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Effect of Salt Stress on Medicinal Plants and its Amelioration by Plant Growth Promoting Microbes

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Abstract

Salt stress is widely recognized as one of the important abiotic stressors results the severe reduction of medicinal plants growth and its herb yield. It also critically reduces the production of medicinally important active chemical content in the plants. There are three main stages on the growth of medicinal plants where the high salinity stress severely affects the plant growth. Recent studies showed that there is reduction of herb yield around 60% and simultaneous active chemical content reduction of around 50% under the exposure of high salinity of 300 mM of NaCl concentration. There are many reasons behind the reduction of growth of medicinal plants due to salt stress. There are also morphological, physiological and biochemical changes observed on the medicinal plants but there is still mystery exists whether any ultra-structural changes occur on the medicinal plants for salinity stress. The strategies employed in recent years to reduce the effect of high salinity stress on medicinal plant production mainly focused on a selection of salinity tolerant host genotypes. However, such efforts need high cost and inputs, there is an immediate urgency to build simple, low cost, sustainable and short term methods for salinity stress management. Hence the use of plant growth promoting microbes inhabiting rhizosphere, phyllosphere or endosphere might play a significant role in this aspect, if we exploit them as a multi-trait PGPR like stress-tolerant, PGPR activities, manipulation of signalling between both partners as plant and microbes with specific compatible solutes.

Keywords: Salinity stress, stress-tolerant, PGPR, medicinal plants, ultra-structural changes

1. Introduction

Medicinal plants frequently encounter unfavourable growth conditions due to salinization of soil and water. Salinity is one of the important abiotic environmental stressors that limit plant growth and development and plays a major role in determining the geographical distribution of medicinal plant species. In fact, almost 40% of the world's land surface is affected by salinity-related problems (Vriezen et al., 2007). According to an estimate, over 800 mha of land throughout the world are salt affected, either by salinity (397 mha) or the associated condition of sodicity (434 mha) (FAO, 2008). In India, according to recent survey around 6.74 mha of total land is occupied by salt affected soil and further categorized by three different types saline soils (1.71 mha), alkali soils (3.78 mha) and coastal saline soil (1.24 mha) (CSSRI, 2016). A saline soil is generally defined as one in which the electrical conductivity (EC) of the saturation extract (EC_e) in the root zone exceeds 4 dSm^{-1} (approximately 40 mM NaCl) at 25 °C and has an exchangeable sodium of 15%. It has been estimated that worldwide 20% of total cultivated and 33% of irrigated agricultural lands are afflicted by high salinity. Furthermore,

the salinized areas are increasing at a rate of 10% annually for various reasons, including low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor cultural practices. It has been estimated that more than 50% of the arable land would be salinized by the year 2050 (Jamil et al., 2011). Tropical and sub-tropical countries like India, China, Egypt etc. are mainly blessed with a rich wealth of medicinal plants because of their high disease curing value. Medicinal plants are cultivated for different plant parts and their active constituents are used in many ways, especially for drugs. As antibiotics are very costly in developing countries people in these countries still mainly relies on herbal medicines for ailment of diseases (Abu-Irmaileh & Afifi, 2000). Among the environmental unfavourable conditions, salinity is the most wide spread in the world. In order to meet the ever increasing demand of medicinal plants, for the indigenous systems of medicine as well as for the pharmaceutical industry, some medicinal plants need to be cultivated commercially, but the soil salinity and other forms of pollutions pose serious threats to plant production (Qureshi et al., 2005; Jaleel et al., 2007c, 2008a). The impact of salt stress has been correlated with some morphological and physiological



traits like reduction in fresh and dry weight (Chartzoulakis and Klapaki, 2000). However, traditional and molecular breeding has been applied for saline tolerant medicinal plant varieties and showed significant tolerance in opposition to the negative effects of salinity. Although the effects of salt stress on traditional crops like wheat, barley, rice etc. have been studied widely, there is a lack of information in the case of medicinal plants.

