Microbiological Research 207 (2018) 41–52

Contents lists available at ScienceDirect

Microbiological Research

journal homepage: www.elsevier.com/locate/micres

Review

Does plant—Microbe interaction confer stress tolerance in plants: A review?

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ARTICLE INFO

Keywords:
Stress
PGPR
Plant-microbe interaction
Plant growth
Mycorrhizae
Food security

ABSTRACT

The biotic and abiotic stresses 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. Since the use of inorganic fertilizers and pesticides in agriculture practices cause degradation of soil fertility and environmental pollutions. Hence it is necessary to develop safer and sustainable means for agriculture production. The application of plant growth promoting microbes (PGPM) and mycorrhizal fungi enhance plant growth, under such conditions. It offers an economically fascinating and ecologically sound ways for protecting plants against stress condition. PGPM may promote plant growth by regulating plant hormones, improve nutrition acquisition, siderophore production and enhance the antioxidant system. While acquired systemic resistance (ASR) and induced systemic resistance (ISR) effectively deal with biotic stress. Arbuscular mycorrhiza (AM) enhance the supply of nutrients and water during stress condition and increase tolerance to stress. This plant-microbe interaction is vital for sustainable agriculture and industrial purpose, because it depends on biological processes and replaces conventional agriculture practices. Therefore, microbes may play a key role as an ecological engineer to solve environmental stress problems. So, it is a feasible and potential technology in future to feed global population at available resources with reduced impact on environmental quality. In this review, we have attempted to explore about abiotic and biotic stress tolerant beneficial microorganisms and their modes of action to enhance the sustainable agricultural production.

1. Introduction

The 21st century has been marked by global climate change. Many research studies have reported that environmental stresses are a major global threat to future of food security (Battisti and Naylor, 2009), while the world population is projected to reach from a current estimated 7 billion approximately to 8.9 billion by 2050 (Singh et al., 2011). Due to increasing climate variation, population and reduction in soil health for crop cultivation are threats for agricultural sustainability. It can become more prevalent in coming future due to these climate change and extensive agricultural practices (Wassmann et al., 2009). Since our traditional agriculture system which is unsustainable while population is increasing (Masciarelli et al., 2014), it is becoming very difficult for farmers and policy makers to produce such large amounts of food to fulfil the needs of growing population. On another hand, the indiscriminate use of chemical fertilizers, pesticides, weedicides etc. in agriculture causes extreme loss of beneficial microbial diversity from the soil.

Our agro-ecosystem is continuously affected by abiotic and biotic stress which directly change the crop productivity and, soil health and fertility. Various stress factors negatively affects the growth and productivity of crop plants. The stresses are simply classified as abiotic and biotic stress. Abiotic and biotic stress contributes 50% and 30% respectively to losses in agricultural productivity worldwide. The abiotic and biotic stress can either be natural or human induced. The major abiotic stresses are temperature, drought, salinity, and heavy metal stress. Stress condition has a wide range of effects on the plant morphology, physiology, biochemistry and even on gene regulation. Temperature, water deficiency, salinity and heavy metal pollutant are major stress factors in relation to climate change. The abiotic stress factors also influence the biotic stress and reduce crop productivity. The major effect of these stresses result loss of soil microbial diversity, soil fertility and competition for nutrient resources (Chodak et al., 2015).

Only the possible alternatives is plant associated microbial community, such as mycorrhizal fungi and plant growth promoting bacteria (PGPB), which helps the plants growth and development under different types of abiotic and biotic stresses. The application of efficient microorganisms like plant growth promoting rhizobacteria (PGPR) and mycorrhizal fungi are helpful in enhancing and improving sustainable agriculture and environmental stability. Microbes associated with plants, on the basis their effects on plants are classified into three groups: beneficial, deleterious and neuter. Various genera of

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https://doi.org/10.1016/j.micres.2017.11.004
Received 12 August 2017; Received in revised form 26 October 2017; Accepted 4 November 2017
Available online 09 November 2017

Pseudomonas, *Enterobacter*, *Bacillus*, *Variovorax, Klebsiella*, *Burkholderia*, *Azospirillum*, *Serratia,* and *Azotobacter* are termed as PGPR which promote plant growth and development under both normal and stress condition. However, most of plant growth promoting microbes (PGPM) and arbuscular mycorrhizae (AM) are unable to tolerate drought, salinity, and heavy metal stress. So, it is a very challenging task for the farmers as well as the scientists to develop biofertilizers which are applicable in such prevailing condition. The PGPM and mycorrhizae, maintains plant fitness and health under abiotic and biotic stress environment (Vimal et al., 2017). The future challenge lies how to develop such a biofertilizers which are applicable in all these stress conditions. However, some of them have the potential to tolerate these stresses and promote plant growth and development. These stress tolerant microbes have a different mechanism to overcome the harsh conditions and also consolidate plants. However, a novel approaches are needed in order to explore plant-microbe interaction to control plant growth and disease resistance under sustainable agriculture (Finkel et al., 2017). Overall, the plant associated beneficial microbes enhance the efficiency of their growth and development under abiotic and biotic stress condition. In this review, we have attempted to explore the beneficial effect of stress tolerant microbes and their modes of action to enhance the sustainable agricultural production.

1.1. Plant–microbe interactions: PGPM assisting stress tolerance

Plant growth and survival under adverse conditions may enhance by the application of stress tolerant PGPM and AM fungi (Nadeem et al., 2014). Indirect and direct mechanisms were used by microbes to promote plant growth and development during stress conditions. Different biochemical and molecular mechanisms are used by microbes to promote growth and development. For example, inoculation with PGPM, promote plant growth by regulating hormonal and nutritional balance, producing plant growth regulator and inducing resistance against phytopathogens (Spence and Bais, 2015). PGPM produce certain metabolites which reduced pathogen population around plant surrounding. For example, Siderophore produced by these microbes in rhizosphere reduced iron availability to certain pathogens and resulted in reduced their growth (Złoch et al., 2016). Further they also facilitate plant growth by fixing atmospheric nitrogen, solubilize phosphate and producing plant hormones (Ahmad et al., 2011). Some other mechanisms include nutrient mobilization, production of exopolysaccharide, rhizobitoxine, etc. (Vardharajula et al., 2011) that help the plant to cope up the unfavourable environment. Rhizobitoxine promote plant growth and development under stress condition by inhibiting ethylene production (Kumar et al., 2009). Besides these, microbes may have the ability to enhance plant growth and development by key enzymes such as ACC-deaminase, chitinase, and glucanase under stress condition (Farooq et al., 2009). In addition, some bacteria have sigma factors to change gene expression under adverse condition to overcome negative effect (Gupta et al., 2013). In addition to PGPM, the interaction of fungi with the root of the higher plant is also another important aspect of growth and development. Most commonly presence of mycorrhizae in agricultural field is AM. These fungi play an important role in nutrient cycling, absorption and translocation of nutrients. These mechanisms of microbes help the plant to maintain its actual growth under stress environment by mitigating the negative impact of stress on plant growth and development. So, the PGPM were found to be a potential substitute for inorganic fertilizers and pesticides. Therefore, the plant-microbe interaction may be important for sustainable agriculture and future food security concern. The plant growth promoting bacteria *Bacillus* and *Paenibacillus* promote plant growth and health in three different ways such as promotion of host plant nutrition and growth, antagonism against pathogens and stimulate defence mechanism and promote sustainable agriculture (Govindasamy et al., 2010). The sustainable agriculture practice with application of stress tolerant PGPM may be enhance the yields and nutritional quality of food grains under changing climate as well as saving of 20–25% cast of chemical fertilizers and pesticides. Using of these practices by the farmers can be enhanced the financial income with production of organic foods and vegetables.

