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REVIEW

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The Role of Plant Growth Promoting Extremophilic Microbiomes under stressful environments

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The induction of plant growth promoting microbiomes (PGPM) in agricultural and horticultural field crops considered an environmental friendly biofertilizers, an alternative to chemical fertilization. The PGPM in extreme environments are halophiles, acidophiles, thermophiles, psycrophiles and metal resistant microorganisms are mainly inoculated onto seeds, roots and soil. PGPEM improve plant growth by enhancing the availability of nutrients, the regulation of phytohormones, and by increasing plant tolerance against biotic and abiotic stresses. These PGPM colonize the rhizosphere of plants inducing the accumulation of osmolytes, antioxidants, upregulation or down regulation of stress responsive genes and alteration in root morphology in acquisition of tolerance under adverse environmental conditions. The PGPM have been reported from all three domain archaea, bacteria and eukarya of different groups such as *Actinobacteria, Ascomycota, Bacteroidetes, Basidiomycota, Crenarchaeota, Euryarchaeota, Firmicutes* and *Proteobacteria*. The microbes possess the diverse plant growth promoting features and these efficient and potential microbes may be applied as biofertilizers for crops improvements and soil health for sustainable agriculture. In order to survive under the biotic and abiotic stress conditions, these PGPM, have developed adaptive features which permits them to grow optimally under one or more environmental extremes, while poly-extremophiles grow optimally under multiple conditions. In this chapter compile the research progress in PGPM will promise on the development of molecular approaches to increase our knowledge of PGPM and to achieve an integrated management of plant growth promoting extremophiles.

Key words: PGPM, soil, acidity, alkalinity, archaea, bacteria, eukarya

Extremophiles are organisms that inhabit the adverse environmental conditions, which are lethal to most forms of life. They are found in extreme environments such as salty lakes, low or high temperature environments, alkaline or acidic environments, etc. (Singh *et al.*, 2019). The Plant microbiomes have capability of colonizing the rhizosphere, phyllosphere and internal tissues for different plant parts and have to synthesise phytohormones, solubilize supplements, and antagonistic against pathogens. The plant related organisms have been secluded from plant becoming under the assorted abiotic stresses conditions and these extremophilic microorganisms help in plant development advancement and transformations. The microorganisms segregated from plant becoming under various abiotic stresses are term as plant related extremophilic organisms. The plant related extremophiles have been accounted for from each of the three groups archaea, bacteria and eukarya of various phylum/groups for example *Actinobacteria, Ascomycota, Bacteroidetes, Basidiomycota, Crenarchaeota, Euryarchaeota, Firmicutes* and *Proteobacteria (α/β/γ/δ).* The organisms have the diverse plant development advancing qualities and these effective and potential microorganisms might be applied as biofertilizers for crops upgrades and soil wellbeing for practical agribusiness. The microorganisms separated from various plants becoming under the abiotic stresses states of temperature, saltiness, pH and water inadequacy are supposed to be psychrophiles (-2°C to 20°C), thermophiles (60°C to 115°C), halophiles (2-5M), acidophiles (pH<4), alkaliphiles (pH>9) and xerophiles (water potential 0.75 kPa) (Yadav *et al.*, 2015, 2021). Extreme habitats/niches represent unique ecosystems which harbour novel biodiversity with potential adaptations ability to diverse stresses. To get by under such limit conditions, these living beings alluded to as extremophiles, have created versatile highlights which allow them to develop ideally under at least one natural limits, while poly-extremophiles develop ideally under numerous conditions (Saxena *et al.*, 2016). Microorganisms adjusted to the cold of outrageous soils have been appeared to have incredible potential for holding onto PGPM (Balcázar et al., 2015; Trivedi et al., 2006; Pandey and Kashyap, 2006; Katiyar and Goel, 2003). The phyllosphere is normal specialties for synergism between various expected organisms and plant. The epiphytic organisms are generally versatile in nature as they endure high temperature (40°C–55°C) and UV radiation. The microorganism identified with various genera such *Agrobacterium, Methylobacterium, Pantoea* and *Pseudomonas* have been accounted for in the phyllosphere of various yields filling in typical just as unforgiving natural conditions (Verma et al., 2017; Meena et al., 2012; Nutaratat et al., 2014). Along these lines, extremophilic microorganisms address a huge repertory of new dynamic biofertilizers, under adverse environmental conditions.