Salt stressed soils are known to suppress the growth of plants (Paul, 2012). Plants in their natural environment are colonized both by endocellular and intracellular microorganisms (Gray and Smith, 2005). Rhizosphere microorganisms, particularly beneficial bacteria and fungi, can improve plant performance under stress environments and, consequently, enhance yield both directly and indirectly (Dimkpa et al., 2009). Some plant growth-promoting rhizobacteria (PGPR) may exert a direct stimulation on plant growth and development by providing plants with fixed nitrogen, phytohormones, iron that has been sequestered by bacterial siderophores, and soluble phosphate (Ahemad and Kibret, 2014). Others do this indirectly by protecting the plant against soil-borne diseases, most of which are caused by pathogenic fungi (Lutgtenberg and Kamilova, 2009). The problem of soil salinization is a scourge for agricultural productivity worldwide. Crops grown on saline soils suffer on an account of high osmotic stress, nutritional disorders and toxicities, poor soil physical conditions and reduced crop productivity (Srivastava and Kumar, 2015). The present review focuses on recent researches and advances in our understanding of salt stress on medicinal plants and the enhancement of plant productivity under salt stressed conditions through application of plant growth promoting microorganisms for alleviation of salt stress.

2. Causes and Problems of Soil Salinization

Salinization is one of the physicochemical process in which soil and water made saline due to presence of different salts. Soil salinity is an enormous problem for agriculture under irrigation. There are two main types of salinity, primary and secondary. Primary salinity occurs naturally in soil and water. Secondary salinity is salting which results from human activities, usually land development and agriculture. Common causes of secondary salinity are rising groundwater tables (from excessive irrigation) or the use of poor quality water or clearing vegetation and changes inland use (Bharti et al., 2013). In the hot and dry regions of the world the soils are frequently saline with low agricultural potential. In these areas most crops are grown under irrigation, and to exacerbate the problem, inadequate irrigation management leads to secondary salinization that affects 20% of irrigated land worldwide (Glick et al., 2007). Irrigated agriculture is a major human activity, which often leads to secondary salinization of land and water resources in arid and semi-arid conditions. Because of improper irrigation, anthropic salinization occurs in arid and semi-arid areas due to water logging. About 2% of

the lands farmed by dry-land agriculture, and more than 45 million hectares of irrigated land (at least 20% of total irrigated acreage) have been already damaged by salt (Lauchli et al., 2008). Irrigation combined with poor drainage is the most serious salinity threat, because it represents losses of once productive agricultural land (Zhu, 2007). The irrigation water contains salts of calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^+). In arid and semi-arid lands, evapotranspiration plays a very important role in the pedogenesis of saline soils. When water evaporates, Ca^{2+} and Mg^{2+} often precipitate into carbonates, leaving Na^+ dominant in the soil (Serrano et al., 1999). Therefore, high concentrations of Na^+ in the soil solution may depress nutrient-ion activities and produce extreme ratios of $\text{Na}^+/\text{Ca}^{2+}$ or Na^+/K^+ (Grattana & Grieveb, 1999).

During the last century, physical, chemical and/or biological land degradation processes have resulted in serious consequences to global natural resources (e.g. compaction, inorganic/organic contamination, and diminished microbial activity/diversity). The area under the affected soils continues to increase each year due to introduction of irrigation in new areas (Patel et al., 2011). In India, Most of saline soil occurs in Indo-gangetic plane that covers the states of Punjab, Haryana, U.P., Bihar and some parts of Rajasthan. Arid tracts of Gujarat and Rajasthan and semi-arid tracts of Gujarat, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh are also largely affected by saline lands.

3. Impact and Reason behind Salt Stress on Medicinal Plants

Soil salinity is a problem of global concern. Plant growth in saline soils is suppressed by nonspecific osmotic effects, toxic solutes and sodicity. Agricultural crops exhibit a spectrum of responses under salt stress. Salinity not only decreases the agricultural production of most crops, but also, effects soil physicochemical properties, and ecological balance of the area (Srivastava and Kumar, 2015). The impacts of salinity include low agricultural productivity, low economic returns and soil erosions (Hu and Schmidhalter, 2002). Salinity effects are the results of complex interactions among morphological, physiological, and biochemical processes including seed germination, plant growth, and water and nutrient uptake (Akbarimoghaddam et al., 2011). Salinity affects almost all aspects of plant development including, germination, vegetative growth and reproductive development. Soil salinity imposes ion toxicity, osmotic stress, nutrient (N, Ca, K, P, Fe, Zn) deficiency and oxidative stress on plants, and thus limits water uptake from soil. Soil salinity significantly reduces plant phosphorus (P) uptake because phosphate ions precipitate with Ca^{2+} ions (Bano and Fatima, 2009). Salinity also affects photosynthesis mainly through a reduction in leaf area, chlorophyll content and stomatal conductance, and to a lesser extent through a decrease in photosystem II efficiency (Netondo et al., 2004). Salinity adversely affects reproductive development by inhabiting microsporogenesis and stamen filament elongation, enhancing programmed cell



death in some tissue types, ovule abortion and senescence of fertilized embryos.

