R-2196
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REVIEW ARTICLE Agricultural Reviews, Volume Issue : ()

Revitalization of Potassium Solubilizing Microbes in Food Production System: An Overview

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10.18805/ag.R-2196

ABSTRACT

Potassium is one of the main nutrients required for plant growth and development. Potassium is useful in agricultural for better plant growth and disease resistance. Potassium deficiency in plants is identified through poorly developed roots, slow growth and higher disease attack, delayed maturity and ultimately lower crop yields. Continuous use of chemical fertilizers makes the soil devoid of organic potassium in the soil. Under such conditions, the application of biofertilizers can be the best approach to increase the solubility of soil potassium. The potassium solubilizing bacteria (KSB) were derived from diffuse potassium, silicon and aluminum from K-insoluble aluminosilicate minerals, such as orthoclase, micas, illite and biotite. KSB plays an important role in increasing nutrient availability in the soil by increasing the soluble form of potassium.

Key words: Fertilizer, Plant, Potassium solubilizing bacteria, Potassium, Soil.

Natural sources of potassium materials are cost-effective. On the other hand, nutrients from them are not readily available to a plant due to their very low solubility that results in slow potassium (K) release in the soil. Similarly, the organic source of potassium represents an insignificant increase in the crop yield. Certain microbial strains are discovered which are quite effective in the rapid solubilization of potassium existing deposits and reduce the environmental residue of chemical fertilizers caused. They have generally named biofertilizers that solubilize the K-bearing minerals. Potassium solubilizing microorganisms (KSM), as biofertilizers, has gain attention in agriculture as a large area is potassium deficient. Muentz (1890) firstly described the role of microbial penetration towards potassium solubilization in rocks. He also stated about bioformulation studies of bacteria in the rhizosphere that promote plant growth. The complete replacement of chemical fertilizers to increase agricultural production and plant health is not possible but reduced to a great extent by the use of microorganisms. Various microorganisms such as *Bacillus*, *Aspergillus* and *Clostridium* have been shown to multiply in orthoclase, microcline, muscovite, micas and biotite under controlled laboratory conditions (Meena *et al.* 2015).

Importance of potassium solubilization

The potassium solubilizing bacteria (KSB) were derived from diffuse potassium, silicon and aluminum from K-insoluble aluminosilicate minerals, such as orthoclase, micas, illite and biotite. Managing the proper population of such type of bacteria would reduce dependence on environmentally unsafe and economically unstable chemical fertilizers. Purushothaman *et al.* (1974) in a study stated that such microbial distribution plays a pivotal role in transforming the excretory metabolic excretion that combines with the mineral surface, dissolving the silicon in the silicate clays. Barker *et al.* (1998) reported that intact microbial respiration, the decomposition of organic matter and its dissolution through carbonic acid production by microbial activity can improve the rate of mineral dissolution. Therefore, a specific type of potassium was analyzed by bacteria that dissolve minerals for the release of K and SiO_2. Several studies on mineral alteration have been reported by Vandevivere *et al.* (1994) that the *Bacillus* species have the potential to solubilize K in the culture medium containing various types of minerals. They showed that *Bacillus* species such as *B. mucilaginosus* optimizes the solubilization of K and SiO_2 from the various primary minerals through the release of organic acids during the decomposition process. In general, KSB plays an important role in increasing nutrient availability in the soil by increasing the soluble form of potassium.

Sources of potassium solubilizing microorganisms

In the last decade, KSB has been isolated mainly in Asian countries from various sources their ability was illustrated to release the K has been tested using different substrates. Although mica enriched locations are the sources of

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How to cite this article: Singh, A., Singh, B., Chinna, G.S., Chahal, H.S. and Devi, R. (2022). Revitalization of Potassium Solubilizing Microbes in Food Production System: An Overview Agricultural Reviews. DOI: 10.18805/ag.R-2196.