The growth rate of global population demands for increasing food production. However, in many situations, boosting agricultural productivity relies heavily on the use of chemical fertilizers, which are economically unavailable to many farmers throughout the world and can cause negative environmental impacts. In addition, environmental stresses may also be major constraints to plant growth and yield, causing low crop productivity, affecting global food security (Mimmo *et al.*, 2018; Asghari *et al.*, 2020). Therefore, to increase worldwide agricultural production in a more economically and environmentally sustainable way, there is the need to utilize less synthetic composts and increment plant resistance to abiotic stresses. The utilization of plant development advancing microorganisms (PGPM) is a conceivably invaluable strategy for improving harvest usefulness, food quality and security in more maintainable and eco-accommodating agrarian frameworks (Abhilash *et al.*, 2016; Etesami, 2020). PGPM act by direct systems, for instance solubilizing phosphate, synthetizing plant chemicals and siderophores, or by roundabout instruments that incorporate phytopathogenic control (Olanrewaju *et al.*, 2017; Yakhin *et al.*, 2017). The endophytic microbial species belonging to different genera including *Achromobacter, Azoarcus, Burkholderia, Enterobacter, Gluconoacetobacter, Herbaspirillum, Klebsiella, Microbiospora, Micromomospora, Nocardioides,* *Pantoea, Planomonospora, Pseudomonas, Serratia, Streptomyces* and *Thermomonospora* have been sorted out from different host plants (Ryan *et al.*, 2008; Hallmann *et al.*, 1997; Verma *et al.*, 2015; Yadav, 2021). The production of cell wall modifying enzymes has also been shown to play a role in PGPM, especially among endophytes, such as Rhizobium, Burkholderia or Azospirillum, as these have to infect the root (Robledo *et al.*, 2018; Razie and Anas, 2008). The enzymes such as chitinases, proteases and cellulases are involved in biological control, as they are able to degrade the cell wall of certain phytopathogens, such as oomycetes or other fungi (Magalhães *et al.*, 2017). PGPM act as biofertilizer, expanding the accessibility of supplements, through bio-fixation of atmospheric nitrogen and solubilization of soil minerals, like phosphorus and potassium. There are rhizobacteria that can work with the creation of siderophores improving iron update (Bhat *et al.*, 2019). They additionally straightforwardly advance plant development as phytostimulator, affecting the phytohormones digestion by upgrading auxin, cytokinins, abscisic corrosive, gibberellins creation, and decrease of ethylene (Martínez-Viveros *et al.*, 2010; Khan *et al.*, 2020). PGPM additionally act by implication, as biopesticide or biocontrol specialists expanding opposition against phytopathogens, through contest for supplements, threat and incites fundamental obstruction (Abhilash *et al.*, 2016; Khan *et al.*, 2020).

PLANT MICROBE INTERACTION

Plants are sessile but do not exist alone always associated with complex microbiome interactions. Plants associated with microorganisms such as fungi, bacteria and archaea, allowing them to inhabit almost all of their tissues; and the resulting in assemblage of microbiome is collectively known as the plant-microbiome or phytomicrobiome (Knack et al., 2015; Smith et al., 2017). This idea has give an understanding, as of late, to begin addressing some normal developmental inquiries in regards to how microorganisms have advanced, along with their host life forms, from their unique predecessors. It is of basic significance to see how plant transformation has been impacted by their cooperations with organisms, however much remaining parts obscure. Plant-microorganism communications are a deep rooted measure for plants, as certain organisms might be leaving the plant-associated community, while others will enter the community (Baltrus, 2017). The capacity of plants and microorganisms to impart before actual contact being set up is a vital (Chagas et al., 2018) as it assists the accomplices with amplifying the opportunity of profiting with each other, without hurt. There are various phytomicrobiome groupings, for example relying upon the plant part colonized by organisms: rhizomicrobiome – roots, caulomicrobiome – stem, phyllomicrobiome – leaves, anthromicrobiome – blossoms, carpo microbiome – natural product, or level of closeness with the plant tissue which are named as endophyte (communication inside plant parts), epiphyte (on the outside of plant constructions like shoots, stems, leaves, blossoms and organic products) (Laksmanan et al., 2014; Chagas et al., 2018). The rhizosphere phytomicrobiome wealth, exercises and variety is far more noteworthy than the phyllosphere. This is primarily on the grounds that a significant part of the root exudation and sloughed off cells contain supplement rich mixtures for organisms related with roots (Meharg and Killham, 1990; Beneduzi et al., 2012). Numerous new investigations have distinguished valuable organisms that help plants, including crop plants, to endure the anxieties they experience, including supplement lopsidedness (Mylona et al., 1995; Yazdani et al., 2009), saltiness (Subramanian et al., 2016), and dry season (Lim and Kim, 2013), with significantly less being accounted for in regards to soil sharpness and alkalinity. In this manner, there is potential to see better and push ahead with a more practical horticulture dependent on information within reach on each actual pressure, and the job organisms can play in agrarian administration of these anxieties. A critical factor in microbial expansion in the wild is pH. The causticity and alkalinity of soils has been connected straightforwardly to soil and plant related microbial populace elements (Biswas et al., 2007; Zhalnina et al., 2015). In spite of its undeniable significance much appears to be indistinct concerning why organisms act the manner in which they do at different pH levels.