Salt stress can be categorized in two different stress effects e.g. short and long terms. In natural environment, salinity often associated with drought. Both drought and salinity impose osmotic stress, as a result of large concentrations of either salt or non-ionic solutes in the surrounding medium, with the resulting deficit of water. Osmotic stress, lowering of external water potential and reduction of water uptake by plants, similar to the situation under drought, all fall in the category of short term effects (Wang et al., 2003); The second effect, long term effect, is much slower process caused by salt accumulation in leaves, leading to salt toxicity in the plants and thus crops are not able to compartmentalize ions properly. The earliest response to salt stress in plants is a reduction in the rate of leaf surface expansion, followed by a cessation of expansion as the stress intensifies (Parida and Das, 2005). As salt composition varies, the plant growth differs accordingly. The plants that have evolved under conditions of low soil salinity and do not display salt tolerance, their yields move towards zero with the increase in salt concentrations. They are severely inhibited or even killed by 100–200 mM NaCl (Munns and Termaat, 1986). High salinity affects plants mainly in two ways, when the salt concentrations is high in the soil, the capacity of roots to extract water is disturbed, and when concentrations of salts within the plant is high, then salt itself can be toxic to the plant, which results in an inhibition of many physiological and biochemical processes such as nutrient uptake and assimilation (Hasegawa et al., 2000; Munns, 2002; Munns et al., 1995; Munns and Tester, 2008). Altogether, these affects plant growth, development, survival and yield. Reduction in shoot growth due to salinity is commonly expressed by reduced leaf area and stunted shoots (Lauchli & Epstein, 1990). The growth of leaves is inhibited due to salt stress and also as a consequence of inhibition by salt of symplastic xylem loading of Ca^{2+} in the root (Lauchli and Grattan, 2007). There is a formation of reactive oxygen species such as super-oxide, hydrogen peroxide, singlet oxygen and hydroxyl radicals, when there is ion excess into the cells. It further causes disruption in cellular homeostasis and also triggers the expression of genes involved in defence mechanisms (Timperio et al., 2008; Du et al., 2010). In addition, gene expression is also influenced by salt stress. Genes involved in the metabolic pathways of nitrogen reduction and fixation and methionine biosynthesis are significantly affected by salt stress (Ouyang et al., 2007). Jaleel et al. (2008) observed contrasting effect of NaCl treatment on medicinal plant *Catharanthus roseus* with significant accumulation of micro and macronutrients in plant cells but subsequent reduction of vegetative plant growth. In another study, Gengmao et al. (2014) reported that *Salvia miltiorrhiza* plant surviving at 75-100 mM NaCl concentrations was not affected by high salt exposure in morphological sense but the accumulation of plant dry matter was severely reduced.

4. Effect of Salt Stress on Medicinal Plants

According to recent reports, salt stress might occur on medicinal plants at three different physiological stages i.e. seed germination stage, seedling stage and maturity or reproductive stage.

5. Effect on seed germination stage

One of the most salt-sensitive growth stages which are severely inhibited with increasing salinity is seed germination stage (Sosa et al., 2005). This negative response of seed germination under salt stress was reported by many authors on *Ocimum basilicum*, *Eruca sativa*, *Petroselinum hortense* and *Thymus maroccanus*. Seed germination can be affected either by two ways. First is there may be decrease in the osmotic potential due to enough salt in the medium. It can be declined to such a point that it slows down the uptake of water necessary for mobilization of nutrient which is required for germination. The second is the salt constituents or ions may be toxic to the embryonic growth.