2. Abiotic stress

2.1. Drought and its impact on crop productivity

Drought is recognized as serious environmental stress that attracted the attention of environmentalists and agricultural scientists. It is a major agriculture problem worldwide, limiting plant growth and productivity. Almost all of major agriculture land world are affected by drought stress. It produces wide variety of implication in human society, including economy (Disante et al., 2011; Mishra and Singh 2010). Drought stress affects various growth parameters and stress responsive gene during stress condition. Limited water content reduces cell size, membrane integrity, produce reactive oxygen species and promote leaf senescence that lead to decreased crop productivity (Tiwari et al., 2015). Despite it, during water deficient condition plants undergo a series of physiological and molecular change, such as increase ethylene production, change in chlorophyll content, damage photosynthesis apparatus and inhibit photosynthesis (Lata and Prasad, 2011). In addition, drought stress results in accumulation of free radicals that induce change in membrane function, protein conformation, lipid peroxidation and finally cell death (Tiwari et al., 2016). The frequency and intensity of drought is supposed to increase in coming future due to impact of climate change.

2.1.1. Mechanism of drought stress tolerance

Drought stress tolerant microbes have ability to enhance plant growth and development under water deficient condition. Microbes have evolved, adapt and/or develop a tolerance mechanism to survive under low water potential (Table 1). They may form thick wall or enter dormant stage, can accumulate osmolytes, produce exopolysaccharides (EPS). These plant associated microbes have various mechanisms to cope up negative impact of drought on plant as well as on soil. Irrespective of water content, they provide nutrient and better environment condition for the continuous growth of plants. The beneficial microbes colonized around rhizosphere, promote plant growth and development through various direct and indirect mechanisms. The potential mechanism includes (1) production of phytohormones such as indole-3-acetic acid (IAA), cytokinins and abscisic acid (ABA) (2) Bacterial exopolysaccharides (3) ACC deaminase (4) induced systemic tolerance. Phytohormones produced by plant play crucial role in growth and development (Farooq et al., 2009; Porcel et al., 2014). In addition, PGPR have ability to synthesize plant hormones that stimulate plant growth and division under stress condition. IAA, a most active auxin that regulates the vascular tissue differentiation, adventitious and lateral root differentiation, cell division and shoot growth during drought stress (Goswami et al., 2015). The ABA is an important growth regulator during drought stress. When seed or plant is inoculated with PGPR, the concentration of ABA increases and regulates physiology of plants to tolerate drought stress. ABA amelorates drought stress via regulating transcription of drought related gene and root hydraulic conductivity (Jiang et al., 2013). For example, *Azospirillum brasilense* ameliorates the response of *Arabidopsis thaliana* to drought mainly via enhancement of ABA levels (Cohen et al., 2015) (Table 1). The 1-Aminocyclopropane-1-carboxylate (ACC) is immediate precursor of ethylene during stresses. Bacterial ACC deaminase hydrolyzes ACC into ammonia and alpha-ketobutyrate (Bal et al., 2013). Drought stress tolerant and PGPR increase biomass, water potential, decreasing water loss in maize plant under stress condition. These inoculants decrease antioxidant activity and also enhance production of proline, free amino acid, and sugar in plants (Vardharajula et al., 2011). Under water deficient condition the chlorophyll content decreases and reduces photosynthesis in soybean

Table 1
Microbial mediated drought stress tolerance.

Plants	Microbes	Effect/Mechanism	References
Maize *(Zea mays)*	*Azospirillum lipoferum*	Increase accumulation of soluble sugar, free amino acids and proline. Affect the growth of root length, shoot fresh weight, shoot dry weight, root fresh weight and root dry	Bano et al. (2013)
	Bacillus Spp.	Increased accumulation of proline, sugars, free amino acids and decrease electrolyte leakage. It also reduce the activity of antioxidants enzyme (catalase, glutathione peroxidase)	Vardharajula et al. (2011)
Soybean	*Pseudomonas putida H-2–3*	Lower the level of abscisic acid and salicylic acid and a higher level of jasmonic acid content. Modulated antioxidants by declining superoxide dismutase, flavonoids and radical scavenging activity	Kang et al. (2014)
Wheat (*Triticum aestivum*)	*Bacillus amyloliquefaciens* 5113 *Azospirillum brasilense NO40*	Bacterial mediated plant attenuated transcript level and improves homeostasis.	Kasim et al. (2013)
	Azospirillum brasilenseNO40 Rhizobium leguminosarum (LR-30), Mesorhizobium ciceri (CR-30 and CR-39), and Rhizobium phaseoli (MR-2	Catalase, exopolysaccharides and IAA produced by the Rhizobia improved the growth, biomass and drought tolerance index	Hussain et al. (2014)
Lavandula dentate	*Bacillus thuringiensis*	IAA induced higher proline and K-content improved nutritional, physiological, and metabolic activities and decreased glutathione reductase (GR) and ascorbate peroxidase (APX) activity	Armada et al. (2014)
Cicer arietinum L.	*Pseudomonas putida MTCC5279 (RA)*	Osmolyte accumulation, ROS scavenging ability and stress-responsive gene expressions	Tiwari et al. (2016)
Lettuce	*Azospirillum* sp.	Promote aerial biomass, chlorophyll and ascorbic acid content, better overall visual quality, hue, Chroma and antioxidant capacity, and a lower browning intensity	Fasciglione et al. (2015)
Arabidopsis	*Azospirilum Brasilense* Sp 245	Improved plants seed yield, plants survival, proline levels and relative leaf water content; it also decreased stomatal conductance, malondialdehyde and relative soil water content	Cohen et al. (2015)
	Phyllobacterium brassicacearum strain STM196	Enhanced ABA content resulted in decreased leaf transpiration, delay in reproductive development, increased biomass and water use efficiency	Bresson et al. (2013)
Brassica oxyrrhina	*Pseudomonas libanensis* TR1 and *Pseudomonas reactans* Ph3R3	Increased plant growth, leaf relative water and pigment content and decreased concentrations of proline and malondialdehyde in leaves	Ma et al. (2016a, 2016b)
Rice (*Oryza sativa* L.)	*Trichoderma harzianum*	promote root growth independent of water status and delay drought response	Shukla et al. (2012a)
Medicago truncatula	*Sinorhizobium medicae*	Root nodulation and nutrient acquisition of nutrient during drought stress	Staudinger et al. (2016)

plant. To overcome this effect, inoculation with *Pseudomonas putida* H-2-3 needs to be done, which alleviate drought stress by enhanced chlorophyll content, improved shoot length and biomass (Kang et al., 2014). In addition combination of endophytic and rhizospheric PGPR improves ability of stress tolerance. Exopolysaccharide produced by microbes improve drought tolerance in certain plants. For example three drought tolerant bacterial strains *Proteus penneri* (Pp1), *Pseudomonas aeruginosa* (Pa2), and *Alcaligenes faecalis* (AF3) inoculated with maize plant showed potential increase in relative water content, protein, and sugar though the proline content (Naseem and Bano 2014).To survive in such drought conditions, bacteria come up with a variety of physiological, biochemical and molecular mechanism to protect from adverse condition. They synthesize EPS, compatible solute and formation of spore (Chithrashree et al., 2011). The EPS producing bacteria make plant resistant against water under drought stress (Sandhya et al., 2009). Compatible solutes such as glycine, proline, betain and trehlose accumulated during drought stress and help bacteria to maintain membrane permeability, enzyme to maintain their integrity and protein in their functional form. Mycorrhizal inoculation combinations with specific bacteria enhance plant growth, nutrient uptake relative water content to reduce impact of drought. The association of *Pseudomonas putida* and *Bacillus thuringiensis* decrease stromal conductance and electrolyte leakage due to accumulation of proline in shoot and root (Ortiz et al., 2015) (Table 1). On the basis of above discussion, it is clear about associations of drought tolerant microbial community with plants can maintain proper growth and survival under drought condition.