PGPM Inoculants on plant growth and development

Extremophiles inoculants combined or separate, can be inoculated into seed, leave, seedling roots, or soil. They colonize the rhizosphere or the interior of the plant, stimulating growth and plant tolerance against abiotic stresses. PGPM directly promote plant growth by enhancing the availability of nutrients, phytohormones regulation, and indirectly inducing systemic resistance (Abhilash *et al.*, 2016; Bhat *et al.*, 2019; Khan *et al.*, 2020; Khoshru *et al.*, 2020; Lopes *et al.*, 2021). The stress conditions inhibited the plant growth and development, mainly due to the increase in the production of reactive oxygen species, lipid peroxidation, accumulation of free radicals and high ethylene production, causing cell death leads in chlorosis, necrosis, leaf senescence, and damage in photosynthesis apparatus, reduction in photosynthetic rates and chlorophyll content, and change in concentrations of metabolites. It also affects seed germination, seedling vigor, plant height, root development, reduce the biomass and productivity of crop plants (Sharma *et al.*, 2012; Khoshru *et al.*, 2020). The beneficial extremophiles improve plant growth by enhancing the availability of nutrients, the regulation of phytohormones, and by increasing plant tolerance against biotic and abiotic stresses. Extremophiles can also secrete volatile metabolites (VOC), which induce disease resistance mitigate stress by increasing exopolysaccharides, osmoregulants and antioxidants, and reducing the oxidative stress (Varma *et al.*, 2019; Khan *et al.*, 2020; Khoshru *et al.*, 2020; Lopes *et al.*, 2021). Thus, PGPM promote the increase foliage and leaf area, chlorophyll content, photosynthetic rates, seed germination, seedling vigor, plant height, root development, and biomass production. Extremophiles inoculants either combination or separate, can be inducted into seed, leaves, seedling roots, or soil. They colonize the rhizosphere or the inside of the plant, animating development and plant resilience against abiotic stresses. PGPM straightforwardly advance plant development by upgrading the accessibility of supplements, phytohormones guideline, and by implication prompting foundational obstruction (Abhilash *et al.*, 2016; Bhat *et al.*, 2019; Khan *et al.*, 2020; Khoshru *et al.*, 2020). The pressure conditions restrained the plant development and improvement, basically because of the expansion in the creation of receptive oxygen species, lipid peroxidation, amassing of free revolutionaries and high ethylene creation, causing cell passing leads in chlorosis, putrefaction, leaf senescence, and harm in photosynthesis contraption, decrease in photosynthetic rates and chlorophyll substance, and change in convergences of metabolites. It likewise influences seed germination, seedling life, plant stature, root improvement, diminish the biomass and efficiency of harvest plants (Sharma *et al.*, 2012; Khoshru *et al.*, 2020). The advantageous extremophiles improve plant development by upgrading the accessibility of supplements, the guideline of phytohormones, and by expanding plant resistance against biotic and abiotic stresses. Extremophiles can likewise emit unstable metabolites (VOC), which instigate sickness obstruction alleviate pressure by expanding exopolysaccharides, osmoregulants and cancer prevention agents, and decreasing the oxidative pressure (Varma *et al.*, 2019; Khan *et al.*, 2020; Khoshru *et al.*, 2020; Lopes *et al.*, 2021). Hence, PGPM advance the increment foliage and leaf region, chlorophyll content, photosynthetic rates, seed germination, seedling power, plant tallness, root improvement, and biomass creation.

Phytohormones

Phytohormones are natural mixtures responsible for plant development and improvement. The PGPM are capable of alteration phytohormones. The differential concentration of phytohormones relieved by microbial inoculants, through the creation of auxin, cytokinin, gibberellin, ACC deaminase, abscisic corrosive, jasmonates, brassinosteroids, and strigolactones (Saravanakumar, 2012; Oosten *et al.*, 2017; Arora *et al.*, 2020; Khan *et al.*, 2020). Auxin and ACC-deaminase are normally researched in PGPM choice tests. This is on the grounds that, auxin delivered by microorganisms will build auxin in the plant, and advance plant development by upgrading supplement and water take-up. Microbial auxins additionally advantageous in the guideline of cell division, shoot development, separation of vascular tissue, extrinsic and horizontal root, prolongation and surface space of root. ACC-deaminase created by microorganisms is a helpful catalyst for lessening ethylene levels, moderating pressure in plants. High ethylene levels cause leaf chlorosis, corruption, senescence, decrease in organic product yield, root improvement, leaf extension, and photosynthesis (Souza *et al.*, 2015). Pseudomonas sp. also, *Bacillus* advance plants development by increment auxin and ACC-deaminase (Samaddar *et al.*, 2019; Khoshru *et al.*, 2020).

Exopolysaccharides

PGPM are known to create exopolysaccharides, shaping a defensive biofilm on root surface. This system upgrades water maintenance in soil particles and keeping up soil dampness in the root zone. Along these lines, it secures root cell against osmotic and ionic pressure, controlling osmotic equilibrium, under evolving pH, saline pressure, dry spell and temperature limits. To moderate pressure PGPM produce exopolysaccharides. This component acts to balance out the dirt ionic equilibrium, immobilizing Na+ under saltiness stress. Exopolysaccharides are created by *Bacillus* to expand its antimicrobial action in the dirt (Hashem et al., 2019). Exopolysaccharides producing *Pseudomonas sp.* and *Acinetobacter sp.* conferred the drought tolerance in pepper plant by forming hydrophilic biofilms around the roots (Rolli et al. 2015). Some strains of *Azospirillum lipoferum* producing abscisic acid (ABA) and gibberellins can prevent the loss of water in their maize plant hosts by regulating the closure of stomatal and various stress signal transduction pathways (Cohen et al. 2009).