6. Effect on Seedling Stage

Seedling stage is one of the most vulnerable stages in the plants' life cycle. It was earlier observed that due to salt stress the seedling growth in *Thymus maroccanus*, basil (Ramin, 2005), chamomile and marjoram (Ali et al., 2007) was severely declined. Because of this salt stress, there is slow or less mobilization of reserve foods, suspending the cell division, enlarging and injuring hypocotyls. Osmotic stress, mainly specific ion toxicity and ionic imbalances occurred when there is an excess of soluble salts in the soil (Munns, 2003) which results death of plants (Rout and Shaw, 2005). Ozturk et al. (2004) observed that all seedlings of *Melissa officinalis* died at EC 6 dS/m. Similar observation was also recorded for sage plants i.e. salinity level up to 3000 ppm resulted in complete obliteration of sage plants (Hendawy and Khalid, 2005). It has been also reported in previous study that survival percentage in thyme was decreased significantly under salinity conditions (Ezz El-Dinet et al., 2009). The similar results were obtained on *Majorana hortensis* (Shalan et al., 2006) and spearmint (Al-Amier et al., 2007). The vegetative growth of five different medicinal plants namely *Lepidium sativum* L., *Linum usitatissimum* L., *Nigella sativa* L., *Plantago ovate* Forssk, and *Trigonella foenum-graecum* L. was significantly reduced when grown in pot house on different concentrations of salinity level viz. 10.0, 12.5 and 15.0 dS/m of NaCl (Muhammad and Hussain, 2010).

7. Effect on Maturity Stage of Medicinal Plant and Reduction of Plant Yield

Productivity of plant is severely affected by salt stress when salinity effect pronounced on plant maturity stage. Due to salt stress, detrimental and damaging effects on plants can be observed at the whole-plant level, as the death of plants



and/or decrease in the productivity (Parida and Das, 2005). Noteworthy drop in the number of umbels, fruit yield/plant and weight of 1000 seeds was observed in fennel, cumin and *Ammi majus* when salt concentrations increased (Nabizadeh, 2002; Ashraf et al., 2004; Abd El-Wahab, 2006). Similar reductions in seed yield and yield components per plant were obtained on milk thistle and *Trachyspermum ammi* (Ghavami and Ramin, 2008; Ashraf and Orooj, 2006). Contradictory reports have been found relating to the response of medicinal plants in terms of essential oil production to salt stress. Essential oil yield decreased under salt stress in *Trachyspermum ammi* (Ashraf and Orooj, 2006). In several medicinal plants e.g., *Mentha piperita* (Tabatabaie and Nazari, 2007), *Thymus maroccanus* (Belaqziz et al., 2009), basil (Said-Al Ahl and Omer, 2011) and apple mint (Aziz et al., 2008) similar results have been documented. It has also been shown that reactions to salt stress might be responsible for the increase or decrease in the content of relevant natural products in some Indian medicinal plants but exact reason is still unknown (Bharati et al., 2013). The concentration of artemisinin, an antimalarial compound decreased significantly in *Artemisia annua* plants when artificially treated with higher concentration of NaCl i.e., 160 mM (Qureshi et al., 2005). Ajmalicine content in *Catharanthus roseus* was significantly reduced when plants grown on 100 mM NaCl concentration under pot house condition (Jaleel et al., 2008). According to recent report, in plant *Bacopa monnieri* the herb yield was reduced up to 60% and active chemical bacoside-A content reduced around 50% when plants were exposed to salinity in the field with concentration of 4 g NaCl/kg soil (Bharti et al., 2013). In *Mentha arvensis*, the biomass yield reduced up to 53% in 300 mM NaCl and 67% in 500 mM of NaCl with significant reduction in oil content (Bharti et al., 2014).

8. Morphological and Physiological Changes by Salt Stress

Morphological features like number of leaves, leaf area, and leaf biomass have been reduced under salt stress in a number of medicinal plants. In *Mentha piperita* var. *officinalis* and *Lipia citriodora* var. *verbena*, there was significant diminution in number of leaves, leaf area and leaf biomass under salt stress (Tabatabaie and Nazari, 2007). *Catharanthus* plants act as an absorber of Na⁺ and may be incapable of coping with it, leading to the leaves eventually suffering from the toxic effects and resulting in reduced leaf growth (Jaleel et al., 2008b). Similar decreases in growth parameters under salt stress were found in *Withania somnifera* (Jaleel et al., 2008a). Negative effects of salt stress have been observed in *Majorana hortensis* (Shalan et al., 2006), peppermint (Aziz et al., 2008), geranium (Leithy et al., 2009), *Thymus vulgaris* (Najafian et al., 2009), sage (Ben Taarit et al., 2009), and *Mentha pulegium* (Queslati et al., 2010). Due to abiotic stress from salt, the plant tries to cope with the situation by decreasing its leaf area, hence, conserving energy. Similarly when *Satureja hortensis* plants grown in different levels of NaCl, the leaf

