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19

PLANT GROWTH PROMOTING RHIZOBACTRIA AS ALLEVIATORS OF SALINITY STRESS IN PLANTS#

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Abstract

Global climate change and increasing population are most serious challenges facing us today. Agriculture is considered to be one of the most susceptiblesectors to climate-change.Salt stress are major constraints for crop yield, food quality and global food security. A number of parameters such as physiological, biochemical, molecular of plants are affected under stress condition. Salts have detrimental effects on plants such as damage to photosynthetic machinery, growth retardation and ultimately yield loss. However, the rhizosphere of plants harbours a diverse community of microbes which have the potential to cope with salinity problem. These microbes assist plants to withstand the increased concentration of salts by the production of antioxidants, secondary metabolites, volatile organic compounds(VOC), EPS and osmotic adjustment in plants. These microorganisms have the potential to work as defensive agents of plants by enhancing growth, productivity, tolerance and defence system under saline environments. In this review, we have attempted to explore about the stress tolerant beneficial microorganisms and their modes of action to enhance the sustainable agricultural production.

Keywords: Plant Growth Promoting Rhizobacteria, plants, Salt stress, Salt stress tolerance, Microorganisms.

#General Article
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Introduction

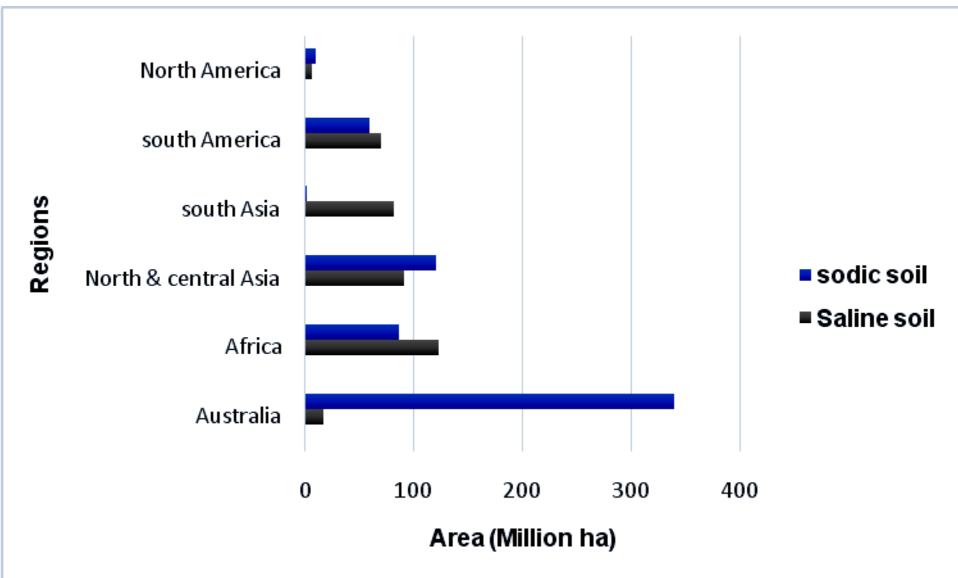
Soil salinity has emerged as a serious problem for global food security. Increasing human population and reduction in land available for cultivation are two threats for agricultural sustainability (Shahbaz and Ashraf, 2013). Many research studies have reported that environmental stresses are a serious global threat to future of food security (Battisti and Naylor, 2009), while the world human population is projected to reach from a current estimated 7 billion approximately to 9.9 billion by 2050 (Singh et al., 2011). As highlighted in 2018 Global Agricultural Productivity (GAP) Index the current growth rate of agricultural production is not enough to meet the projected food demand of 10 billion people in 2050 (GAP Report, 2018). The report also stated that under such circumstances GAP must be increased by 1.75% annually. Due to increasing climate variations, population and reduction in soil health for crop cultivation are major threats for agricultural sustainability. It can become more extensive in coming future due to these climate change and extensive agricultural practices (Wassmann et al., 2009). it is becoming very difficult for farmers and agricultural scientist to produce such large amounts of food to fulfil the needs of growing population. In addition, the extensive use of chemical fertilizers, pesticides, weedicides etc. in agriculture causes extreme loss of beneficial microbial diversity from the soil.