Nutrients

PGPM has been studied as biofertilizer which could enhance the supply of macro and micronutrients, promote plant growth and reduce the need of chemical fertilization. Nitrogen, phosphorus and iron are essential nutrients for plants. Hence, in PGPM selection test, the nitrogen fixation, phosphate solubilization and siderophore production capacity are usually investigated. Nitrogen is an essential macronutrient for synthesize of proteins and nucleic acids. The microbes viz., *Azospirillum, Azotobacter, Achromobacter, Bradyrhizobium, Beijerinckia, Rhizobium, Clostridium, Klebsiella., Anabaena., Nostoc, Frankia* are biological nitrogen fixers through reduction of nitrogen gas to ammonia (Souza et al., 2015; Bhat et al., 2019). Phosphorus is an essential macronutrient for production of phospholipids, adenosine triphosphate (ATP), and increases the photosynthesis. The large proportion of P in the soil is in insoluble forms PGPM changes the pH of the soil to solubilise inorganic phosphates. In alkaline soils, PGPM reduces pH by excretion of organic acids, such as gluconate, citrate, lactate and succinate, solubilizing $Ca_3(PO_4)_2$. In acid soils, PGPM increases the pH by production of protons, during the assimilation of ammonium, solubilizing $AlPO_4$ and $FePO_4$ (Martínez-Viveros et al., 2010). Sulfur is an essential macronutrient found in cysteine and methionine amino acids, these are important in maintaining of enzymes and protein synthesis. Cysteine is important in cell division, and methionine is a precursor of ethylene, responsible for fruit ripening (Taiz and Zeiger, 2017). *Bacillus* are producers of volatile compounds, such as dimethyl disulfide that provides sulfur for plants. In addition, *Bacillus* and *Aspergillus* produces organic and inorganic acids, acidolysis, chelation and exchange reactions which are capable of solubilize potassium (Varma et al., 2019).

Antioxidants

PGPM inoculants promote the plant development and resistance to abiotic stresses by expanding cell antioxidants levels, diminishing the reactive oxygen species (ROS) and oxidative stress. Temperature, pH, weighty metal, water accessibility and UV-B radiation cause disturbance of cell homeostasis, expanding of responsive oxygen species, like superoxide anion, hydroxyl revolutionary, hydrogen peroxide and singlet oxygen. An expanded centralization of ROS is an essential aftereffect of abiotic stress, and is incredibly destructive, causing oxidative pressure in cell. In addition, in chloroplasts, mitochondria, and peroxisomes, ROS actuate oxidative harm to lipids, proteins, nucleic corrosive, catalyst hindrance and enactment of modified cell demise (Sharma *et al.*, 2012; Khoshru *et al.*, 2020). Microbial inoculants decrease the harming impacts of ROS, in this way getting the cell, layers, and biomolecules by expanding the creation of tumour prevention agents like catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase

(AsA), glutathione (GSH), carotenoids, tocopherols and phenolics (Gouda *et al.*, 2018; Arora *et al.*, 2020).

Osmolytes

During biotic and abiotic stress conditions, microbial inoculants induce production of osmoregulants, such as carbohydrates, proteins, amino acids, lipids, proline, glycinebetaine, and trehalose. Consequently, osmoregulation keeps up the homeostasis, forestalling layer plasmolysis, expanding union of warmth stun proteins (HSPs) and managing natural enzymatic instruments. Under saltiness, osmoregulators settle the osmotic equilibrium across the film, keep up the turgor pressure, and guarantee the right collapsing of proteins (Sharma *et al.*, 2012; Oosten *et al.*, 2017; Khoshru *et al.*, 2020). *Burkholderia sp.* expands plant resilience against low temperature by altering sugar digestion (Fernandez *et al.*, 2012). Submerged pressure, Pseudomonas fluorescens advance plant resilience by expanding the movement of catalase and peroxidase, and the amassing of proline (Saravanakumar *et al.*, 2011). Extremophiles microorganisms improve resilience in plants, expanding the aggregation of osmolytes in the plant cell cytoplasm. This keeps up the cell turgor and adds to improved pressure resilience in plants. The osmoregulation component is significant for plants to endure and improve resistance under outrageous conditions by decreasing cell harm brought about by abiotic stress (Fernandez *et al.*, 2012; Khoshru *et al.*, 2020).

ROLE OF PLANT GROWTH PROMOTING EXTREMOPHILES ON ABIOTIC STRESSES

Microbial diversity in the soil is affected by plant roots, soil texture and molecule size, mineral composition agricultural and horticultural practices (Doornbos *et al.*, 2012; Hartman and Tringe, 2019). The productions of root exudates, most microorganisms are aggregated in the rhizosphere. The rhizosphere is the locale of the dirt associated with plant roots, where mixtures are oozed by plant roots to draw in organic entities. These mixtures, can be helpful, impartial, or destructive to plants (Souza *et al.*, 2015; Bhat *et al.*, 2019). Host plant utilizes root exudation mixtures to choose explicit organisms in its rhizosphere microflora, setting up plant species-explicit rhizosphere networks (Doornbos *et al.*, 2012; Hartman and Tringe, 2019). Root exudation likewise figures out which creatures will deliver adhesive in the root framework, diminishing the roots stripping and improving the contact between the roots and the dirt arrangement (Venturi and Keel, 2016; Gouda *et al.*, 2018). Use of PGPM might be an ecofriendly, maintainable, and savvy way to deal with defeat abiotic stresses in plants. Nonetheless, if there is an adjustment of the exudative example of the plant, the equivalent confine and a similar plant genotype may collaborate in an unexpected way. Such changes can prompt hereditary changes in microorganisms making then, at that point lose the capacity to colonize the rhizosphere and, thus, their PGPM potential (Oosten *et al.*, 2017; Enebe and Babalola, 2018; Hartman and Tringe, 2019).