Submitted: 19-03-2021 **Accepted:** 01-02-2022 **Online:** 12-03-2022

potassium solubilizing biofertilizers (Gundala *et al.* 2013). KSB strains capable of releasing microcline, potassium muriate, etc. were isolated from soils grown with various types of vegetation (Saiyad *et al.* 2015) where bacterial and fungal strains exhibited solubilization of potassium from various minerals (Prajapati *et al.* 2013). Rhizospheric soils are good sources of KSB (Padma and Sukumar 2015) that are capable of solubilizing potassium from different insoluble sources, as is the case of black pepper using wood ash with isolated deformations of the rhizosphere (Sangeeth *et al.* 2012) and with wheat and corn like crops root zone isolates using media enriched with different types of mica (Parmar and Sindhu 2013). Biofertilizers related to potassium can also release it from montmorillonite, feldspar (Hu *et al.* 2006), silicate materials (Liu *et al.* 2006), potassium rocks (Liu *et al*. 2012) and feldspar (Zeng *et al.* 2012) was isolated from different soils. Besides, KSB was also detected from the cotton-growing zones (Sheng and He 2006) and from the rhizospheric soil of different plants capable of releasing K from feldspar K in solid or liquid media (Kumar *et al.* 2015). Zarjani *et al.* (2013) isolated almost six bacteria strains from different Iranian soils and. Leaungvutiviroj *et al.* (2010) also found several KSB strains in rhizospheric soil in Thailand whereas, In Russia, the KCTC 3870T strain of *Paenibacillus mucilaginosus* was isolated from rocks. Similarly, In Brazil, Rosa-Magri *et al.* (2012) isolated two strains of fungi capable of solubilizing K from the ultramafic dust of alkaline rocks from the sugarcane rhizosphere and sugarcane vinegar by Lopes-Assad *et al.* (2010).

Diversity of potassium solubilizing microbes (KSM)

Different groups of soil microorganisms are involved in the release of potassium (Singh *et al.* 2010). A large group of soil microorganisms such as *Bacillus spp*., *Pseudomonas*, *Aspergillus terreus*, *A. niger*, etc. (Wu *et al.* 2005; Rajawat *et al*. 2016) demonstrated their ability to solubilize K minerals. These microbes are ubiquitous and their dominance depends on soil structure, texture organic matter and other properties. Most soil microorganisms are well known to colonize the rock's surfaces (Gundala *et al.*, 2013). Among these microbes, *B. mucilaginosus* can solubilize potassium from feldspar (Aleksandrov *et al.,* 1967). Potassium solubilizing bacteria, for example, *B. mucilaginosus* were detected from the rhizosphere which had soils modified with K and silicates (Mikhailouskaya and Tcherhysh, 2005). These microbes (silicate solubilization) are present in rhizospheric and non-rhizospheric soils (Zahedi, 2016). Over the past decade, a wide variety of bacterial species involved in the solubilization of K have been found, including *B. edaphicus*, *B. mucilaginosus*, *Burkholderia* sp. *A. ferrooxidans*, *Arthrobacter* sp. *etc.* (Sangeeth *et al.,* 2012). These bacteria can release K in the rhizosphere to some extent, but only a few bacterial strains such as *B. mucilaginosus* and *B. edaphicus* are very effective in solubilizing K minerals (Rajawat *et al.,* 2012).

Solubilization mechanisms of K-biofertilizer

Certain organic synthesis is produced by microbial metabolism through the transition from crystalline biotite, mica, vermiculite and certain rocks to an amorphous form (Weed *et al.,* 1969). Extracellular enzymes, metabolic by-products and chelates and acids and light organic compounds form several organic ligands that can increase the release of aluminosilicate minerals. Organic acids control the further degradation of various minerals such as sandstone, granite and limestone, which is ultimately related to a decrease in the pH of the soil environment. According to Chen *et al.* (2007), certain strains of *B. megaterium* and *Arthrobacter spp*. were able to produce organic acids and siderophore monohydroxamate. The release of elements such as K, Si and Fe in the liquid medium is linked to organic acids and siderophores (Hutchens *et al.* 2003). Interactions between the soil microflora and the minerals have been extensively studied to produce technologies such as biomineralization, bioremediation and biohydrometallurgy (Venkateswarlu *et al.* 2012,). Jones *et al.* (2003) stated that processes like nutrient recovery from the roots, mineral decomposition, microbial chemotaxis, etc were related to organic acid production (Fig 1). Besides, capsular polysaccharides production helps to alter the minerals like illite and feldspar to release potassium in soil (Sheng *et al.* 2006). Mobilization of K resources, producing biofilms in the rhizospheric soil of the mineral surface by certain conclusive bacterial strains is also a chief factor affecting solubilization (Balogh-Brunstad *et al.* 2008). It was found that ectomycorrhizal cardiac networks implanted in biofilms transport nutrients to the host plants. These studies indicated that biofilms help to stimulate the alteration of soil minerals and, therefore, increase the absorption of nutrients by the plant. Some decomposing fungi can exude organic anions in