area, leaf and stem fresh weight, as well as dry weight of leaves, stems and roots were decreased (Najafi et al., 2010). In another study, the growth of root was declined in *Melissa officinalis* when irrigated with each increase in irrigation water salinity (Ozturk et al., 2004). Salt stress can affect the all plants by disrupting their physiological mechanisms such as decreasing photosynthetic efficiency, gas exchange, membrane disruption, water status, etc. Increasing salinity causes a reduction in chlorophyll content (Sheng et al., 2008) due to suppression of specific enzymes that are responsible for the synthesis of photosynthetic pigments (Murkute et al., 2006). A reduction in the uptake of minerals (e.g. Mg) needed for chlorophyll biosynthesis also reduces the chlorophyll concentration in the leaf (El-Desouky and Atawia, 1998). In NaCl treated *Artemisia annua* plants, oxidative stress induced due to a decreased stomatal conductance in response to the osmotic imbalance and reduced leaf-water potential (Qureshi et al., 2005). Chlorophyll content in *Catharanthus roseus* was significantly reduced when plants grown on 100 mM NaCl concentration under pot house condition (Jaleel et al., 2008).

9. Biochemical Changes on Plant

Major biochemical changes occur in all plants including medicinal plants by accumulating a number of osmoregulatory nitrogen-containing compounds in Plant cells exposed to saline stress. The most common of these include amino acids, amide and proteins; also quaternary ammonium compounds (betaines) and polyamines (Rabie and Almadini, 2005). These compounds are generally present in low concentrations when the plant is not under salt stress (Feng et al., 2002). The specific nitrogen-containing compounds that accumulate in saline environments vary with plant species (Rabie and Almadini, 2005). Recently reported on proline concentration in the leaf of *Echium amoenum* was increased with increasing salinity, particularly at the highest external salt level and showed the positive role of proline in the salt tolerance of this medicinal plant (Ramezani et al., 2011). Osmoregulation allows cells to maintain turgor and turgor-dependent processes including cellular expansion and growth, stomatal opening and photosynthesis, while keeping a gradient of water potential favourable to water entering the plant.

10. Ultra-structural Changes on Plants

Salinity is reported to bring about drastic ultra-structural changes in plants (Yamane et al., 2004; Mahmoodzadeh, 2008; Evelin et al., 2009). Salt stress caused an increase in membrane surface and quantity of vesicles in root cells of Sorghum (Evelin et al., 2009). The plant cell membranes are generally considered as primary sites of salt injury. Membrane destabilization is frequently attributed to lipid peroxidation, which can be initiated by activated oxygen species such as O², OH⁻ or ¹O² or by the action of lipooxygenase. Thickened cell wall, increased frequency of plasmodesmata and vacuolization of cytoplasm were reported in the shoot



apical meristem of canola (Mahmoodzadeh, 2008) due to salt stress. Yamane et al. (2004) observed disruptions in thylakoid and thylakoid membrane, while Sun et al. (2004) reported induction of ovule abortion in *Arabidopsis thaliana* due to dissipation of mitochondrial membrane potential (Hauser et al., 2006). Subsequently, cells in the gametophyte accumulate reactive oxygen species which gradually leads to programmed cell death (Hauser et al., 2006). The aborting gametophytes develop concentric rings of endoplasmic reticulum (autophagic bodies) surrounding chloroplasts, mitochondria, micro-bodies and cytoplasm. The cytoplasmic contents and organelles were invaginated into the vacuole. However, the formation of autophagic bodies and vacuoles is not found in every aborting ovule suggesting that these events are not related to programmed cell death (Hauser et al., 2006). Still date no such ultra-structural changes on medicinal plants reported or studied in details.