Soil: A nucleus for plant microbe interaction

Soil is a reservoir of basic natural resources, such as nutrients, for animals, plants and microbes. It is a day to day existence naturally supportive network that gives a wide scope of essential biological system labor and products going from capacity of carbon, to water sanitization, soil fruitfulness and horticultural creation (Rojas and Caon, 2016). Variety in soil attributes all through the world is influenced by climate/environment and how it is geopositioned on the globe. Aside from supplements, soil likewise contains plant-accessible water which assumes a critical part in making a fluid supplement arrangement, the structure taken up by plants (Sassenrath *et al.*, 2018). The way that all living natural cells are water-based frameworks makes a cell's endurance reliant upon watery equilibria. For any fluid arrangement response to happen, presence of anions and cations is required. The need of suitable pH in an organic framework is essential as it helps keeping up biochemical equilibria, right degrees of proton dissociable gatherings and keep up the phone pH at close to unbiased constantly. Like some other living cells, organisms need a suitable pH equilibrium to keep up physiological capacities (Msimbira and Smith, 2020).

Soil pH

The proportion of soil response is measured as pH. It is generally estimated in water arrangements and to lesser degree, for research purposes, 0.01 M calcium chloride is utilized (Blake *et al.*, 1999). Soil pH is a key condition with substantial influence on soil biology, chemistry and physical processes which have direct impacts on plant growth and development. It is clear soil and harvest efficiency are connected to pH. The United States Department of Agricultural National Resources Conservation Service has classified soil pH as follows: super acidic (<3.5), incredibly acidic (3.5–4.4), firmly corrosive (4.5–5.0), unequivocally acidic (5.1–5.5), reasonably acidic (5.6–6.0), somewhat acidic (6.1–6.5), nonpartisan (6.6–7.3), marginally basic (7.4–7.8), tolerably antacid (7.9–8.4), emphatically basic (8.5–9.0) and emphatically basic (>9.0) (Burt, 2014). Rural harvest creation is for the most part led inside the scope of marginally acidic to somewhat soluble, a window that is related with ideal accessibility of soil supplements. In all dirts, solvency, versatility and bioavailability of minor components is firmly influenced by pH. Notwithstanding, soils which fall outside of the scope of ideal supplement accessibility are assembled as either acidic or antacid and represent a scope of difficulties to plants. In spite of the fact that plants vary in their resistance to outrageous pH, most farming plants perform ideally at a pH close to lack of bias (Läuchli and Grattan, 2012). With regards to edit creation, pH variety is related with every one of the manners in which the dirt is overseen previously, during and after crop creation, which incorporates; soil culturing, planting of cover crops, compost application and lime expansion, just as precipitation and other environment factors. A full comprehension of pH is essential for improving supplement cycling, soil remediation and plant nourishment, as it influences the whole associating framework. To build up approaches to manage different angles that are influenced by soil pH, one ought to at first comprehend what causes variety in the dirt pH. One of the significant reasons for pH variety is the inborn mineral arrangement of the parent soil material. In this survey, fermentation and alkalization of soil are talked about to edify our comprehension of reasons for pH changes in the soil.

Acidity

It is the consequence of different immediate and aberrant variables connecting with the soil; these include nutrient cycling and organic matter disintegration, high and acidic precipitation, fertilizer application, crop development and enduring. Acidification is a continuous and reformist cycle which is affected by rural practices and now by environmental change (Filipek, 1994; Hao *et al.*, 2019). It is the result of increased HC concentration with the HC released from Carbon (C), Nitrogen (N) and Sulfur (S) during transformation and cycling. In agricultural soils a major contributor to acidity is the application of ammonium-based fertilizers, urea, sulfur and legume cultivation. The salts from applied fertilizers have strong effects on acidification of the soil through nitrification and fixation. Comparatively, legumes are known to cause more soil acidification than non-legumes, due to excessive uptake of cations relative to anions during N_2 fixation, and also leaching of nitrates eventually resulting from fixed N (Tang, 1998; Tang *et al.*, 1999). However, variation in N_2 fixation among legumes exists, which results in variation of the acid generated with a range of 0.2 to 1 mol HC for each mol of fixed N (Bolan *et al.*, 1991). Other factors which influence acidification by legumes are soil nutrients and nitrogen (Yan *et al.*, 1996; Marschner, 2011). Crop growth is another factor which causes localized soil acidification as a result of nutrient uptake. Plants take up nutrients from the soil solution in ionic form with a preference for cations over anion, which leads to cation reduction in the soil (Tang and Rengel, 2003). To counteract the effect of charge imbalance, plants release HC from roots to the rhizosphere, hence lowering soil pH. In addition, roots naturally exude organic acids which cause acidification of the soil.