Salinity stress is the foremost vital abiotic stresses which results in significant damages of agricultural production, particularly in arid and semi-arid areas of the world. The soil with excessive amount of salt affects the productivity of plant and is known as salt-affected soil. In the root area, the saturation extract of saline soil has the electrical conductivity (ECe) more than 4 dS m−1 or 40 mM NaCl. The yield of many crops decreases at this electrical conductivity (Jamil et al., 2011). Two types of salinity occur in the soil; primary salinity occurs naturally when soil material is the main source of insoluble salts, whereas secondary salinity is caused by anthropogenic activities such as poor irrigation organization, unsatisfactory drainage, rotations, inappropriate cropping patterns, chemical contamination and vegetation sheath, which change the ecosystem of water balances (Singh, 2009). The key soluble salts in soil are cations: K+, Na+, Ca2+, Mg2+ and the anions Cl−, NO3 − and HCO3−) (Rengasamy, 2006). Salt-affected soils can be divided into saline, sodic and saline-sodic depending in type of salts, salt amounts, amount of sodium present and soil alkalinity. Each type of salt-affected soil will have various characteristics, which will also determine the way they can be managed. Salts in saline water accumulate in soil gradually increase concentration of soluble ions and decrease water level Thus, salt level increase at the surface of soil resulting in the appearance of a saline soil. High concentration of salts in the soil also disturbs various soil processes and the level of sodium at the interchange complex of the soil (sodicity) that affects the mechanical strength of soil. However, the harmful effects of salts depend on various factors e.g. Type of plant, climatic conditions, and soil-water regulation. Due to an increase in the soil salinity, there is a great need to find out the solution to this serious problem. The world population is increasing and world salt affected area will not be cultivable which would lead to global scarcity.

It is estimated that salt affected area including sodic and saline soil about 6% irrigated and 20% of world's total cultivable land is under the influence of salinity. Salinity problem is caused by the various natural and anthropogenic activities and increasing terribly with time. It is estimated that currently about 62 million hectares or 20 percent of the world's irrigated land is affected by salinity. It is also estimated that 50% of the cultivable land will affect due to salinity by 2050.

Global Distribution of Salt Affected Area

Although, it has been realized that all regions on the globe are facing the problem of soil salinity (Figure 1) yet accurate estimation of the locations and distribution of saline soils is missing. The Food and Agriculture Organization (FAO), United Nations Educational, International Society of Soil Science (ISSS) and Scientific and Cultural Organization – United Nations Environment Programme (UNESCO-UNEP) are the leading world agencies that paid attention in gathering data on quality of soil across the world. The Soil Map of the World (FAO, 1971– 1981) documented that a total area of 953 Million hectares (mha) is salt-affected worldwide. According to the report of FAO on "Status of the World's Soil Resources" soil of more than 100 countries with an estimated area of approximately one billion hectares is afflicted with the problem of salinity (FAO and ITPS, 2015). Due to very high amount of soluble salts (NaCl and Na2SO4) the Electrical Conductivity (EC) of these soils exceeds 4 dSm−1. At present, the soil classification system is driven by the World Reference Base for Soil Resources (WRB) which is authorized by the International Union of Soil Sciences (IUSS) and it replaced the FAO/UNESCO Legend for the Soil Map of the World. Probably, salinity is one of the leading problem in the coming decades due to global increase in salt-affected area by 1 to 2% every year (Kasim et al., 2016).It is reported that agricultural land will lose its capability of cultivation due to degradation by extensive use of man-made fertilizers, the salinity of soil, physical and chemical weathering (Ladeiro, 2012, Paul et al., 2003).



Graph 1. Global Distribution of Saline and Sodic Soil, Source: FAO and ITPS, 2015