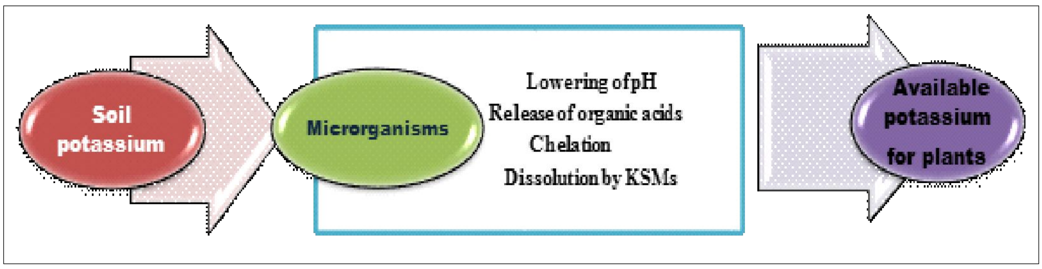

Fig 1: Mechanism of K-Solubilizing bacteria in soil ecosystem.

the minerals present in the soil, which consequently increase the rates of mineral alteration (Van Scholl *et al.* 2008).

Molecular characterization of KSM

Previously, in the application of KSM in the cultivation fields, they were known by various biochemical tests (coloration, amylase, carbohydrates and IMViC) and PGPR activities. Therefore, molecular techniques (such as metagenomics) have provided ways to determine bacterial diversity. The limiting factor in the exploration of new enzymes and activities that promote plant growth due to the very limited variability has been the isolation and identification of microbes. Therefore, microbiology focused on two areas of study: (i) detailed study of microbial communities (ii) microbial activity (Fenchel, 2005). So main focus should based on soil microbial diversity to develop sustainable microbial pools of potassium solubilizing microorganisms.

Factors that affect potassium solubilization

Biotic factors, such as pH, temperature and mineral type containing K affect the release of potassium (Sheng and Huang 2002a). Yakhontova *et al.* (1987) also stated that the ability of KSB depends on the mineral composition. Welch *et al.* (1999) described that extracellular polysaccharides type significantly affects the release of K from minerals. Sheng *et al.* (2002) also demonstrated a release of 35.2 mg / L of potassium from strains of KSM in 7 days at 28^{o}C, at a pH of 6.5 to 8.0. Lian *et al.* (2008) found that the K release rate showed a direct relationship with pH w. Lopes-Assad *et al.* (2010) found that the percentage of K solubilization decreases at higher volumetric scales (Supanjani *et al.* 2006).

Main processes responsible for the solubilization of K

Many processes are involved in the solubilization of K, as shown below.

Erosion

Soil microorganisms accelerate the decomposition of rocks and minerals. This is also called abiotic change. It involves a change in mineral composition that includes physical and chemical changes. For example, a symbiosis between fungi and algae (lichens) improves the alteration of minerals and the transfer of loose materials. On the other hand, rhizobacteria, produce 2-ketogluconic acid that binds calcium and therefore acts as a powerful degradation agent in basic rocks. Alternatively, soil microorganisms during respiration produce CO_2 which reacts with water and forms carbonic acid which imposes a strong dissolution impact on soil minerals.