2.2. Salinity stress: a major challenge for agriculture

Salinity stress is one of the most common abiotic stress factors in modern agriculture. Most of the agricultural lands of the world are highly affected by salinity due to various reasons. Salinity results in poor microbial activity due to toxic effect of ions and osmotic stress leading to reduced plant growth and development. Salinity causes low water potential in soil and it is difficult for plant to uptake water and nutrients from soil and result osmosis stress. The salinity in soil is caused by cations such as Na^+ (sodium), Ca^{2+} (calcium), K^+ (potassium) and anions Cl^- (chloride), $NO_3{}^-$ (nitrate) mostly under different conditions. Salt are found in soil as electrically charge ions due to inadequate rain fall or weathering of soil (Shrivastava and Kumar, 2015). Salinity stress have a detrimental impact on all aspects of plants such as agricultural productivity, seed germination, water and nutrient uptake and also disturb physicochemical and ecological balance (Shrivastava and Kumar, 2015). In addition it also causes adverse effect on nodulation process, reducing nitrogen fixation and crop yield. Among these nitrogen fixation, one on the most important process highly affected under salt stress condition. The Nitrogenase enzyme is responsible for nitrogen fixation is reduced during salinity stress. Soil salinity decreases water uptake through root from soil and higher amount of salt water within cell are toxic to plant hence suppress the growth of plant. Salinity affects plant growth and microorganism functioning mainly through osmotic effect and ion toxicity. Fungi are more sensitive to higher salt concentration than bacteria. Both low and high osmotic potential result difficulties for plant and microorganism to uptake water from soil.

2.2.1. How to manage salinity stress

Soil salinity is a challenging task in front of farmers and agricultural scientist. Accumulation of toxic Na and Cl ions and nutrient imbalance in the soil causes severe impact on plant growth and microbial activities. Much has been reported, that inoculation with PGP microbes and endophytic microbes mitigate the negative salt effect on different plants. PGP microbes can promote plant growth under salinity stress through various direct and indirect mechanisms. In addition biofilm formed by PGPB under salinity stress effective in alleviating deleterious effects (Kasim et al., 2016). *Azospirillum* inoculated lettuce seed showed

Table 2
Microbial mediated salinity stress tolerance.

Plants	Microbes	Effect/Mechanism	References
Groundnut (*Arachis hypogaea* L.)	*Brachybacterium saurashtrense* (JG-06), *Brevibacterium casei* (JG-08), and *Haererohalobacter* (JG-11)	Higher K^+/Na^+ ratio and higher Ca^{2+}, phosphorus, and nitrogen content. Shoot and root has higher concentra-tion of auxin	Shukla et al. (2012a, 2012b)
Mung bea (Vigna radiate)	*Rhizobium* and *Pseudomonas*	ACC-deaminase for improving growth, nodulation and yield of mung bean under natural salt-affected conditions	Ahmad et al. (2011)
Barley and oats	*Acinetobacter* spp. *and Pseudomonas* Sp.	Production of enzyme ACC deaminase lower ethylene and IAA promote plant growth	Chang et al. (2014)
Wheat	*Azospirillum* Sp.	Increased shoot dry weight and grain yield. Plants accumulate some organic solutes (e.g. proline and soluble sugars)and inorganic ions to maintain osmotic adjustment	
	Pseudomonas Sp. Serratia Sp.	Have ACC deaminase activity, reduce ethylene level and enhance plant height, root length and yield	Zahir et al. (2009)
Maize (Zeya Mays)	*Pseudomonas* and *Enterobacter*	Reduce triple response and more N, P, and K uptake and high K^+–Na^+ ratios	Nadeem et al. (2009)
Rice GJ-17	*Pseudomonas pseudoalcaligenes and Bacillus pumilus*	Reduced the toxicity of reactive oxygen species(ROS) and reduce lipid peroxidation and superoxide dismutase activity. Reduce lipid peroxidation and superoxide dismutase activity	Jha and Subramanian, (2014)
Rice	*Bacillus amyloliquefaciens* NBRISN13 (SN13)	Modulating differential transcription in a set of at least 14 genes	Nautiyal et al. (2013)
Barley (*Hordeum vulgare* L.)	*Hartmannibacter diazotrophicus* E19	Increased root and shoot dry weight. ACC-deaminase activity of and lower ethylene content	Suarez et al. (2015)
lettuce seeds	*Azospirillum*	Promoted higher biomass, ascorbic acid content antiox- idant capacity, and a lower browning intensity	Fasciglione et al. (2015)
Brassica napus (canola) and Maize	*Pseudomonas putida* UW4	Modulation of plant protein differential expression and ACC deaminase activity	Cheng et al. (2011)

better germination and vegetative growth comparison to control in saline condition (Barassi et al., 2006). In an another study, inoculation of plant with growth-promoting bacteria *Pseudomonas stutzeri* to salt tolerant and salt susceptible chili pepper reduce negative effect on soil salinity (Bacilio et al., 2016). While some microbial species ameliorate salinity stress activity of biofilm formation on barely grains (Kasim et al., 2016). Co-inoculation of AM fungi along with salt tolerant bacteria significantly improves the salinity tolerance in certain plants. For examples, the co-inoculation of *R. intraradices* and *Massilia* sp. RK4 renovate Arbuscular mycorrhizal fungi (AMF) root colonization and nutrient accumulation under salt stress in maize plant. These associations of fungal and microbial, exhibit significant impact on salinity tolerance in maize plant (Krishnamoorthy et al., 2016).

2.2.2. Mechanism of salinity stress tolerance

Diversity of salinity stress tolerant microbes is involved in promotion of growth under stress condition (Table 2). The direct mechanisms include phytohormones production (e.g. auxin, cytokinin, ethylene and gibberellins), nitrogen fixation, nutrient mobilization and siderophore production (Hayat et al., 2010). They have different mechanism and mode of action. These mechanisms lead to increase root length, surface area and root number there by nutrient uptake (Egamberdieva and Kucharova, 2007). The major indirect mechanism includes, reduction in frequency of disease causing plant pathogens. Root colonizing rhizobacteria produce ACC deaminase which convert ACC in to ammonia and alpha ketobutyrate and lower ethylene. Vijavan et al. has demonstrated that enzyme Rhizobitoxine inhibit ethylene production and enhance nodulation under stress condition. PGPB ameliorate salt stress by potentially accumulating osmolytes in their cytoplasm, which counteract on osmotic stress and maintain cell turgor and plant growth. Microbial EPS induce resistance against salinity by binding with cations thus making it unavailable to plants under stress conditions (Vardharajula et al., 2011). Co-inoculation with PGPR strains such as *Rhizobium* and *Pseudomonas* can overcome these detrimental effects and facilitate plant growth in saline soil (Bano and Fatima, 2009). Two rhizospheric bacteria *Bacillus pumilus* and *Bacillus subtilis* isolated from saline soil showed PGPR traits, such as IAA production, ammonia and hydrogen cyanide (HCN) production, phosphate solubilization and also salt stress tolerance (Damodaran et al., 2013) (Fig. 1). Bano and Fatima, (2009) reported that PGPR, *Rhizobium* and *Pseudomonas* alleviate salt stress in NaCl affected maize plant. The stress tolerance in maize plant is due to decrease in electrolyte leakage, osmotic potential, enhanced production of proline and selective uptake of K ions. Rice plant inoculated with P. *pseudoalcaligenes* and *Bacillus pumilus* enhance salinity tolerance, show higher concentration of glycine betaline (Jha et al., 2011). *Acinetobacter* spp. and *Pseudomonas* sp. produce of ACC deaminase and IAA during salt stress in Barley and oats and promote plant growth (Chang et al., 2014) (Table 2). Jha and Subramanian (2014) has been reported that *Pseudomonas pseudoalcaligenes* and *Bacillus pumilus* reduce lipid peroxidation and superoxide dismutase activity in salt sensitive rice GJ-17 during salt stress (Fig. 2).