Alkalinity

Soil alkalinity can be a consequence of characteristic enduring cycles or man-made conditions. Enduring of silicates, aluminosilicates and carbonate containing mixtures, for example, NaC, Mg_2C, KC, and Ca_2C is connected to silicates being hydrolyzed and resulting OH^- discharge, which builds soil pH. Water system is additionally connected with alkalinity of the soil, particularly when the pre-owned water contains huge amounts of bicarbonates (Oshunsanya, 2018). Dry spell is another normal reason for soil alkalinity because of lacking water to filter dissolvable salts, permitting their amassing in the upper soil profile. Soluble soils are portrayed by high groupings of carbonates and bicarbonates which can kill acids (Bailey, 1996). Thus, soluble soils are related with desertification in many pieces of the world, and this is additionally firmly connected with soil saltiness. As of late, the interest for aluminum on the planet has added to expanded alkalinity in encompassing biological systems since mining and discarding the antacid bauxite buildup (Kong *et al.*, 2017). In conclusion, over liming additionally prompts alkalization of soil. Subsequently, liming ought to painstakingly consider the information on soil acridity so that required liming material can be determined before it can bring about soil alkalization.

Drought

Water is necessary for life, but most land plants, particularly crops, are negatively impacted by long-term inundation by water which a lack of water causes stress to plants. Studies characterizing drought-induced changes in non-mycorrhizal, root-associated fungal communities appear to be limited, however, and have concluded that root-associated fungal communities are either unresponsive (Furze *et al.*, 2017) or exhibit negligible changes (Bouasria 2012), possibly because bulk soil fungal communities have also been reported to be generally unresponsive to drought conditions (Yuste *et al.*, 2011; Fuchslueger *et al.*, 2016; Barnard *et al.*, 2013). Precipitation is the significant water hotspot for developing crops in numerous parts of the world (Enebe and Babalola, 2018). Water accessibility, lack (drought) or abundance (flood), can result in abiotic stress, restricting harvest creation (Ipek *et al.*, 2019; Danish *et al.*, 2020). PGPM can improve plant tolerance to drought stress (Fleming *et al.*, 2019), as *Azotobacter chroococcum* and *Azospirillum brasilense* in *Mentha pulegium* L. (Asghari et al., 2020), and *Pseudomonas sp.* And *Azotobacter sp.* in *Cymbopogon citratus* (Mirzaei et al., 2020) and *Zea mays* (Danish et al., 2020). *Klebsiella variicola* and *Azospirillum sp.* can improve flooding stress tolerance by adaptations, such as the formation of adventitious roots resulting from endogenous hormonal regulation, as reported in *Glycine max* (Kim et al., 2017) and *Zea mays* (Czarnes et al., 2020). Inoculation of drought-tolerant microbes such as *Azotobacter, Flavobacterium, Bacillus, Burkholderia, Methylobacterium, Pseudomonas* and *Serratia* mitigates the drought stress in plants, increasing plant growth and enhanced the crop yield. Plant microbiomes have a high potential bioresources as biofertilizers, biostimulators, and biopesticides for agriculture because they could be used for plant growth promotion under the abiotic conditions. Nonetheless, water stress can impact the plant-microorganism cooperations. Drought expands soil temperature, which can restrain increase of advantageous microorganisms. Flooding lessens O_2 availability in soil, limiting microorganisms that are not equipped for anerobic respiration (Enebe and Babalola, 2018; Hartman and Tringe, 2019; Ipek et al., 2019). This will influence plant-microorganism association, which may restrain the microorganism potential to advance plant development. Thus, it is critical to know where the objective plant species is typically adjusted. Considering environmental change, it is essential to concentrate what the abundance and the absence of water would mean for the connection among plants and PGPM.

Temperature

High temperature is a major environmental concern that constrains vital plant functions such as seed germination, seedling growth, plant metabolism, and reduces its yield in various agro-ecological zones throughout the world (Fahad, *et al.*, 2017; Khan 2019). However, elevated temperature has a strong impact on crop yield that varies with different severity levels and duration of heat stress (Barnabas *et al.*, 2008; Hedhly *et al.*, 2009). High and low temperatures potentially caused by climatic change may become a major threat to global agriculture, reducing crop production, with drastic economic results (Ipek *et al.*, 2019; Mukhtar *et al.*, 2020). Beneficial microorganism inoculation is efficient in enhancing plat growth and mitigating adverse stresses caused by extreme temperature, as Pseudomonas putida in *Triticum* sp. (Ali et al., 2011) and *Bacillus* cereus in *Solanum lycopersicum* (Mukhtar et al., 2020) under high temperature. Under low temperature Burkholderia sp. increased tolerance to low temperature by modification of carbohydrate metabolism and increased plant yield in *Vitis vinifera* (Fernandez et al., 2012). Extreme temperatures are recognized stress in agriculture, reducing seed germination, seedling growth, yield and altering plant metabolism (Ipek et al., 2019; Mukhtar et al., 2020). Temperature impacts morphological, biochemical and physiological attributes of plants, interfering with plant-PGPM interaction by changing root exudation composition (Ali et al., 2011; Meena et al., 2015; Ipek et al., 2019). Therefore, for PGPM to be able to withstand environmental transformations that crop plants are exposed, it is necessary to isolate these microorganisms from different rhizosphere environments, under diverse environmental conditions, such as prevalent high and low temperatures (Etesami, 2020). This is because rhizobacteria that persist under change temperatures have the ability of improving plant growth and productivity on these adverse environmental conditions (Meena et al., 2015).