Impact of Salinity on Plant

Salinity affects the soil properties and equilibrium of the area and reduces the yield of crops, thus it plays role in reducing commercial earnings. Different research studies reported that salinity effects plants in many ways as reduced growth and development, germination, and vegetative growth, reproductive development, reduction in delayed spike, spikelet per spike, development and fertility, which leads to low grains (Munns and Rawson, 1999). The harmful impact of salinity occurs in cell cycle and cell differentiation due to the decrease in the action of cyclins and expression of cyclin-dependent kinases, which causes the less cells growth in the meristem followed by the growth inhibition (Seckin et al., 2009). Salt affected soil causes ion toxicity, oxidative and osmotic stress in plants and nutrient deficiency which restrict the uptake of water from soil. The elevated levels of sodium, chlorine, and boron have particular harmful effects on plants. Various salts are present in nutrients of plant; their increased salt concentration in the soil can disturb the equilibrium of nutrient or affect the nutrient uptake by plant. Under salt stress, the metabolism and plant growth is severely affected by increased uptake of Na+. Ion toxicity can change concentration of K+ ions in chemical responses, which produce conformational variations in amino acids. High K+ level is imprtant for tRNA binding with ribosomes and synthesis of amino acids (Zhu, 2003). The high accumulation of Na+ in plants defeats the photosynthesis and produces reactive oxygen species (ROS), which cause DNA damage, protein degeneration and membrane injury (Islam et al., 2015). The cell walls with the increase of sodium causes cell death and osmotic stress (Ashraf, 2004). Salinity also interrupts photosynthesis mostly by decrease in chlorophyll content, leaf area, stomatal conductance, and reduced efficiency of photosystem II efficiency. Disturbance in osmotic equilibrium causes damage of turgidity, cell dryness, and finally the death of cells. Osmotic stress and ion toxicity can result in metabolic inequality, and resulting into oxidative stress. Plants possess various natural tolerance mechanisms to protect the damages due to the salt stress (Netondo et al., 2004).

Soil salinity has an overall negative effect on plant's health. Salinity affects flowering and fruiting pattern, abnormality in reproductive physiology, which ultimately influences crop yields and biomass. Salinity may leads up to 50% reduction in flowering of pigeon pea (Promila and Kumar, 1982). In tomato, high salt concentration (150 mm NaCl) is reported to affect flowering transition time and causes delay in the first in florescence along with reduction in the growth of shoot and root In chickpea (Cicer arietinum L.), Salt Overly Sensitive (SOS) pathway is a chief defence pathway involved in Na+ extrusion and maintaining ion homeostasis at the cellular level (Zhu et al., 1998; Zhu, 2003; Ji et al., 2013). There are many reports where both SOS and photoperiodical and circadian clock switch proteins related with flowering are deactivated by salt stress(Parketal. 2016; Ryuetal.,2014).

Salt stress remarkably affects plant reproductive physiology. Ghanem et al. (2009) reported that in tomato the exposure of salinity stress results into Na+ accumulation in style, ovaries, and anther intermediate layers which caused an increase in the rate of flower abortion and reduction of pollen number and viability of the plant. The extreme effect of salt stress can be seen in terms of yield loss. The primary effects related to crop yield can be in terms of germination which either decreases or sometimes terminates under extreme saline conditions. A study by Ali Khan et al. (2012) showed that under saline conditions growth, yield and biomass of pearl millet is negatively affected in terms of germination percentage, leaf area, plant height, total biomass and grain yield plant. Impact of salinity on pea was also found to negatively affect growth, yield and biomass. Wolde and Adamu, 2018; Farooq et al. 2017 also reviewed the effects of salt stress on grain legumes, and they described that in various legumes salinity may reduce crop yield by 12–100%. Salt tolerance of black cumin (Nigella sativa L.) and its effect on seed germination, emergence and yield were studied by Faravani et al. (2013). According to them an increase in salinity level from 0.3 to 9 dS m^{-1} reduced the average seed and biological yield.

Plant Response Against Salt Stress

In plants, different stress recognition and signaling pathways interact with one another in various ways by producing stress tolerance hormones, production of poly amines, ion homeostasis, activation and synthesis of antioxidant enzymes/compounds, and production of osmoprotectant (Groß et al., 2013). Several genes such as SOS1 were associated with the abiotic stress response in tomato seedling (Huang et al., 2012, Koussevitzky et al., 2008). During salt stress condition Ca^{2+} signaling pathway is triggered due to the expression of salt sensitive gene (SOS1) (Hrynkiewicz et al., 2015). These genes protect cells from damage by producing several vital metabolic proteins. Downstream signaling of the stress pathway is identified by receptors of plasma membrane, which produces unique secondary messengers as inositol phosphates inducing oxidative bursts due to increased ROS level. The resulting SOS1 genes help plant to survive during salt stress condition (Martínez-Atienza et al., 2007). Elevated ROS level damages nucleic acids, Lipids and proteins (Halo et al., 2015). Plants respond to toxic level of ROS by producing antioxidants enzymes that results into ROS detoxification and protect cells from its harmful effects by producing secondary metabolites like phenolic compounds. Ultimately, phenolics act as defensive agents under salt and drought stress condition (Miller et al., 2010). Several approaches have been established to reduce the damaging effects of salinity on plant both by genetic engineering and through the use of PGPR (Wang et al., 2003). The beneficial microorganisms inhabit the plant rhizosphere and stimulate plant growth via several direct and indirect mechanisms (Upadhyay et al., 2012). Recent studies shows that microbial communities were also helpful to mitigate the plant stress responsive genes and plants showed enhanced growth, yield, and development under stress conditions.