The PGPR-induced physical and chemical changes results in induced systemic tolerance (IST), enhanced tolerance to salinity stress. They stimulate root and shoot growth and reduced disease susceptibility to fungi such as *Fusarium solani* to cotton plant. It also induced resistance against red rot disease in cotton (Egamberdieva et al., 2015). Salinity tolerant *Azospirillum* strains promote plant growth and enhance total plant dry weight, grain weight etc. in wheat crop under water salinity stress (Nia et al., 2012). Plant hormone, ABA plays a significant role in salinity stress through acidification of apoplast in maize plant. Lettuce seed inoculated with *Azospirillum* promote growth, product quality and storage life under stress condition (Fasciglione et al., 2015). *Hartmannibacter diazotrophicus* E19 a PGPR isolated from *Plantago winteri*, promote plant growth of barley (*Hordeum vulgare* L.) under saline condition (Suarez et al., 2015). Egamberdiyeva, (2007) demonstrated that three PGPR isolates *Pseudomonas alcaligenes* PsA15, *Bacillus polymyxa* BcP26 and *Mycobacterium phlei* MbP18 have potential ability to survive in saline soils like calcisol soil. Co-inoculation of PGPB, *Rhizobium* and *Pseudomonas* showed increased accumulation in proline content along with decreased electrolyte leakage, maintenance of relative water content of leaves and selective uptake of K ions improve salt tolerance in *Zea mays* (Bano and Fatima, 2009). Three PGPR strains *P. fluorescens*, *P. aeruginosa* and *P. stutzeri* were isolated from the tomato rhizosphere containing more sodium chloride concentration. These microbes have the ability to induce production of phytohormones and ACC deaminase enzyme to improve salinity tolerance in tomato plant (Bal et al., 2013; Tank and Saraf, 2010). Nautiyal et al. (2013) have reported that salt tolerant *Bacillus amyloliquefaciens* NBRISN13 (SN13) inoculated with

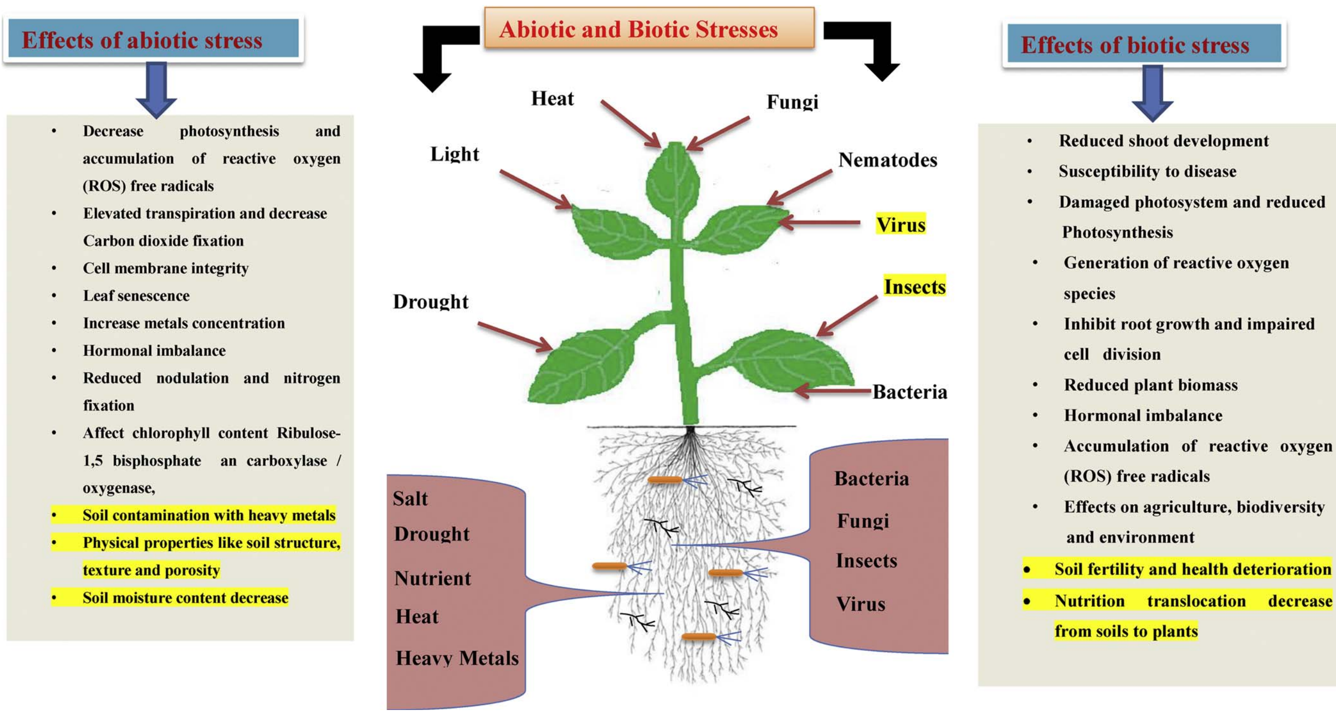

Fig. 1. Effects of different abiotic and biotic stresses on morphological, biochemical and physiological attributes of plants.

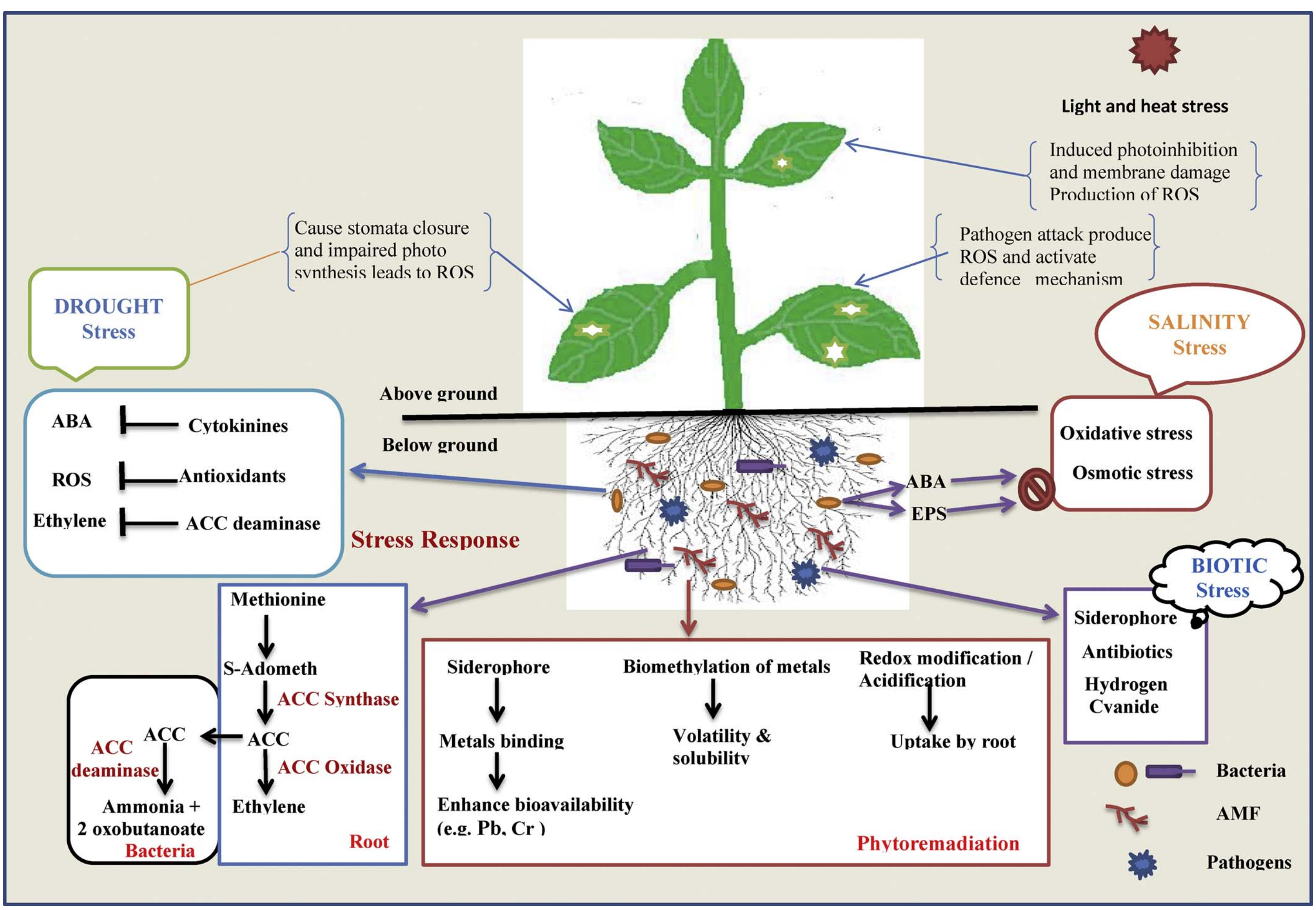

Fig. 2. Mechanism of rhizosphere microbes to minimize the various types of abiotic and biotic stress for enhancement of plant growth and development, ROS: Reactive Oxygen Species; ABA: Abscisic Acid; EPS: Exopolysaccharide; ACC: 1- Aminocycloprpane-1-Carboxylate; AMF: Arbuscular Mycorrhizal Fungi; Pb: Lead; Cr: Chromium.