Salt

Salinity is a great threat for agriculture by affecting soil, microorganisms, and plants throughout their development cycle, from germination to maturation. PGPM show an extraordinary limit with respect to saline pressure mitigation essentially due to their opposition, flexibility, and a colossal inconstancy of the systems engaged with this interaction (Slimane 2020). PGPM engaged with plant–microorganism connections are markers of plant wellbeing, creation, and soil ripeness. The PGPM that foster more close associations with plants, similar to the endophytes, might be more successful in plant development improvement (Souza *et al.*, 2015). The utilization of microorganisms for saline soil reclamation might be an earth maintainable, more secure, and more effective technique, as the halophilic microorganisms can possibly wipe out salt from saline soils (Arora *et al.*, 2013). Such microorganisms likewise give remarkable models to considering the pressure opposition, variation, and reaction measures which may therefore be coordinated into horticultural harvests to adapt to the pressing factors brought about by environment change (Grover *et al.*, 2011).Many strains of PGPM have been discovered to be decidedly connected with stifling assorted plant microbes by creating hostile metabolites and upgrading the resistance capability of yields to pathogenic pressure (Berendsen *et al.*, 2018). The key instruments associated with PGPM saltiness resilience incorporate explicit film or cell divider structures, emptying particles from the phone through salt efflux, or change of their intracellular climate through gathering of nontoxic natural osmolytes, and adjusting catalysts and proteins to work under high solute particle fixations (Ruppel *et al.*, 2013).The capacity of PGPM to improve crop yields during salt pressure incorporates numerous immediate and backhanded pathways like ferrous iron minerals and inorganic phosphate solubilization, exopolysaccharides and biofilms synthesis.

BIOTECHNOLOGY OPPORTUNITIES AND PGPM FOR CROP IMPROVEMENT

Molecular techniques have opened up new possibilities concerning the application of beneficial microbes to the soil for the promotion of plant growth and the biological control of soil-borne pathogens. The nutritional and environmental requirements of these microbes are very diverse. The microbial inoculation has a much better stimulatory effect on plant growth in nutrient deficient soil than in nutrient rich soil. An understanding of microbial diversity perspectives in agricultural context is important and useful to arrive at measures that can act as indicators of soil quality and plant productivity. The nutritional and natural necessities of these microorganisms are exceptionally different. The microbial induction has a greatly improved stimulatory impact on plant development in nutrient deficient soil than in nutrient rich soil. A comprehension of microbial diversity viewpoints in agricultural and horticultural setting is significant and valuable to show up at measures that can go about as indicators of soil quality and plant efficiency. The different groups of microbes have been reported as plant associated such as archaea, eubacteria and fungi, which included different phylum mainly: Acidobacteria, Actinobacteria, Ascomycota, Bacteroidetes, Basidiomycota, Deinococcus-Thermus, Euryarchaeota, Firmicutes and Proteobacteria. Generally speaking the dissemination of microbes shifted in every bacterial phylum, Proteobacteria were most predominant followed by Actinobacteria. Least number of organisms was accounted for from phylum Deinococcus-Thermus and Acidobacteria followed by Bacteroidetes (Yadav *et al.*, 2015, 2017a, 2017b; Sun *et al.*, 2008; Sahay *et al.*, 2017). Soil saltiness is a significant restricting component for farming harvests particularly in dry and semi-bone-dry locales of the world. Albeit numerous innovations have been embroiled in the improvement of salt resilience, just PGP microorganisms evoked plant resistance against salt pressure has been recently considered (Verma *et al.*, 2016; Yadav *et al.*, 2015, 2017; Paul *et al.*, 2008). Organisms related yields have a high potential for horticulture since they can improve plant development, under restricting or stress conditions of temperatures. The microorganisms from extreme environments are of particular importance in global ecology since the majority of terrestrial and aquatic ecosystems of our planet are permanently or seasonally submitted to cold temperatures. Plants have created different systems because of ecological boosts, like actuation of different metabolic safeguard atoms. Among the metabolic particles created by plants to upgrade protection limit are salicylic corrosive, ethylene, calcium and jasmonic corrosive (Klessig and Malamy, 1994). Of the referenced safeguard atoms salicylic corrosive has been affirmed to give alkalinity resistance to tomato plants, when applied exogenously, by decreasing responsive oxygen species (ROS) age and improving cell reinforcement protection against antacid pressure. Likewise, it was shown that SA applied in blend with Si effectsly affected alkalinity resistance in tomatoes (Khan *et al.*, 2019). From such reports, obviously much is still to be perceived in regards to how extraordinary resistance particles and useful components cooperate in assisting plants with developing soluble pressure conditions. Plant reproducing is one significant way to deal with guaranteeing crop efficiency in pressure inclined regions, including alkalinity of soil and water. A scope of plants have shown different systems of resistance to soluble pressure, a large portion of them showing early seed germination and seedling foundation. Cultivars of lentil open minded to alkalinity stress are known to have shoots with a thicker epidermis than delicate cultivars (Singh *et al.*, 2018). Likewise, open minded lentils (Singh *et al.*, 2018), finger millet (Krishnamurthy *et al.*, 2014) and *Lotus tenuis* (Paz *et al.*, 2012) limit Na^+ take-up by having unblemished pericycle and stele areas. Despite the presence of tolerance mechanisms for alkalinity stress by plants much remains unknown in relation to other related stresses, such as salinity and drought. Microorganisms capable for adapting to low temperatures are far and wide in these natural environments where the frequently address the predominant vegetation and they ought to accordingly be viewed as the best colonizers of our planet. In the previous few years, the variety of microorganisms possessing cold conditions has been broadly explored (Yadav *et al.*, 2016, 2017; Singh *et al.*, 2016; Mishra *et al.*, 2010). Drought stress restricts the development and usefulness of harvests, especially in parched and semi-bone-dry regions (Verma *et al.*, 2014, 2019; Lim and Kim, 2013). Alkaline/Acidic conditions are additionally problem area for microbial variety with plant development advancing qualities. Numerous acidotolerant bacterial genera have been accounted for from plant growing in acidic conditions. The different groups of microbes have a potential role in different possess and applications e.g. Archaea for P-solubilization and mobilization (Yadav *et al.*, 2015), bacteria and cyanobacteria as probiotics (Panjiar *et al.*, 2017; Yadav *et al.*, 2017d), biodegradation at low temperature (Shukla *et al.*, 2016; Yadav, 2015), cold adapted enzymes such as lipase, amylase, protease, cellulase and xylanase for industrial applications (Yadav *et al.*, 2016), anti-freezing compounds production from psychrophilic and psychrotrophic microbes (Singh *et al.*, 2016) and microbes with multifarious PGP attributes for plant growth and soil helath for sustainable agriculture (Verma *et al.*, 2015, Yadav *et al.*, 2017c).