Ion exchange process

Plants always require balanced availability of nutrients throughout the life cycle. Nutrients become available to plants by ion exchange processes. Ion exchange processes involve fixation, solubilization and adsorption and desorption in soils. Plants absorb only nutrients or ions that reach the soil solution when the proper equilibrium between soil adsorption sites and the soil solution is maintained. Lindsay (1979) also described the chemical equilibrium between the ions in the soil solution phase and the solid phase. Nutrients are adsorbed to the maximum extent, especially K when the soil is negatively charged. Soil microorganisms also contribute to ion exchange processes through the production of H^+ ions and acids. In this way, potassium is released into the soil solution and becomes easily available to plants. Exchange of two K^+ ions from the soil adsorption sites occurred when Ca^{2+} is present in excess in the soil solution and ultimately it contributes to the desorption and solubilization of it. These ions also exchange K which is trapped in mineral lattices.

Decomposition of organic waste

Decomposition of organic matter is one of the chief processes contributing to solubilization or release of K in soils. The decomposition of organic matter adds K and other nutrients to the soil. Decayed plant parts are recycled due to the action of soil microorganisms on them. These microorganisms take their food from the dead material and convert it into an inorganic form which is readily available form.

Role of KSM in K solubilization

Soil microorganisms including bacteria, fungi and actinomycetes, *etc.* play important role in the alteration of mineral elements. Bacterial species are chief players in this system. They are responsible for the solubilization of potassium from insoluble sources and potassium mineral lattices. The potassium released in this way becomes available for plants (Gundala *et al.* 2013). The history of the use of bacteria for the solubilization from K minerals is very old. For example, Aleksandrov *et al.* (1967) isolated silicate bacteria in agricultural soils capable of solubilizing K from aluminosilicates. Muentz (1890) also stated the participation of microbes in the potassium solubilization in rocks. Gundala *et al.* (2013) also reported that microbes are capable of solubilizing K from feldspar and aluminosilicates. Today, a wide range of species in the genera *Bacillus, Paenibacillus, Acidithiobacillus, Pseudomonas*, *etc*. have been reported to have the solubilization capacity of K. K solubilized by bacteria and fungi in the soil contributes significantly to the increased soil potassium availability (Sindhu *et al.* 2009). Mineral silicate solubilizing bacteria (MSB) have also been reported in the rhizosphere of many croplands (Lian *et al.* 2002). According to Mikhailouskaya and Tcherhysh (2005), KSB is also present in the roots of cereals making a symbiotic association. A huge variety of soil bacteria is reported as K solubilizers. Some examples of K solubilizers include *Bacillus mucilaginosus* (Basak and Biswas 2009), *Burkholderia* (Uroz *et al.* 2007), *Enterobacter hormaechei* (Prajapati *et al.* 2013) and *Arthrobacter. spp.* (Zarjani *et al.* 2013). These bacteria can be used in mines, animal feed and metallurgy in addition to being used as biofertilizers in agricultural fields (Zhao *et al*. 2008). Likewise, as rhizobia species can fix atmospheric nitrogen, *Pseudomonas* has also been reported as a K solubilizer (Requena *et al.* 1997).

Role of potassium solubilizing microbes in maintaining soil fertility and crop productivity