Table 3
Microbial mediated heavy metals stress tolerance.

Heavy Metals	Plants	Microbes	Effect/Mechanism	References
Cd, Ni, As, Cu, Pb and Zn	*Alnus firma*	*Bacllus thuringiensis* GDB-1	Production of phytohormones, siderophore, (ACC) deaminase and solubilization of Phosphorus. Increased biomass, chlorophyll content, nodule number, and heavy metal (As, Cu, Pb, Ni, and Zn) accumulation in A. firma seedling	Babu et al. (2013)
Cd and Pb	*Gladiolus grandiflorus* L.	*Thiobacillus thiooxidans* and *Pseudomonas putida*	Promote root length, plant height, dry biomass of the plant and enhanced accumulation of Cd and Pb	Mani et al. (2016)
Cd, Zn and Cu	*Solanum nigrum* L.	*Pseudomonas* spp. Lk9	Improved soil Fe, P and heavy metal availability, shoot dry biomass and uptake of Cd, Zn and Cu biosurfactants. Production of siderophores and organic acids that induce growth and metal uptake by Cd hyperaccumulator *Solanum nigrum* L.	Chen et al. (2014)
Cd, Zn and Cu	*Sedum*	*Bacillus pumilus E2S2,*	Production of IAA, siderophores, ACC deaminase and solubilization of Phosphorus. Increased water extractable Cd and Zn contents in soil, Improved plant growth and metal uptake	Ma et al. (2015)
	Plumbizincicola	*Achromobacter* sp. *E4L5 and Stenotrophomonas* sp. *E1L*		
Cd and Pb	*Lettuce*	*Bradyrhizobium japonicum*	IAA production enhance the growth and increased the shoot root lengths and dry biomas	Seneviratne et al. (2016)
Cd Pb, and Zn	*Polygonum pubescens*	*Enterobacter* sp. JYX7 and *Klebsiella* sp. JYX10	Production of IAA, siderophores, ACC deaminase, solubilized inorganic phosphate improved phytoremediation efficiency	Jing et al. (2014)
Zn	*Brassica juncea*	*Pseudomonas brassicacearum and Rhizobium leguminosarum*	Induced metal chelation, toxicity attenuation and microbial-assisted phytoremediation.	Adediran et al. (2015)
Pb	*Calopogonium mucunoide*	*Glomus etunicatu*	Promoting plant nutrient(P,S and F)acquisition, attenu- ating the negative effects of Pb on membranes and contributing to the reduction of ROS generation	De Souza et al. (2012)
Cd and Zn	*Helianthus annuus* L.	*Glomus fasciculatum* and *Pseudomonas putida*	promoted the dry biomass of the plant, accumulation of Zn and Cd in root and shoot	Mani et al. (2016)
Cd and Pb	Marigold(*Calendula officinalis* L.)	*Claroideoglomus claroideum Funneliformis mosseae*	Accumulation of secondary metabolites(phenols, flavonoids, carotenoids) and enhanced antioxidant capacity	Hristozkova et al. (2016)

rice plant increase growth and salt tolerance through the up-regulation and repression of 14 genes in rice plants. Phytohormones producing endophytic bacteria are also induce salinity stress tolerance in plants. ABA and auxin produced by *Bacillus amyloliquefaciens* RWL-1 has been reported to induce salinity stress tolerance in *Oryza sativa* (Shahzad et al., 2017). In addition to the endogenous production of plant hormones, plant growth promoting endophytic bacteria, combine with exogenous jasmonic acid overcome the negative impact of salinity in *Solanum pimpelifolium* (Khan et al., 2017) (Table 2). Involvement of tricarboxylic acid (TCA) cycle in salinity tolerance in tomato plant is another dimension to made resistance against salinity tolerance (Torre-González et al., 2017).

Salinity and drought stress cross talks result in secondary stress such as oxidative and osmotic stress. PGPB induce salinity and drought stress tolerance through modulation of physiological and biochemical process, induced systemic resistance. The major steps involved in defence mechanism include phytohormones level, production of antioxidant and osmotic adjustment. In response to salinity and drought stress, compatible osmolytes are produced by microbial strains and in plants to promote plant growth. Plants induced by microbes enhance proline production during salinity and drought stress.

2.3. Mycorrhizal fungi mediated salinity and drought stress tolerance

Plant associated fungi play a crucial role in drought and salinity stress tolerance. AM symbiosis alters hormonal physiology, and physiology of plants alleviates drought stress. In addition, it also improves photosystem II efficiency and photosynthetic product under water deficit condition (Ruiz-Lozano et al., 2016). *Trichoderma harzianum* encourages root growth despite water content and detain drought response in rice plant (Shukla et al., 2012a, 2012b). Strigolactone level also increases in order to mitigate drought stress condition by establishing symbiosis and renovate drought tolerance in lettuce and tomato (Ruiz-Lozano et al., 2016). AM fungi have also been regarded as an important component to ameliorate soil salinity. It has been reported that inoculation with AM enhance plant growth under salt stress condition. They inhibit the uptake of Na or Cl in citrus plant in saline condition (Navarro et al., 2014). So inoculation with PGPR and other microbes could serve as potential tools for alleviating salinity stress in salt sensitive crop. The efficiency of drought and salinity stress tolerance may also enhance by co-inoculation of PGM microbes and plant associated fungi.

2.4. Heavy metals stress

Continued industrialization, intensive agricultural practices and anthropogenic activities lead to heavy metals contamination in soil. These heavy metals have severe impact on plants and human health. Heavy metals are metallic elements that have a higher density than 4 g/cm3, non-degradable and also poisonous at low concentration (Duruibe et al., 2007; Ma et al., 2016a, 2016b). To safeguard and conserve environment from their toxic effect, it is utmost necessary to remove these heavy metals through sustainable and effective approach. Because most of the techniques used for remediation are very costly and deleterious to soil structure (Glick, 2010). Phytoremediation, an emerging technique makes use of plants and their associated microbes to clean up heavy metals pollutant from soil. In addition it is cost effective and sustainable approach for removal of heavy metals (Ma et al., 2016a, 2016b; Chirakkara et al., 2016). Further, on another hand, use of microbes enhanced the efficiency of phytoremediation. Microbes are more sensitive than other living organism and may be a good indicator of heavy metal stress (Broos et al., 2004; Chen et al., 2014). The Use of microbial diversity for assisting of heavy metals remedy in recent year has been attained because of low cost, environment friendly and aesthetic approach and also applying in different situation.

2.4.1. Microbial assisted remedy of heavy metals

A wide range of heavy metal tolerant microorganisms and plants associated microbes such as rhizobacteria, mycorrhiza, and firmicutes have the ability to promote plant growth and development during metal stress condition (Table 3). These microbes are involved in various mechanisms such as efflux, impermeability to metals, volatilization, EPS sequestration, metal complexation and enzymatic detoxification. In addition, these plant associated microbes promote plant growth and development through lowering ethylene concentration, production of plant growth regulator such as IAA, ACC deaminase and suppress disease (Glick, 2010) (Fig. 1). Apart from these, nitrogen fixation, nutrient mobilization, siderophores and phosphate solubilization, enhance both plant growth and removal of heavy metals (Verma et al., 2013; Ahmad et al., 2011). Both living as well as non-living microbial biomass have been used for removal of heavy metals. The cell wall properties of bacterial, fungal and their functional group have a major concern. (Vijayaraghavan and Yun, 2008). Bioaccumulation by microorganism is a potent method for removal of heavy metals from contaminated soil. It has been reported that Proteobacteria, Firmicutes, Actinobacteria, potentially removed higher concentration of Mn, Pb and As from metal polluted soil (Zhang et al., 2015). Fatnassi et al. (2015) study reveals that above 1 mM concentration of copper (Cu) damaged plant growth of *Vicia faba*, but when inoculated with rhizobia and PGPR, reduced its effects. AM fungi alleviate deleterious effect of cadmium stress by reducing malonaldehyde and hydrogen peroxide (Hashem et al., 2016). The removal of Cd, Pb and Zn metal from contaminated soil, Jing et al. (2014) has demonstrated that *Enterobacter* sp. and *Klebsiella* sp. are efficient metal tolerant by producing plant growth substances (Table 1). Another study by Prapagdee et al., 2013 in contaminated soil that cadmium resistant PGPB, *Micrococcus* sp. MU1 and *Klebsiella* sp. BAM1 enhance cadmium mobilization and promote root elongation and plant growth. Arsenic resistant bacteria (ARB) from *Pteris vittata* is an efficient siderophore producer, enhances plant growth and acquisition of nutrition by Phosphate solubilization (Ghosh et al., 2015). Armendariz et al. (2015) has reported that two bacterial species *Bradyrhizobium japonicum* E109 and *Azospirillum brasilense* Az39 efficiently colonized in arsenic (As) contaminated soil, accumulate As in cell biomass and promote plant growth. So that PGPR contribute to plant development under heavy metal stress or limit incorporation in plant tissues (Li et al., 2007) (Table 3 and Fig. 2).