FUTURE PROSPECTIVE

Plants assume a significant part in choosing and improving the sorts of microbiomes by the constituents of their root exudates. Consequently, contingent upon the nature and groupings of natural constituents of exudates, and the comparing capacity of the microorganisms to use these as wellsprings of energy, the microbial local area creates in the communication as epiphytic/endophytic/rhizospheric. Organisms related with crops are of agriculturally significant as they can upgrade plant development; improve plant nourishment through natural N_2 - fixation and different instruments.

Microorganisms may expand crop yields, eliminate toxins, hinder microbes, and produce fixed nitrogen or novel substances. The development incitement by organisms can be a result of biological N_2 - fixation, creation of phytohormones, like IAA and cytokines; biocontrol of phytopathogens through the creation of antifungal or antibacterial specialists, siderophores creation, supplement rivalry and acceptance of obtained have opposition, or upgrading the bioavailability of minerals. The need of the present world is high yield and upgraded creation of the harvest just as ripeness of soil to get in an eco-accommodating way. Subsequently, the examination must be centered around the new idea of microbial designing dependent on well apportioning of the outlandish biomolecules, which make a one of a kind setting for the collaboration among plant and organisms. The utilization of plant-related microorganisms is an eco-friendly alternative that can increase crop water use efficiency. Manageable farming requires the utilization of procedures to increment or keep up the current pace of food creation while lessening harm to the climate and human wellbeing. The utilization of microbial plant development advertisers is an option in contrast to traditional agrarian innovations. Plant development advancing microorganisms can influence plant development straightforwardly or in a roundabout way. The immediate advancement of plant development by PGPM, generally, involves furnishing the plant with a compound that is incorporated by the bacterium or working with the take-up of specific supplements from the climate. The roundabout advancement of plant development happens when PGPM diminish or forestall the malicious impacts of at least one phytopathogenic creatures. Future examination in microorganisms will depend on the improvement of atomic and biotechnological ways to deal with increment our insight into organisms and to accomplish an incorporated administration of populaces of microbial networks. Examination on ACC deaminase and P solubilization by plant development advancing microorganisms is in progress, and leads in organism interceded mitigation of different abiotic stress. The utilization of diverse PGPM or consortium over single immunization could be a viable methodology for lessening the unsafe effect of weight on plant development under the abiotic stress conditions. Future research in microbes will rely on the development of molecular and biotechnological approaches to increase our knowledge of microbes and to achieve an integrated management of microbial populations of endophytic, epiphytic and rhizospheric. The established commercial success in the field of genetic engineering the DNA polymerase, biofuels, biomining, and carotenoid areas of biotechnology, extremophiles and their compounds have a broad traction in the market that is relied upon to continue to develop. Notwithstanding, to satisfy this extraordinary potential, inventive techniques should be created to conquer current barricades. The most huge is a current absence of capacity to deliver most extremophiles/extremozymes for the enormous scope needed by modern cycles. Some recombinant extremozymes can be created in huge amounts by mesophilic organic entities like Escherichia coli; notwithstanding, this isn't valid for most. Consequently, new articulation frameworks should be created with extremophilic organic entities as the host to accomplish high articulation of dissolvable proteins. Another critical barricade is the overall absence of associations among the scholarly community, industry, and government. More freedoms for ties between each of the three gatherings ought to be energized, sustained, and upheld from all sides. For it is just with each of the three cooperating that the most advancement will be made.

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CONFLICTS OF INTEREST

The authors declare that they have no potential conflicts of interest.

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