Role of PGPR in Salt Stress Tolerance

PGPR are Rhizospheric and endophytic bacteria that colonize root interior or exterior. According to previous reports, bacteria belong to different genera such as *Microbacterium, Pantoea, Pseudomonas, Rhizobium, Bacillus, Paenibacillus, Enterobacter, Achromobacter Burkholderia, Methylobacterium, Azospirillum, and Variovorax*, etc. provide tolerance to host plants during abiotic stresses (Shahid et al., 2018). These bacteria are useful in agricultural fields and can alleviate many abiotic stresses such as drought, salinity, heavy metal toxicity etc. (Ashraf, 2004, Banaei-Asl et al., 2015). Several studies reported that stress tolerance is enhanced in plants by these microorganism through different mechanisms as producing indole acetic acid, gibberellins and some unidentified elements that results in increased root surface, root tips, root length area and most importantly enhance nutrient content, thus improving the health of plant under salt stress (Shahid et al., 2018). Growth of different plants was improved by PGPR such as canola tomato, lettuce, bean and pepper in salt stress conditions. Many PGPR can produce cytokines; accumulate abscisic acid (ABA) and antioxidants that can detoxify ROS. Several parts of plant are ethylene-dependent, thus production of ethylene is essential for post-transcriptional and transcriptional modifications that are regulated during salinity stress (Barassi et al., 2006). Under stress condition the ethylene hormone also controls plant homoeostasis (Tewari and Arora, 2014). ACC deaminase which is produced by bacteria degrades plant ACC for acquiring energy and nitrogen. Moreover, it also decreases the harmful effect of ethylene, by enhancing stress tolerance and promoting growth of plant. Bacteria also produce exopolysaccharides (EPS), which show the mitigating effects against salinity and water pressure to enhance the structure of soil. Cations containing Na+ bind to EPS thus Na+ cations are inaccessible to plants in saline environment (Timmusk et al., 2014, Tewari and Arora, 2014). Expression of proBA gene in *Arabidopsis thaliana* increased concentration of free proline which is responsible to enhance osmotic tolerance of these genetically modified plants (Chen et al., 2007). Inoculation of *Pseudomonas and Rhizobium* in Zea mays increases proline concentration, reduce electrolyte leakage and selection of K+ ions enhance the salt tolerance (Vardharajula et al., 2011). Inoculations of specific PGPR help to encourage salt stress tolerance of plants via induced systemic tolerance (IST) which causes many biochemical and functional changes (Yang et al., 2009).

The diazotrophic salt-tolerant bacterial strains of *Klebsiella, Pseudomonas Agrobacterium* and *Ochrobactrum* isolated from the roots of a halophytic plant, *Arthrocnemum indicum* showed salinity tolerance ranging from 4 to 8% NaCl and improved the productivity of peanut in saline as well as in control conditions (Sharma et al., 2016). *Planococcus rifietoensis,* an alkaliphilic bacterium is reported to enhance growth and yield of wheat crop under salt stress (Rajput et al., 2013). Upadhyay et al. (2009) explored the genetic diversity of ST-PGPR isolated from the wheat rhizosphere. They found that most of the isolates were able to tolerate up to 8% NaCl and belong to the genus Bacillus. The diversity of salt-tolerant bacteria isolated from paddy rhizosphere in Taoyuan, China was reported by Zhang et al. (2018). They isolated 305 bacterial strains, and among them, 162 were tested for salt tolerance up to 150 g/l NaCl concentration. Phylogenic analysis of 74 of these salt-tolerant strains showed that they belong to *orders Bacillales* (72%), *Actinomycetales* (22%), *Oceanospirillales*(4%) and *Rhizobiales*(1%). Most of the isolates also showed their potential in improving salt tolerance, growth, and yield of rice under salinity stress condition. ST-PGPR strain *Bacillus licheniformis* SA03 isolated from Chrysanthemum plants grown in saline-alkaline soil of China conferred increased salt tolerance in Chrysanthemum (Zhou et.al. 2017). The diversity of salt-tolerant bacilli was also deciphered in the soil of eastern Indo Gangetic plains of India by Sharma et al. (2015). They isolated 95 bacterial strains and among them, 55 showed plant growth promoting characteristics and salt tolerance to more than 4% NaCl. Several researchers also report the diversity of ST-PGPR in the coastal areas of the world. For example, in Tsunami affected areas in Andaman and Nicobar Islands of India, 121 bacterial strains were isolated, and among them 23 showed salt tolerance up to 10% NaCl with PGP characteristics including production of indole acetic acid (IAA), siderophore, extracellular enzymes and phosphate solubilization (Amaresan etal.,2016).The study revealed that the majority of isolates were *Bacillus spp.* and rest were *Enterobacter sp., Alcaligenes faecalis, Microbacterium* resistance*, Lysinibacillus sp.*