2.4.2. PGPM assists mechanism of heavy metals removal

Phytoremediation is advanced over traditional methods and their efficiency can enhance through use of PGPM for removal of heavy metals from contaminated soil (Glick, 2010). This method is most effective, innovative and healthy for heavy metals removal. PGPB available metals by chemical and physical process for accumulations and removal (Ullah et al., 2015).The major mechanism applied by microbes to cope up include extracellular, intracellular accumulation, sequestration and biotransformation high toxic to less toxic one (Babu et al., 2013; Qian et al., 2012). Some microbes have ability to completely degrade heavy metals. For examples PGPM such as *Pseudomonas* sp. MBR show the biotransformation of single Fe (III)–, Zn– and Cd–citrate complexes and their removal (Qian et al., 2012). PGP microbes improve phytoremediation in to different ways; either directly or indirectly.

2.4.3. Direct mechanism of phytoremediation

The major processes that are involved in direct assistance to phytoremediation by PGPM consist of solubilization, bioavailability, and accumulation of heavy metals (Vymazal and Březinová, 2016). Different mechanisms were used by plant associated microbes for removal of heavy metals from metal contaminated soil. Siderophore, a low molecular weight organic compound, chelating heavy metals and enhance their availability in rhizosphere, produced by plants associated microbes. However, it has primary role in chelation with ferric iron, but also has high affinity with metals and form complex which is transported in to cytosol (Saha et al., 2016; Złoch et al., 2016). Siderophore iron complex transfer into cytosol more frequently than other heavy metals (Złoch et al., 2016). Like rhizobacteria, some other microbes reside inside plant tissues may assist in phytoremediation. For instance, endophytic bacteria have metal resistance properties and promote plant growth under metals stress by directly providing mineral nutrient, plant growth regulator and enzyme. Rhizosphere bacteria are more potent in production of siderophore than endophytic bacteria (Ma et al., 2016a, 2016b; Złoch et al., 2016). Endophytic microbes have the ability to synthesize Nitrogenase enzyme under metals stress and poor nitrogen condition by providing abundant nitrogen to associated plants. Dory et al. has isolated stem Endophytic genera *Burkholderia*, *Rahnella*, *Sphingomonasand Acinetobacter* from the *Populus trichocarpa* and *Salix sitchensis* synthesize Nitrogenase enzyme and able to fix atmospheric nitrogen. The rate of nitrogen fixation is also increased by endophytic bacteria during long term deficiency of nitrogen (Gupta et al., 2013). Phytohormones (mainly auxin), produced by endophytic bacteria enhance root growth and improve nutrient uptake. In addition some other low molecular weight organic acid produced by PGPM play an effective role in phytoremediation. Gluconic, oxalic and citric acids are most effective in mobilization and availability of heavy metals to plants (Ullah et al., 2015; Janoušková et al., 2006).

In addition, mobility of heavy metals such as As, Cr, Hg, and Se, is highly influenced by oxidation or reduction reaction. Some metals are less soluble in their higher oxidation state as compared to low oxidation state. Whereas solubilises of metalloids are governed by both oxidation state and ionic form (Bolan et al., 2014).In addition, Bio-methylation is another method for mobilization of heavy metals which involves the transfer of methyl group through bacterial activity. The methylation Pb, Hg, Se, As, Tn and Sn are mediated by many bacteria (Bolan et al., 2014). Phytochelatins (PCs) are metal binding cysteine-rich peptides, enzyme actually synthesized in some fungi and plants from glutathione in response to heavy metal stress (Gadd, 2010).

2.4.4. Indirect mechanism of phytoremediation

The indirect assistance involves improvement of plant growth, inhibiting pathogen infection and enhanced accumulation of heavy metals. The higher concentration of heavy metals in rhizosphere disturb uptake of nutrient and inhibit plant growth. Plant growth promoting microbes have potential ability to provide nutrient under such limiting condition. PGPB fix atmospheric nitrogen and provide to plant under metals stress condition through symbiotic association (Nonnoi et al., 2012). Phosphorus is another important element found abundantly in the soil in complex form and unavailable to plants. Phosphorus mostly occurs in the soil in an insoluble form (Lavakush et al., 2014). Microbes produce organic acids that solubilize by acidification and provided to plants (Nautiyal et al., 2000). The endophytic bacteria promote plant growth under metal stress through controlling pathogens or induced systemic resistance (Ma et al., 2016a, 2016b). Overall the microbial diversity promotes removal of heavy metals from the polluted environment as well as promotes plant growth and development. Microbes with strong assistance in phytoremediation ability enable the plant to survive easier in the heavy metal environment and play an important role in growth promotion.

2.4.5. PGPB and AM fungi assisting phytoremediation

A large number of PGPM have been reported to assist phytoremediation. Phytoremediation of heavy metals by various plants is also assisted by use of microbes which bioavailable and soluble forms through the action of siderophores, organic acids, biosurfactants, biomethylation, and redox processes (Ullah et al., 2015; Doble and Kumar, 2005). Plant exposed to heavy metals may cause 30–35% reduction in length, mass and shoot and root ratio. Inoculation with PGPR restores and enhances growth and productivity (Pishchik et al., 2009). The addition of PGPB enhances the efficiency of phytoremediation. AM fungi form a symbiotic association with most of the plant and enhance their ability to absorb water and nutrients from soil (Miransari, 2011). In addition combined use of heavy metals resistance bacteria, *Bacillus*, *Lysinibacillus* and *Pseudomonas* chelates could improve phytoremediation of heavy metals (Vigliotta et al., 2016). Phytochelatins produced by microbes have an ability to bind with heavy metals and their removal from polluted environment. Clone of *Schizosaccharomyces pombe* and *Pseudomonas putida* KT2440 enhance accumulation of heavy metals from polluted heavy metals environment (Yong et al., 2014).

2.5. Temperature stress

Climate change has increased the frequency and intensity of temperature stress. Both heat stress (HS) and cold condition are becoming a significant abiotic stress condition for crop productivity and food security worldwide. The major effect of temperature stress is, change in plasma membrane, water content (transpiration), impaired photosynthesis activity, enzyme functioning, cell division and plant growth. The greatest impact of climate change is found in tropical and subtropical regions, including India (Rodell et al., 2009; Alam et al., 2017). Temperature may affect different components of cell and cell membrane. For example heat may increase fluidity while cold make them more rigid. Heat stress is a consequence of numerous physiological and biological resorts if not properly managed. Heat stress is one of the most serious abiotic stresses and causes much change in plant hormone concentration and responses. The concentration of jasmonic acid (JA) increase many fold during stress condition. Plants have complex regulatory mechanism to direct crop tolerance. Innumerable plant species have acclimated to low and higher temperature. Such variable environment condition induces many physiological changes in plant species which enables them to acclimatize and survive in changed temperature condition. Plants employ various mechanisms to overcome heat stress which includes production and accumulation of enzymes and osmolytes. Heat shock proteins (HSP20, HSP 60, HSP70, HSP 90, HSP100) and reactive oxygen species (ROS)-scavenging enzymes (ascorbate peroxidase and catalase) are major functional proteins (Qu et al., 2013; Kotak et al., 2007). But most of crops were unable to tolerate extreme temperature both heat stress and cold shock. Hence, there is an urgent need to have such a mechanism of extreme temperature tolerance.