11. Plant Growth Promoting Microbes (PGPM) on Mitigating Salt Stress

The use of plant growth promoting microbes plays an important role on improvement of agricultural crop production including medicinal plant yield. It acts as a supplement to improve the growth and yield of several agricultural, horticultural and also for medicinal plants (Murthy et al., 1998; Lugtenberg & Kamilova, 2009). This approach might constitute two broad different ways first accomplished through all kinds of microbes inhabiting rhizosphere, rhizoplane, phyllosphere and endophytes. Second approach strongly focussed on the exploitation of the plant growth promoting rhizobacteria or PGPR because it possesses more direct effect and wider cross talk with host as plant than others (Figure 1). Hence, the

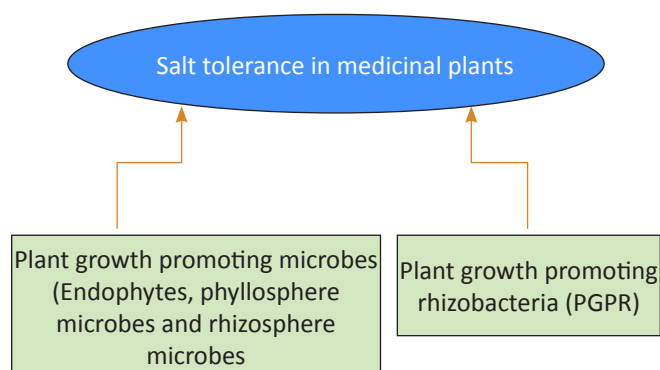


Figure 1: Improvement of salt tolerance in medicinal plants by two different approaches

opportunity and scope for success on manipulating the PGPR are far greater than others. The role of microorganisms in plant growth promotion, nutrient management and disease control is well known and well established. The association between plant-beneficial microbes (including PGPR) and their host plant(s) is thought to be ancient (Lambers et al., 2009) and has

probably been shaped by co-evolutionary processes, which suggests that the microbial partners could have significant effects on host physiology (Bharti et al., 2013). These beneficial microorganisms colonize the rhizosphere/endorhizosphere, phyllosphere or inhabit inside the plants and promote growth of the plants through various direct and indirect mechanisms (Lugtenberg and Kamilova, 2009).

There are profound literature based on the mechanism by which they aid plant growth and productivity. Still the exact mechanism in this regard is quite puzzling and intriguing. It showed that they can minimize the harsh effects of external stress factors, and protect plants from soil-borne pests and diseases by producing different antibiotics, hydrolytic enzymes, capable of producing phytoestrogens etc (Kachhap et al., 2015). Plant growth and productivity is highly affected by these interactions. Different types of microorganisms such as bacteria, fungi including mycorrhiza, protozoa, and algae coexist among them. Beneficial microbes including rhizospheric bacteria, plant growth promoting rhizobacteria (PGPR), endophytes (arbuscular mycorrhiza, bacteria and actinomycetes) were successfully studied for the ameliorating effects on soil salinity in medicinal plants. Plant growth-promoting microbes found in the rhizosphere of various plants grown in different soils and climatic conditions can provide a wide spectrum of benefits to plants (Mayak et al., 2004). The growth promotion of PGPR will be discussed separately. It has been demonstrated that inoculations with AM (arbuscular mycorrhizal) fungi improves plant growth under salt stress as well as acidic stress (Evelin et al., 2009; Mondal et al., 2016). Several studies investigating the role of AMF in protection against salt stress have demonstrated that the symbiosis often results in increased nutrient uptake, accumulation of an osmoregulator, an increase in photosynthetic rate and water-use efficiency, suggesting that salt-stress alleviation by AMF results from a combination of nutritional, biochemical and physiological effects. The inoculation of AM fungi *Glomus intraradices* in medicinal plants *Ocimum basilicum* significantly increases potassium uptake in plants and on the other side reduced the uptake of Na^+ and Cl^- ions when plants grown indigenously on soils with 7.56 dS/m of salinity (Zuccarini and Okurowska, 2008). The inoculation with diazotrophic endophytic bacteria *Achromobacter xylosoxidans* in medicinal plant *Catharathus roseus* resulted significant reduction of the level of stress hormone ethylene when plants grown on highly salt affected coastal saline soil of Tamil Nadu, India (Karthikeyan et al., 2012). Inoculation of *Glycyrrhiza glabra* with AM fungi *Glomus aggregatum* along with *Trichoderma harzianum* and *Bacillus coagulans* enhanced significantly its growth, plant biomass yield, nutrition and secondary metabolites (Selvaraj and Sumithra, 2011). Plant growth promotion in medicinal plants through mediated by phyllosphere microbes is yet to be investigated and there is no literature found in this regard.