Mechanisms of PGPR to Tolerate Salt Stress

The PGPR have indirect (antioxidant defence, VOC, EPS, osmotic balance) and direct (phosphate solubilization, nitrogen fixation, IAA synthesis etc.) mechanisms for improving plant growth and enhancing tolerance against salinity stress. Many bacterial factors are involved in enhancing IST such as IAA synthesis, exopolysaccharide production activity of ACC deaminase, VOCs and siderophore production (Yang et al., 2009).

Antioxidants

Normally, ROS is produced in less quantity during cellular metabolism of plants. However, under various stress conditions, ROS increases which changes redox state, denature membrane bounded proteins, DNA damage, reduce membrane fluidity, changes the protein formation, damage the enzymatic actions and homeostasis of cell, which can damage the cell and finally cell death (Halo et al., 2015). During salt stress lipids are main targets of ROS that affects phospholipids (poly-unsaturated fatty acids) of membrane and start peroxidation of lipid (Miller et al., 2010). Enzymatic antioxidants as mono dehydro ascorbate reductase, catalase (CAT) superoxide dismutase (SOD), ascorbate peroxidase (APX), glutathione reductase (GR), and non-enzymatic antioxidants as, tocopherols, cysteine, ascorbate and glutathione are involved in degrading ROS and promote tolerance against oxidative stress (Kim et al., 2014).Several PGPR are reported to tolerate the oxidative stress with the help of antioxidants enzymes. APX activities increased under salt stress in inoculated tomato seedling by *Enterobacter spp.* (Sandhya et al., 2010). Inoculation of PGPRs to gladiolus plant showed higher the CAT, and SOD as compared to control (Damodaran et al., 2013). Still, Inoculation gladiolus plant with PGPRs showed higher CAT and SOD as compared to control (Kim et al., 2014).

EPS

Rhizobacteria produce EPS, which are in the form of homo or hetro polysaccharides that bind to the surface of the cell like a capsule and form a biofilm (Upadhyay et al., 2011). Polysaccharide composition differs between different species but some common monomers contain glucose, galactose. and mannose. Neutral sugars (galacturonic), Amino sugars (N-acetylamino sugars), uronic acids, (fucose and rhamnose), pyruvate ketals, and ester-linked substituents are EPS constituents. The PGPR inoculated plants have increased potential to mitigate the oxidative stress (Miller et al., 2010). PGPR that produce EPS show important role in growth of plant during salinity stress conditions by forming hydrophilic biofilms (Rossi and De Philippis, 2015). Rhizobacteria producing EPS have potential to fight against salt stress by producing rhizo-sheaths around the roots of plants by attaching the EPS with Na^+ ions. Attachment of EPS to Na^+ ions reduces the toxicity of Na^+ making it unavailable for plants. It was reported that inoculation of *Bacillus subtilis* to *Arabidopsis thaliana* reduces the influx of Na^+ through down regulating the expression of HKT1/K^+ transporter (Zhang et al., 2008). In another research study, inoculation of *Pseudomonas aeruginosa* to Helianthus annuus reduced the salt stress by producing the EPS, thus resulting in enhanced yield, growth and development (Tewari and Arora, 2014).