2.5.1. Temperature stress microbes

There is an urgent need to find out solution for crop production under changing climate. One approach focuses on the use of microbes to mitigate adverse effects of heat and cold stress. Temperature plays a significant role in regulating physiology and metabolism of microbes in extreme temperature. Microbial enzymatic feature helps microbes in adaptation to low and high temperature. These microbes have effective mechanism to protect their protein, membrane and nucleic acid to live under such conditions. Gene expression of heat and cold tolerant protein and enzyme are enhanced under these conditions. Molecular chaperons are one of the most efficient to defend heat. On the basis of growth microbes are divided in to two group, psychrophilic and psychrotrophic microorganisms. The growth of psychrophilic lie maximum at or below 15 while psychrotrophic microbes growth at are above 15 °C. Heat stress induced expression of gene responsible for survival of microbes. DnaK gene in *Alicyclobacillus acidoterrestris* expression enhance during heat stress to code HSP, protect microbes from heat. It grow from 23 to 70 and maximum growth at 45–50. Expression of HSP is a strategy for adaptation to high temperature. Though the induction of heat shock proteins are an important mechanism to survives under severe heat stress. Under heat stress condition they maintain by getting efficient nutrient and water uptake, and enhance photosynthesis. Trehalose synthesis induces during heat stress and protects micro-organism from heat and cold shock injury and oxidative stress. Accumulation of trehalose in bacteria and fungi increase many fold during heat stress. During heat stress and cold shock trehalose accumulated in microbial cell protects from thermal injury (Li et al., 2009). It plays a major role in stabilization of protein in cell. In fungi trehalose reduces heat stress induced denaturation and aggregation of protein hence maintain in native conformation. Trehalose can also provide certain protection to protein against heat induced protein denaturation. It has been reported that trehalose is most active against freezing and desiccation. The amount of metabolites produced by microbes during drought stress varies according to plant and microbes.

2.5.2. Mechanism of heat stress tolerance

Majority of earth biosphere have been successfully colonized by high and low temperature tolerant microbes. Microbes adapted for low temperature show plant growth properties under low temperature. Yadav et al. (2014) have reported that *Pseudomonas cedrina, Brevundimonas terrae*, *Arthrobacter nicotianae* adapted for low temperature show multifunction plant growth promoting ability. The PGPR isolated from root nodule of low temperature growing pea plant have efficient biofertilizer ability in low temperature (Meena et al., 2015). Further, Javani et al. (2015) have reported that psychrophilic bacteria isolated from Antarctica show antimicrobial activity. On another hand inoculation of thermotolerant phosphate solubilizing microbes in agriculture field acts as multifunctional bio fertilizer. It functions as biogeochemical phosphorus cycling in agriculture field. The major function of phosphate-solubilizing microbes is the transformation of insoluble phosphorus to soluble forms through acidification (Chang and Yang, 2009) (Fig. 3).

3. Biotic stress and plant health

In nature, soil and plant roots are habitat for colonization of variety of soil borne pathogens and beneficial microbes. Plants root exudates and other chemical generated by plants attract the microbial diversities. Plant pathogens e.g. bacteria, fungi, viruses, and pests caused massive destruction of crop yield (Ramegowda and Senthil-Kumar, 2015). The common impacts of these biotic factors include imbalanced hormonal regulation, nutrient imbalance and physiological disorder. Further growing cost of pesticides and their harmful effects on soil are highly noticeable. Many plants have the ability to change gene expression and cope with these stresses through acclimatization and adaptation while others cannot. However, the non-pathogenic microbes have shown ability to suppress many diseases caused by these pathogens. So use of beneficial microbes as biological control, PGPM has been viewed as alternative and sustainable approach to replace pesticides and chemical fertilizers. The naturally associated bacteria and fungi colonize root hair and promote plant growth and development. PGPM has been considered as an eco-friendly and cost effective means for control of diseases. They provide the defence against pathogens through activation of cellular component including cellular burst, cell wall reinforcement and accumulation of secondary metabolites. The defence related hormones include JA, ethylene and Salicylic acid (SA) plays a primary role in signal transduction and defence mechanism (Verhage et al., 2010; Bari and Jones, 2009). Co-inoculation of PGPR with mycorrhizae also ameliorates harmful impact of biotic stress. They protect plants from pathogen through enhancing growth attributes and reducing the susceptibility for disease (Dohroo and Sharma, 2012).

3.1. Mechanism of biotic stress tolerance

The plant-microbe interactions in natural habitats are crucial for proper growth and development. They play an important role in nutrient mobilization and protection to pathogens (Shoebitz et al., 2009). The biological controls of soil borne diseases to replace chemical agents, significantly contribute to crop yield under abiotic stress condition (Table 4). Interaction of microbes to plant releases different elicitors and trigger physiological and biochemical changes in plants. These changes lead to disease resistance to plant for several months.

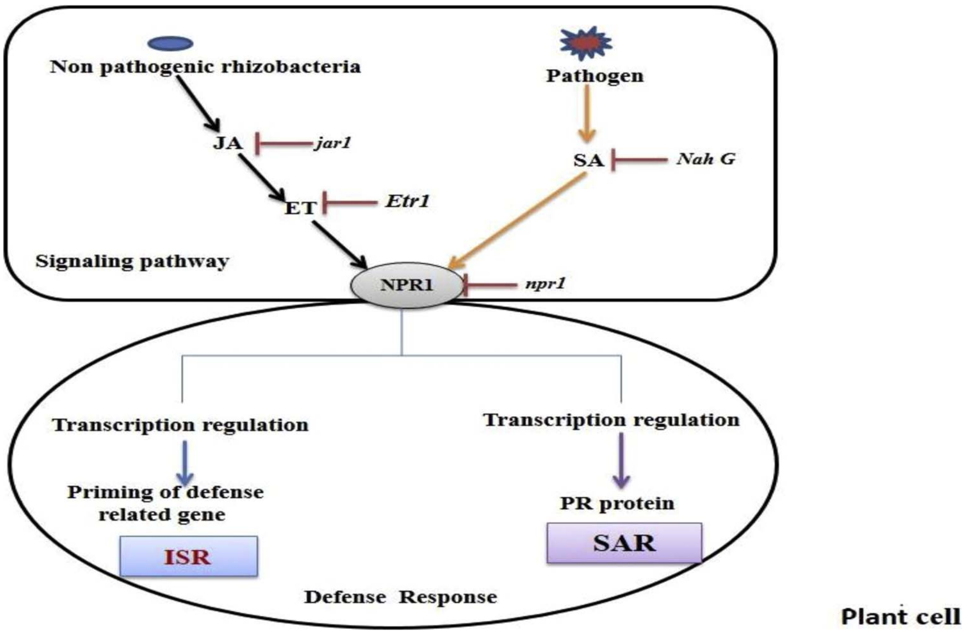

Fig. 3. Mechanism of nonpathogenic rhizobacteria mediated biotic stress tolerance, JA: Jasmonic Acid; ET: Ethylene; SA: Salicylice Acid; NRP: Nonexpresser of *PR* genes; ISR: Induced Systemic Resistance; SAR: Systemic Acquired Resistance.

Production of reactive oxygen species (ROS) and oxidative burst is an important mechanism for biotic stress tolerance (Miller et al., 2010). Defensive reaction mechanisms activated by microbes involve two different pathways, induce systematic resistance (ISR) and systemic acquired resistance (SAR). The ISR may be strengthened by non-pathogenic root associated plant growth promoting microbes, while SAR involves change in molecular gene expression and associated with pathogenesis related (PR) proteins. Induction and expression of the gene in both ISR and SAR is different which depend on elicited and regulatory pathway (Nawrocka and Małolepsza, 2013). PGPM trigger SAR which involves accumulation of PR proteins and SA, while ISR relies on pathways regulated by jasmonate and ethylene under biotic stress (Salas-Marina et al., 2011; Bari and Jones, 2009). Reactive oxygen species and nitrogen oxygen species (NOS) highly influences SA, JA or ET production and form a complex network to modulate pathogens (Bari and Jones, 2009; Choudhary and Johri, 2009). Ethylene and regulatory factor plays an important role in expression of PR genes. Depending on elicitor released by non-pathogenic microbes and interaction of these molecules determine induction of resistance in plants (Fig. 3).