12. Alleviation of Salinity stress in Plants by Plant Growth Promoting Rhizobacteria (PGPR)

Nowadays, several strategies have been developed in order

to decrease the toxic effects caused by high salinity on plant growth, including recently the use of plant growth-promoting rhizobacteria (PGPR) (Dimkpa et al., 2009; Srivastava and Kumar, 2015). Previous studies suggest that utilization of PGPR has become a promising alternative to alleviate plant stress caused by salinity and the role of microbes in the management of biotic and abiotic stresses is gaining importance. The subject of PGPR elicited tolerance to abiotic stresses has been reviewed recently (Srivastava and Kumar, 2015; Mondal et al., 2017). To be an efficient PGPR, bacteria must be able to colonize roots because bacteria need to establish itself in the rhizosphere at population densities sufficient to produce beneficial effects (Lugtenberg & Kamilova, 2009; Kachhap et al., 2015). They have been known to stimulate and enhance plant growth directly as they can improve and mobilize the supply of nutrients, such as nitrogen (Dobbelaere et al., 2003) and phosphorous and make them available for plant uptake or by production of phytohormones and growth regulators as well as indirectly by the suppression of pathogens by resisting, inhibiting through mechanisms of antibiosis, iron sequestration by siderophores, secreting cell wall degrading enzymes like chitinase, cellulase etc and improving soil structure by production of polysaccharide (Kachhap et al., 2015). It was also reported that the higher levels of the catalase and ascorbate peroxidase enzymes in the rhizobacteria inoculated plants can be associated with the enhanced tolerance towards salinity stress (Bharti et al., 2013). In medicinal plants it was previously reported that PGPR are able to enhance the rate of seed germination, seedling emergence, root and shoot growth, nutrient uptake, seed weight, yield, protecting plants from adverse effects of external stress factors and soil-borne diseases is documented for many plant species (Dobbelaere et al., 2003; Egamberdieva et al., 2010; Egamberdieva et al., 2012). The bacterial genera such as *Agrobacterium*, *Arthrobacter*, *Azotobacter*, *Azospirillum*, *Bacillus*, *Flavobacterium*, *Pseudomonas* and *Serratia* belong to PGPR. One of the recent potential approaches to mitigate the salt stress problem is the use of plant growth-promoting rhizobacteria (PGPR). Many Gram positive and Gram negative PGPR have been reported to colonize the plant rhizosphere and boosted plant growth by various direct and indirect mechanisms (Glick, 1995).

Investigations on the interaction of PGPR with other microbes and their effect on the physiological response of crop plants under different salt effected regimes are still at an incipient stage (Singh et al., 2011; Srivastava and Kumar, 2015). Rhizosphere microbes appeared to use carbon rich root exudates in the forms of sugar and acids for growth and production of secondary metabolites including phytohormones, and it will stimulate root growth, development and root surface area for enhancing nutrients uptake (Compant et al., 2005; Adesemoye et al., 2008). PGPR also help in enhance plant resistance to adverse environmental stresses such as salinity, drought, water-logging and heavy metals (Glick et al., 2007; Mondal et al., 2017). These PGPR (e.g., *Rhizobium*, *Azospirillum*,