Volatile Organic Compound (VOCs)

Rhizobacteria-oriented VOCs are lipophilic fluids having high vapor pressures. They are species-specific and communicate between organisms through cell signaling in order to promote growth. The VOCs promote biosynthesis of glycine betaine and choline which improves plant tolerance against osmotic pressure. The VOCs of *Bacillus subtilis* trigger tissue specific gene regulation of HKT1/K+ transporter that inhibits sodium ions influx through roots in order to eliminate the salinity stress (Zhang et al., 2008). The VOCs produced by Bacillus subtilis encourage the synthesis of glycine betaine and induce less uptake of Na+ through roots and also improve nutrients transport from root towards shoot during salt stress. The level of VOCs is low in plants and it is higher under various stress conditions. The high level of VOCs is a sign to activate self-protective response against salt stress (Timmusk et al., 2014).

Osmotic Adjustment

Increase of compatible solutes to retain the cell turgidity within borderline that is important for regular cell functions is called osmotic adjustment. It is chief cellular machinery in plants that reduces osmotic stress produced due to salt stress (Gill and Tuteja, 2010). In salinity stress, PGPR produce compatible osmolytes to help plants for promoting their growth. During stress condition, glycine betaine and proline are accumulated in plants; however, plants lack the production of organic osmolytes such as trehalose. Proline is the key of osmolytes that formed in plant by the hydrolysis of proteins to reduce osmotic stress (Krasensky and Jonak, 2012). Under salt stress conditions proline play multifunctional role like proteins maintenance, regulating cytosolic acidity, decrease lipid peroxidation and ROS scavenging. Rhizobacteria inoculation in plants showed improved proline levels under salt stress. Inoculation of ProBA gene to A. thaliana resulting into regulated by 35 S promoters stronger of cauliflower mosaic virus and produce proline (Wang et al., 2016). It is involved in the osmotolerance of transgenic plants, synthesis of trehalose which protect the plants when inoculated with PGPR and maintains proteins and membrane integrity (Chen et al., 2007). Additionally, trehalose also acts as osmoprotectant under stress conditions like osmotic stress, high salt stress, drought and low temperature (Liu et al., 2016). The quaternary compound glycine betaine, found in different animals, plants and microorganisms is involved in inducing tolerance against stressful conditions (Cho et al., 2008). Glycine betaine is not only protecting the plants against various stresses but also protects several stress-relieving enzymes by forming proteins quaternary structure and other macromolecules (Ahmad et al., 2013). Several salt tolerant bacteria have enormous number of genes to survive under salt stress including sodium/hydrogen (Na+/H+) antiporter genes etc. These genes are involved in maintaining the cells by Na+ detoxification, adjustment of cell volume, formation of Na+ electrochemical gradient and homeostasis of cellular pH. The *Escherichia coli* and many *Enterobacter spp*. have Na+/H+ antiporter gene that plays role the ion homeostasis mechanism with the help of nhaA gene. NhaA is necessary for adaptation of plants in high salinity due to its distinctive capacity for 'sensing' the environmental signals given by Na+/ H+ and maintains cellular homeostasis. NhaA gene is identified in *Enterobacter ludwigii* (Padan, 2008), to tolerate the salt stress as shown in (Padan, 2008).

Agricultural and Industrial Application of Stress Tolerant Microorganism

Bio Protection

Many root colonizing bacteria which have been shown to provide protection against different types of biotic stresses can also enhance a plant's tolerance to various abiotic stresses. For example *Pseudomonas putida UW4, P. fluorescens TDK1, Bacillus sp.* and Arthrobacter *sp*. have been shown to enhance resistance against various soil borne pathogens, and also mitigate salt, as well as drought stress in different plants (Mayak et al. 2004, Haas & Defago 2005).

Bacillus subtilis is widely recognized for its biocontrol properties (reviewed in Kloepper, Ryu & Zhang 2004) and has recently been shown to enhance tolerance to iron toxicity (Asch & Padham 2005; Terre et al. 2007). Similarly, siderophore production by beneficial bacteria, which protects plants against pathogenic bacteria through better competition for iron, has also been shown to be able to protect plants from metal induced oxidative stress. Ideally, in future commercially available biocontrol agents should simultaneously provide cross protection against various stress factors, making agricultural systems environmentally and economically more sustainable by reducing the need for pesticides, chemicals, irrigation and other ecologically problematic and costly crop management strategies.