3.1.1. Induced systemic resistance

Infection by microbes e.g. bacteria, fungi, the virus can induce the plant to develop resistance to a future attack called induced systemic resistance (Heil, 2001). Induced systemic resistance induced by phytopathogens, immunizes plant against broad spectrum pathogens. Induced systemic resistance accompanied by PGPM through the production of the allopathic compound, competition for ecotype and nutrient. Allelochemicals such as siderophores, antibiotics, act effectively against pathogens and inhibit their growth (Jain et al., 2013; Choudhary and Johri, 2009). PGPM induced defence mechanisms first reported in response to pathogen *Fusarium* sp. causes wilt disease in carnation (*Dianthus caryophillus*) and cucumber (*Cucumis sativus*) in response to pathogen *Colletotrichum orbiculare* caused foliar disease (Compant et al., 2005). In his study, the induction of systemic resistance in *Panax ginseng* against *Phytophthora* Lee et al. (2015) has reported that root associated B. *amyloliquefaciens* strain HK34 effectively induced resistance against *P. cactorum*. In addition, *Pseudomonas* and *Bacillus* strains manage plant disease in many crops through induced systemic resistance. *Paenibacillus* P16 showed an effective biological control agent (BCA) in cabbage for black rot (*Xanthomonas campestris*) disease and has potential ability of induced systemic resistance (Ghazalibigla et al., 2016). PGPB species such as *Bacillus* strains induced systemic resistance in rice against

Table 4
Microbial mediated biotic stress tolerance in plants.

Plants	Diseases/Pathogens	Biological control microbes	Mechanism/Effect	References
Greengram (*Vigna radiate* L.)	Fungicide-induced phytotoxicity	*Pseudomonas aeruginosa*	Solubilized phosphate significantly and produced indole acetic acid(IAA) siderophores, *exo*-polysaccharides, hydrogen cyanide and ammonia	Ahmad et al. (2011)
Cabbage *(Brassica oleracea)*	Black rot (*Xanthomonas campestris*	*Paenibacillus* sp.	Induce systemic resistance	Ghazalibigla et al. (2016)
Cucumber	*Cucumber mosaic cucumovirus* (CMV)	*Bacillus subtilis, Pseudomonas Fluorescens Azotobacter chroococcum*	Higher peroxidase and b-1,3-glucanase enzyme activities Production of pathogen related (PR) protein	El-Borollosy and Oraby (2012)
Mustard (*Brassica compestris*)		*Pseudomonas putida*	Plant growth promoting activity, Phosphate solubilizing, siderophore and IAA etc.	Ahmad and Khan (2012a, 2012b)
Panax ginseng	Root diseases (*Phytophthora cactorum)*	*Bacillus amyloliquefaciens*HK34	Induced systemic resistance	Lee et al. (2015)
Rice	Bacterial leaf blight *(Xanthomonas oryzae)*	*Bacillus* sp.	Increased accumulation of phenylalanine ammonia lyase, peroxidase and polyphenol oxidase	Chithrashree et al. (2011)
Pepper	Gray leaf spot disease *(Stemphylium lycopersici)*	*Brevibacterium iodinum* KUDC1716	Enhanced expression of pathogenesis-related (PR) protein genes	Son et al. (2014)

bacterial leaf blight caused by *Xanthomonas oryzae* pv. *Oryzae* (Chithrashree et al., 2011).

3.1.2. Systemic acquired resistance (SAR)

The SAR develops in plant as fully active defence mechanism in response to primary infection. The host plant can recognize nature of pathogen based on molecular pattern and detoxify its effects by changing gene expression, production of hormones and metabolites (Sunkar et al., 2012). According to Banerjee et al. (2010) *Arthrobacter* sp. and *Bacillus* sp. isolated from the rhizosphere of tomato show plant growth promoting potential such as phosphate solubilization, IAA production and biocontrol properties. Some bacterial species acts against fungicides produced by fungi. For instance, *P. aeruginosa* strain PS1, an efficient PGPB applied in soil against fungicides to ameliorate their effects. Siderophores, phytohormones, hydrogen cyanide and ammonia were produced under stress condition (Ahemad and Khan, 2012) (Table 4).

4. Agricultural and industrial application of stress tolerant microbes

4.1. Biofertilizers

Biofertilizers are formulation product of variety of living microorganism having ability to provide nutrient from unusable to usable through biological process. Due to their ability to enhance plant growth under the abiotic and biotic condition they may be used as a potential bio fertilizer. Microorganisms 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 *Azospirillum, Acetobacter*, *Azotobacter*, and *Pseudomonas* are some active microbes. In addition, *Pseudomonas* and *Bacillus* spp. act as potent biocontrol and plant growth promoting strains under stress condition (Kumar et al., 2014). 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 worldwide. 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, yield quality, nutrient mobilization, soil health and reduced susceptibility to disease due to environment change. Therefore, the selection of efficient microbes and formulation biofertilizers for changing environment can be beneficial in coming years.

4.2. Industrial application

Microbes play a chief role in resolving environmental problems. The greater diversity of beneficial microbes 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. To enhance soil productivity people are expending huge money on fertilizers and pesticides. The PGPR initially recognized as a microbial agent that has to defend capacity to tolerate stress and promote plant growth. Microbes from the vital living components of soils are contributing ecosystem sustainability due to their cosmopolitan survival, massive efficient genetic pool, catabolic versatility 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. Thermotolerant or themophilic microbes are used for the production of bio ethanol through the fermentation process. Such thermotolerant microbes are *Clostridium thermowell*, *C. thermohydrosulfuricum*, *C. thermosaccharolyticum*, *Caldicellulosiruptor* sp., *Thermotoga* sp., *Thermoanaerobium brockii, Thermoanaerobacter ethanolicus, T. thermalhydrosulfuricus, T. mathranii* (Arora et al., 2015; 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. In addition, 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. Microbes help to remove these toxic heavy metals from soil and reduce their uptake by plants.

5. Conclusion and future prospective

The different types of biotic and abiotic stresses are affecting plant growth attributes, productivities, and their survivability. Those crops and plants sustain in stress conditions which can change their physiological and biological properties due to an expression of cold, heat, drought, salinity and alkalinity tolerant proteins. These stresses are a major constraint for crop yield, food quality and global food security. The hormonal imbalance, nutrient mobilization, ion toxicity and susceptibility to disease are continue affect the plant growth and development due to various stress under the current scenario. The only alternative solution of stresses problem in plants is to develop some microbial tools and techniques of plant-microbe-soil interaction. The application of stress tolerant microbial consortium of PGPM strains and mycorrhizal fungi may be used for enhancing plant growth under abiotic and biotic stress condition. These microbes could promote plant growth by regulating plant hormones, improve nutrition, siderophore production and enhance the antioxidant system. The other mechanism includes, Induced ASR and ISR during multiple stresses. AM enhanced the supply of nutrient and water during stress condition and increase tolerance to stress. The use of microbes has a potential to solve future food security problems and also maintain soil health. Therefore, in the present review, the microbes may play a key role as an ecological engineer to solve environmental stress problems. On the basis of this review, we would like to recommend the scientific societies and policy planner for making a better future plan for solving the problem of abiotic and biotic stress and their impact on global economy and food security. So, considering a current scenario, future research is needed to identify potential stress tolerant PGPM. Certainly, diversity of microbial strains should be tested to formulate effective microbial consortia to overcome the negative impact of changing the environment.

Acknowledgment

Authors thanks to funding agency DIC-BHU, DBT and DST-NRDMS for providing fund for starting research work on climate resilient strains or stress tolerant strains for sustainable agricultural production.

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