For sustainable crop production, it is very important to maintain soil health. An intensive agricultural system makes the soil devoid of nutrients. Soil nutrient availability can be improved through the adoption of an integrated nutrient management system (Vlek and Vielhauer, 1994). For sustainable agriculture, the use of biofertilizers is very useful to decrease the use of chemicals (Ghorbani *et al.* 2008). The application of biofertilizers constitutes an important element of the integrated nutrient management system. Biofertilizers are economical and ecological products (Mohammadi and Sohrabi 2012). Biofertilizers contain a series of microorganisms that increases nutrient in soil (Shanware *et al.* 2014). Biofertilizers also protect the plant against a series of biotic and abiotic stresses (Nadeem *et al.* 2013). As biofertilizers increase the solubility of native nutrient from soil, it also reduces the dependence on chemical fertilizers to achieve the required crop yield (Habibi *et al.* 2011). KSM increases the potassium solubility by certain mechanisms, as discussed in the previous sections. Although K rock is a cheaper source of potassium, however, a slow release of potassium results in an insignificant increase in its use in agricultural fields (Zapata and Roy 2004). The use of KSB as *B. mucilaginosus* can escalate the soil K content. They observed that the mere application of P and K rocks did not improve significantly the content of phosphorus and potassium in the soil; however, the application of KSM increased the P and K availability. Similarly, Supanjani *et al*. (2006) also demonstrated the influence of organic fertilizers that contain P and K solubilizers in the growth and yield of peppers (*Capsicum annuum* L.). Rock phosphate (RP) application with biofertilizers increased the K content in the soil. Abou-el-Seoud and Abdel-Megeed (2012) also reported an increase in nutrient availability after the application of biofertilizers containing PSB. It was observed that the Application of KSB with the fungus *A. terreus* impacts the root to shoot ratio of okra with increased K availability in the soil (Prajapati *et al.* 2013). It was concluded that the solubilization of K and the release of organic acids by KSM increased plant growth. Patel (2011) also demonstrated that the microbial-based product containing *F. aurantia* produces a plant growth-promoting substance that has increased plant growth and solubility of potassium. El-Haddad *et al*. (2011) demonstrated the influence of four strains of nitrogen-fixing bacteria (*Paenibacillus polymyxa*) and three strains of PSB (*B. megaterium*). They described that these biofertilizers significantly decreased the nematode attack. Similarly, KSM caused a significant increase in corn growth (Wu *et al*. 2005). The biofertilizer not only improved plant growth but also had a positive effect on soil health. Dasan (2012) also demonstrated the effectiveness of KSM (*F. aurantia*) against agrochemicals. These strains could grow in the presence of agrochemicals and can be used as agents against plant pathogens as biological control. Short shelf life, the effect of storage temperature and inadequate packaging are certain factors that affect the efficiency of biofertilizer use (Verma *et al*. 2011). The support material used for the preparation plays an important role in the better life of the biofertilizer before its application in the field (Brar *et al*. 2012). According to Bhattacharyya and Kumar (2000), the vehicle-based formulation has a longer useful life and can be used without compromising its quality for 6 months. The useful life of K solubilizer-based biofertilizers was assessed high in liquid broth formulation. Using KSB as a biofertilizer to improve agricultural productivity can also improve the quality of the environment (Liu *et al*. 2012). Therefore, it could be used as an ecological approach to conserving nature (Sindhu *et al*. 2010). Bacteria can be isolated and grow easily to develop a biofertilizer for agricultural purpose

The continuous use of chemical fertilizers deteriorates the soil as well as affects the diversity of the microorganisms. Lin *et al.* (2002) evaluated a significant escalation in the solubility of K in tomato crop inoculated with a bacterium that dissolves silicate (*B. mucilaginosus*) compared to control. The treatment with *B. mucilaginosus* produced 36.6% more biomass as compared to control (Basak and Biswas 2009). Similarly, *Aurantia* significantly increases respective crop yields (Ramarethinam and Chandra 2006). Apart from it, microorganism activity also secretes amino acids, vitamins, gibberellic acid, *etc*. which help to improve plant growth (Ponmurugan and Gopi 2006). Shrubs growth in terms of the number of plumage points, intermodal length, *etc*. may be attributed to the action of KSB (Bagyalakshmi *et al*. 2012). Prajapati *et al*. (2013) reported okra growth by inoculation with the bacterial strain *E. hormaechei*. Silicate bacteria can alter K minerals in the soil, solubilize K in soil and make it available to plants (Sun and Zhang 2006). *B. mucilaginosus* grows well medium with potassium feldspar. Improvement in nutrient K may favor changes in a series of ~70 enzyme activities (Ai-min *et al.* 2013). KSM is one of the best ways to cope with the nutrient supply chain to plants (Burgstaller *et al.* 1992).