Pseudomonas, *Flavobacterium*, *Arthrobacter* and *Bacillus*) utilize osmoregulation, oligotrophic, endogenous metabolism, resistance to starvation, and efficient metabolic processes to adapt under dry and saline environments (Lugtenberg et al., 2001; Egamberdieva and Islam, 2008). This group of bacteria, with a physiological adaptation and genetic potential for increased tolerance to drought, increasing salt concentration, and high temperatures, could improve plant production in degraded sites. Recent studies on the effect of PGPR for mitigation of salinity stress on medicinal plants showed the potential aspect for future. The salt tolerant, IAA producing bacterial strains *Pseudomonas aureantiaca* TSAU22 and *P. extremorientalis* TSAU20 were able to alleviate salt stress in medicinal plant *Sylebum marianum* grown under saline conditions (Egamberdieva et al., 2013). Egamberdieva (2013) have observed that the inoculation of pepper with bacterial strains of *P. putida* TSAU1, *P. extremorientalis* TSAU6, *P. chlororaphis* TSAU13 and *P. aureantiaca* TSAU22 significantly increased the shoot, root length and dry weight of whole plants grown in saline arid soil. *P. chlororaphis* TSAU13 strain were found the most effective strain for growth stimulation, where the shoot length increased upto 27%, root length 21% and dry weight of plant upto 20%. There are also existing evidences showed that the correlation between the ability of phytohormone production on PGPR and suppressing the negative effects of salt stress on medicinal plants and enhance their productivity. *Galega officinalis* L. commonly known as goat's rue, used for medicinal purposes (Atanasov, 1994; Atanasov & Spasov, 2000; Pundarikakshudu et al., 2001), is one of the cultivated medicinal salt sensitive plants. Co-inoculation of salt-stressed goat's rue with *Rhizobium galegae* and *Pseudomonas extremorientalis* significantly improved the root and shoot growth, nodulation and N content of plant roots grown in potting soils (Egamberdieva et al., unpublished data). The salt tolerant, IAA producing bacterial strains *P. aureantiaca* TSAU22 and *P. extremorientalis* TSAU20 were able to alleviate salt stress in medicinal plant *Sylebum marianum* grown under saline conditions (Egamberdieva et al., 2013). Inoculations with selected PGPR and other microbes could serve as the potential tool for alleviating salinity stress in salt sensitive crops. Therefore, an extensive investigation is needed in this area, and the use of PGPR and other symbiotic microorganisms, can be useful in developing strategies to facilitate sustainable agriculture in saline soils. A novel PGPR bacteria *Exiguobacterium oxidotolerans* STR36 inoculated *Bacopa monnieri* plants recorded 109 and 138 % higher herb yield (Table 1.) and also recorded 36 and 76 % higher active chemical bacoside-A content under severe salinity stress in field condition with salinity level of 4 g NaCl/kg in soil (Bharti et al., 2013). At salinity levels of 100 and 300 mM NaCl, *Halomonas desiderata* inoculated *Mentha arvensis* plants recorded the highest herb yield, whereas at 500 mM NaCl, the plants inoculated with *E. oxidotolerans* yielded maximum herb (Bharti et al., 2014). The recent studies on the effect of PGPR on medicinal plant yield are summarised in Table 1.



Table 1: Role of PGPR on medicinal plants in amelioration of salt stress

PGPR	Medicinal plants	Effect	References
<i>Bacillus megaterium</i>	<i>Catharanthus roseus</i>	Plant growth, enhanced secondary metabolites content	Karthikeyan et al., 2009
<i>Pseudomonas extremorientalis</i>	<i>Silybum marianum</i>	Increased biomass	Egamberdieva et al., 2013
<i>Azotobacter chroococcum</i>	<i>Catharanthus roseus</i>	Increased biomass	Karthikeyan et al., 2009
<i>Pseudomonas putida</i>	<i>Ocimum basilicum</i>	Increased biomass and secondary metabolites content	Golpayegani and Tilebeni, 2011
<i>Bacillus lentus</i>	<i>Ocimum basilicum</i>	Increased biomass	Golpayegani and Tilebeni, 2011
<i>Exiguobacterium oxidotolerans</i>	<i>Bacopa monnieri</i>	Increased herb yield and bacoside-A content	Bharti et al., 2013
<i>Bacillus pumilus</i>	<i>Bacopa monnieri</i>	Plant weight, bacoside-A content	Bharti et al., 2013
<i>Bacillus coagulans</i>	<i>Glycyrrhiza glabra</i>	Increased biomass and secondary metabolites content	Selvaraj and Sumithra, 2011
<i>Azospirillum brasilense</i> and <i>Pseudomonas fluorescens</i>	<i>Catharanthus roseus</i>	Increased biomass and ajmalicine content	Karthikeyan et al., 2009
<i>Halomonas desiderata</i>	<i>Mentha arvensis</i>	Increased herb yield	Bharti et al., 2014
<i>Exiguobacterium oxidotolerans</i>	<i>Mentha arvensis</i>	Increased herb yield	Bharti et al., 2014

13. Conclusion

The growing menace of salinity stress on medicinal plant yield is still increasing on steady state due to the increment of soil salinization rate day by day. There are a few approaches like development of salinity stress-tolerant plant genotypes though it is cost effective and takes long time to develop such genotypes. Hence, the use of plant growth promoting microbes gives light to construct a sustainable approach to mitigate high salinity stress on medicinal plants. In near future, further exploitation of beneficial microbes and manipulation of interaction of plant microbiome sphere give better hope for this strategy.

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