.	*Bacillus aryabhattai* (SK1-7)	Firmicutes	Gram positive	China	*Populus alba*	[38]
19.	*Nocardiopsis alba*	actinobacteria	Gram positive	Morocco	Desert soils	[50]
20	*Rhizobium pusense* and *Stenotrophomonas maltophila*	Proteobacteria	Gram negative	India	Banana	[62]
21.	SS 7-6		Gram negative	India	Potato	[54]
	SS-13		Gram positive		Mango	
	P-21		Gram positive			
	SS 7-7		Gram positive		Potato	
	P-4-1		Gram negative		Turmeric	
	Fungus F1, F2-*Aspergillus* sp. F3-Penicillium sp.	Ascomycota				

6. IMPACT OF POTASH RELEASING BACTERIA ON CROPS

The potassium releasing microorganisms which make the potassium in available form, also produces some plant hormones such as IAA, that have a beneficial effect on the plant growth and development. Several studies showed that inoculation of soil with KRB had a positive influence in the growth of different crops such as wheat [30], okra [33], egg plant [63], rape and cotton [64], sorghum [65], cucumber and pepper [66], peanut [67], Sudan grass [68,69], maize [70-72], tea [73], potato [59], tomato [74].

Bagyalakshmi et al. [73], came up with a conclusion that, balanced application of potassium fertilizers along with KRB remarkably improved the yield potential and conserved the soil health in tea ecosystem. The research organism, *Pseudomonas putida*, boosted up the tea plant growth and decreased the banji content. The chlorophyll, carotenoids, and catechin contents were enhanced with application of KRB along with NPK, which improved the photosynthesis and thereby the yield. A pronounced increase in polyphenols like theaflavins and thearubigins was noticed with combined application of $N_{100}P_{100}K_{75}$ and KRB. Improvement in quality parameters like caffeine content (3.9% than control), colour, flavour and briskness index were also noteworthy. *Paenibacillus glucanolyticus* strain IISRBK2 isolated from black pepper rhizosphere was found to increase the plant dry weight by around 37 to 68.3% and K uptake by 125-184% [75]. *Pantoea* sp., *Pseudomonas* sp., and *Rahnella* sp. found in paddy rhizosphere produced IAA, solubilized K and conferred the plant tolerance against stress condition [61]. The CX7 strain (*Paenibacillus kribensis*), inhibited the growth of pathogens like *Pestalotiopsis microspora*, *Fusarium graminearum* (wheat scab), *Fusarium oxysporum* (cotton wilt), *Rhizoctonia solani* (Wheat root rot) and cotton yellow wilt pathogen [43]. Okra plant rhizospheric soils inoculated with *Enterobacter hormaechei* showed an increase in root and shoot length and also showed increased efficiency of K mobilization in plants [33]. The potassium releasing strains XF11, JM3, when inoculated to tobacco seedlings also showed increased seedling height, dry weight, biomass yield and adsorption of N and P [53].

According to the study conducted by Verma et al. [57], in KRB isolated from wheat rhizosphere from north eastern hills of India, plant growth promoting activities were shown by some bacteria like *Arthrobacter methylotrophus, Arthrobacter nicotinonovarans, Bacillus* sp., *Flavobacterium psychrophilum* etc. They aided in P and Zn solubilization apart from K solubilization. Some strains were antagonistic against *Fusarium graminearum, Rhizoctonia solani* and *Macrophomina phaseolina*.

The KRBs, *Micrococcus varians* and *Corynebacterium kutscheri* treated groundnut plants had shown higher number of pods per plants, increased biomass, increased root and shoot length, with increased production by 3.43 times [47]. KRB strains *viz*; *Mesorhizobium* sp.(S-15), *Paenibacillus* sp. (S-17), *Arthrobacter* sp.(S-18), isolated from rape rhizospheric soil enhanced the potassium uptake in rye grass, growth vigour, and biomass yield [55]. Kasana et al. [76], reported that the potassium solubilizing fungal strain, *Fomitopsis meliae* RCKF7 when treated with the seeds of wheat showed increased shoot dry weight, weight of spikes and grain yield. In rice samples inoculated with KRB isolates, KSB 37, KSB 39 and KSB 44, grain yield and K uptake was prominent. There was an increased concentration of K in both grain and straw with increase in the agronomic efficiency (AE) and physiological efficiency (PE) which ranged from 9.25 to 20.67g per grain and 25.25 to 128.2g per grain respectively. KRB inoculums markedly increased chlorophyll a, chlorophyll a+b, SPAD value and stomatal conductance in paddy [77]. Potash releasing bacteria *viz.*, *Rhizobium pusense* KRBKKM1 and *Stenotrophomonas maltophila* KRBKKM 2 along with *Azospirillum*, phosphobacteria on application to banana gave better results with a reduction of chemical fertilizers by 25% [78].

Primary root length, number of leaves, plant height, dry weight, K^+ content in leaves, stem and roots, were found to be more in apple seedlings inoculated with potash releaser *Paenibacillus mucilaginosus*. It was also found to produce phytohormones like zeatin, kinetin, gibberellin and auxins which promoted the growth of apple seedlings [46]. When the influence of biofertilization was studied with *Bacillus cereus* in potato plants, a total increase in plant height (15%), number of branches (21%), biomass production (39%), shoot fresh weight, leaf area, chlorophyll content, N, P, and K uptake by the plants (34%,32%, and 62% respectively), organic matter (10%) were observed in comparison with the control and thereby caused a rise in potato yield by 21% more than the uninoculated plants [59]. Sun et al. [56], reported that the KRB strain *Lecleracia adecarboxylata* GZ18 had increased the potassium adsorption as well as the growth of *Mikania micrantha.* Also, increased resistance against stress, pathogen and insect attack due to the enhanced K content was noticed. When *Bacillus aryabhattai* SK1-7 strain was applied to soil in which Poplar was grown, it was noted that there was an increase in the rate of plant height from 1.91 to 21.1%, rate of plant diameter from 4.88 to 9.7%, plant fresh weight by 38.3% (68.6 to 94.9), plant dry weight by 22.7% (43.5 to 53.4), chlorophyll content by 39.8% (32.7 to 45.7), root activity by 31.7% (68.7 to 90.6) and total plant K from 0.43 to 0.6 as compared to control. There was also an increase in the available K content in the rhizosphere soil from 15.68 to 164 mg/kg of soil [38]. Potash and phosphate solubilizing bacteria increased seed germination, hypocotyl length, root length etc. in wheat when fertilized with rock phosphate. In wheat *Nocardiopsis alba*, was appeared to be the best potassium solubilizer that enhanced plant height (8.92- 23.5%), root length (1.75-23.84%), shoot dry weight (2.56-65.68%), and root volume (41.57-71.46%) over control [50].

7. CONCLUSION

The biggest challenge in front of a developing country like India is to curtail the import of chemical fertilizers. India is one of the leading importers of potash fertilizers and though most of the Indian soils are rich in potassium, the availability is a big question. As like all other chemical fertilizers, in long run, potassium too became hazardous due to accumulation in soil. The requirement to shift to a sustainable form of agriculture production by reducing the ecological foot print demands the use of microbial solubilizers, releasers and mobilizers. KRBs can solubilize the available sources of potassium and could make it available to plants. With the use of potash releasers along with chemical fertilizers we can be sure of the availability of potassium to crops, with minimum residues in soil. So, altogether, we can conclude that usage of these KRBs is a reassuring, reliable, sustainable and a cost-effective way for balanced potassium transformation by unlocking the locked potassium in the soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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