Many researchers have shown a significant increase in germination rate as well as seedling vigor. Aleksandrov (1985) stated that the application of organo-minerals in conjunction with silicate bacteria increased plant growth. Sheng (2005) demonstrated the influence that the application of *B. edaphicus* NBT promotes plant growth and nutrient absorption in cotton and oilseed rape. Sheng and He (2006) experimented with a deficient soil in potassium under wheat crop and described that after inoculation with biofertilizer, the growth of roots and sprouts of Wheat increased significantly. Likewise, Badar *et al.* (2006) demonstrated that the application of KSM in sorghum increased the biomass yield. Supanjani *et al.* (2006) reported that the combined use of K rocks with KSM increased the availability of K. According to Sugumaran and Janarthanam (2007), studied the effect of biofertilizers in peanut and found that *B. mucilaginosus* increased dry matter as well as oil content. Archana *et al*. (2008) isolated KSM from the rhizosphere of green grass (*Vigna radiata* L.) and reported that these KSM improved the availability of potassium in soils. Basak and Biswas (2009) observed that under sudanese herb, application of K solubilizing bacteria (*B. mucilaginosus*) improved the biomass yield as well as K availability. Singh *et al.* (2010) performed a hydroponic experiment under corn and wheat with *B. mucilaginosus, Azotobacter chroococcum and Rhizobium spp.* and they reported that, among Rhizobacteria, *B. mucilaginosus* resulted in maximum K mobilization significantly among other. According to Archana *et al*. (2012), *Bacillus spp.* resulted in a significant increase in plant growth and development. Bagyalakshmi *et al.* (2012) evaluated the effect of KSM under tea plantation and stated that solubilization is more in the presence of KSM as compared to control. Abou and Abdel (2012) evaluated the synergistic effects of biofertilizers with chemical fertilizers under corn crop and reported higher dissolution of K. Prajapati *et al.* (2013) performed a trial with *Enterobacter hormaechei* and K-releasing strains of fungi *A. terreus* to demonstrate the influence of both on plant growth and nutrient availability in soil under okra (*Abelmoschus esculantus*) in K. deficient soils. *E. hormaechei* improved the growth of roots and shoots as compared to *A. terreus*.

Role of potassium solubilizing microbes in disease resistance and stress in crops

Plants are exposed to many abiotic and biotic stresses, such as cooling, drought, pest and diseases (Cakmak, 2005) Optimum K availability to the plant provide resistance to them against stress, disease and pest attacks (Rehm and Schmitt, 2002) and also stated that potassium protection to the plant against various diseases. It promotes better growth and development of the roots and strengthens the stem which offers resistance against frost and drought resistance. Potassium also improves the quality of produce (Cakmak, 2005). Microbes like *Frateuria* showed greater potential for providing greater resistance to water stress (Cakmak, 2005). KSM can improve plant growth, root growth and resistance to external biotic and abiotic stress. Bacterial species such as *Bacillus, Enterobacter, Pseudomonas*, *etc*. have also been used in various experiments due to their beneficial role in the plant's growth mechanism (Hoflich *et al*., 1994).

The role of KSM in sustainable agriculture

Potassium is one of the main nutrients required for plant growth and development (Zhang *et al*. 2011). The role of potassium is well known for improving plant life and stress resistance (Khawilkar and Ramteke 1993). Potassium is useful in agricultural land along with plant growth and disease resistance, it also activates many enzyme systems, maintains turgor pressure and translocation sugars and starch. Potassium deficiency in plants is identified through poorly developed roots, slow growth and higher disease attack, delayed maturity and ultimately lower crop yields. Continuous use of chemical fertilizers makes the soil devoid of organic potassium in the soil. The solubility of organic K is very less and the maximum part of potassium exists in an insoluble form. The largest deposits of potassium are sludge, clay and sand. The most common minerals containing K are feldspar and mica and fortunately, India has the largest mica mines in some districts of Bihar and Jharkhand. Under such conditions, the application of biofertilizers can be the best approach to increase the solubility of soil potassium (Zhang and Kong 2014). Jhang and Kong (2014) conducted an experiment under tobacco, inoculated with the strains of *Klebsiella variicola* JM3, XF4 and XF11, showed greater height and dry weight as compared to control.