Biofertilizers

Biofertilizers are formulation product of variety of living microbes having ability to provide nutrient from unusable to usable through biological process. Due to their ability to enhance plant growth under the biotic and abiotic condition they may be used as a potential bio fertilizer. Microbes which are used as biofertilizers have ability to convert atmospheric nitrogen in to ammonia and phosphate solubilization in plant rhizosphere. Biofertilizers are substances containing living organism, which when inoculated with seed or plant enhance plant growth and development. Stress tolerant PGPM actively participate in mainly in nutrient mobilization and fix atmospheric nitrogen (Kantachote et al., 2016). It is a potential substitute for inorganic fertilizers and pesticides. Most common bacteria such as Acetobacter*, Azospirillum, Azotobacter,* and *Pseudomonas* are some active microbes. In addition Bacillus *spp* and *Pseudomonas spp* act as potent biocontrol and plant growth promoting strains under stress condition. They provide protection and disease resistance to plants from pathogens. These microbes improve the nutrient availability, competition for nutrient and induced systemic resistance. Biofertilizers are commercially used across the globe. Therefore, inoculating stress tolerant microbes in agriculture field as multifunctional biofertilizer is potential substitute for inorganic fertilizer and pesticides. Finally, the beneficial effect of biofertilizers include promotion of plant growth, nutrient mobilization, yield quality, soil health and reduced susceptibility to disease due to environment change. Therefore, the selection of efficient microorganism and formulation biofertilizers for changing environment can be beneficial in upcoming years.

Industrial Application

Microbes play a key role in resolving environmental problems. The greater diversity of beneficial microorganism in soil may facilitate ecosystem sustainability. It may enhance the efficient microbial diversity in degraded land and maintain functional equilibrium. The loss of beneficial microbial diversity in soil significantly declines soil fertility and crop quality and crop production. To enhance soil productivity people are expending huge money on fertilizers and pesticides. The PGPR initially recognized as a microbial agent that has capacity to tolerate stress and promote plant growth. Microorganism from the vital living components of soils are contributing ecosystem sustainability due to their cosmopolitan survival, catabolic versatility, massive efficient genetic pool and stress tolerance potential. In addition, bioethanol has been used as sustainable alternative biofuel to replace traditional fossil fuel. Lignocellulose based production of bio-ethanol; an eco-friendly energy source is an alternative to progressive depletion of non-renewable energy sources. Thermophilic or Thermotolerant microbes are used for the production of bio ethanol through the fermentation process. Such thermotolerant microbes are *Clostridium thermowell, Clostridium thermosaccharolyticum, Clostridium thermohydrosulfuricum, Caldicellulosiruptor sp., Thermotoga sp., Thermoanaerobium brockii, Thermoanaerobacter ethanolicus, T. thermal-hydrosulfuricus, T. mathranii* (Salim et al., 2015). The coconut milk, pineapple juice, and tuna juice, use to promote the synthesis of bioethanol by yeast Saccharomyces cerevisiae CDBB 790. Additionally, phytoremediation of heavy metals from soil helps in sustainable crop production and positive effect on soil. Metals accumulation in the agricultural food product causes many skin and blood-related diseases in human. Microorganism helps to remove these toxic heavy metals from soil and reduce their uptake by plant.

Conclusion

Under salt stress conditionssalt tolerant PGPR and soil microflora play a vital role in the amelioration of physiological abnormalities induced by salts in plants. Salt tolerant PGPR are involved in inducing the salt tolerance in various plants to help them survive under salt stress conditions and followed by improvement in their morphological parameters. They can easily withstand at high salt stress through various mechanisms such as efflux systems, production of antioxidants, Exopolysaccharides, Volatile Organic Compound and osmotic adjustment in plants, formation of ROS, secondary metabolites and other means. Several genes and metabolites are involved in maintaining the cell integrity and plant-microbe interactions under salinity stress. Still a lot is yet to be explored at biochemical level and molecular level on how the salt tolerant PGPR support themselves and their symbiotic partner under salinity stress which has multi-dimensional impacts on the cell of both plant and bacteria. So, considering a current scenario, future research is needed to identify potential stress tolerant PGPR. Certainly, diversity of microbial strains should be tested to formulate effective microbial consortia to overcome the negative impact of changing the environment.In future, the salt tolerant PGPR can be utilized as biofertilizer to ameliorate salt stress and increase crop production in an economically sustainable manner.

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