Today, biofertilizer is the best alternative for chemical fertilizer to maintain soil fertility along with sustaining crop productivity. The use of biofertilizers seems the too good possible solution to improve plant production and nutrients (Vessey 2003). Biofertilizers are applied to seeds/roots or the soil in liquid, powder, or granule form, which increased the mobility of nutrients, particularly NPK Biofertilizers can prevent nutrient leaching and lead to higher nutrient availability in the soil. They are cost-effective and environmentally friendly compared to chemical fertilizers. Although the use of biofertilizers has grown in recent years because chemical fertilizers are expensive and can have adverse environmental impacts (Aseri *et al*. 2008).

Strategies to improve the efficiency of potassium solubilization for use as a biofertilizer

Soil microorganisms play a crucial role in different biogeochemical cycles (Wall and Virginia 1999). Microorganisms provide a sustainable and safe ecological system. The mechanism of potassium solubilization by microbes has been studied extensively, but K solubilization is a complex phenomenon affected by various factors, such as microorganism type, soil fertility, mineral type and environment. Apart from it, the vitality of microbes after inoculation into the soil is the chief factor. Intensive scientific work paved the way for a better understanding of the specific regulatory and signaling processes that govern the association of microorganisms with the plants (Matilla *et al*. 2007). The use of molecular techniques for the genetic modification of microorganisms resulting in their better functioning in the rhizosphere (Ryan *et al*. 2009), which leads to a substantial improvement in nutrient cycling. Proper characterization of bacterial isolates that solubilize K for other characteristics that favor plant growth and nutrient solubility are also necessary to find out bacterial strains with many other useful functions (Sindhu *et al*. 2002). Soil engineering with the inoculation of these beneficial bacterial strains with optimum availability of soil organic matter is extremely important to maintain the life cycle of these microorganisms. There is a need to maintain prime levels of quality insurance in terms of microbial populations in the formulation with a long shelf life in commercial formulations (Lian *et al.* 2007). Care must also be taken while selecting strains that are well adapted to the local environment (high temperature, alkaline/acidic, or low water soils) (Kirk *et al.* 2004). Bacterial strains having effective solubilization activity under high buffer conditions should be isolated and analyzed deeply. Mutagenesis remains a powerful tool for the development of more efficient and effective strains. Strategies are needed to clone genes from KSM and transfer these genes to microbial strains with good colonization potential (Zhang *et al*. 2013). Synthesis of genes through metagenomic analysis is another area of research (Ryan *et al*. 2001). The microbial interactions in the soil between the N, P and K solubilizing microorganisms are also in need to study (Sindhu *et al*. 2014). The development of better cultural practices and better administration systems can also improve the establishment of microorganisms in the rhizosphere (Sindhu and Dadarwal, 2000). Production of liquid-based formulations is also expected to advance the biofertilizer use technology compared to other older carrier-based technologies. Mixture application of PGPR with various useful activities may be a more ecological approach, as they can lead to their better establishment in the environment. Therefore, the use of biotechnological approaches for the manipulation of bacterial characteristics will improve the efficiency of KSM.

KSB's potentials and challenges in the industry

KSB increases the process of solubility of K from different mineral surfaces by various means of action. Efforts were made to use KSM to release K from different minerals containing K (Saha *et al.* 2016) and thus increase plant nutrient availability. Although KSB can be a reasonable alternative to increase the solubility of insoluble K forms. Its application in agricultural practices is still limited due to a lack of proper knowledge among farmers. Similarly, low curiosity among scientists about the progress of K biofertilizer improvement techniques and the development of microbial deposit banks are not yet established well for KSB. In particular, due to such type less interest in working on KSB. Therefore, the inadequacy of innovation related to the durability of carriers and product formulations are among the major limitations of the industry, which should need to be soon improved.

CONCLUSION

KSM plays an important role in increasing the availability of potassium in the soil by increasing the soluble form of potassium. Besides, vigorous research in this area is necessary to isolate native strains of microorganisms capable of not only solubilizing K but also other nutrients. In this way, these microbes can be more beneficial for soil health and crop quality.

Conflict of Intrest: None

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