Development of Systematic Drought Tolerance in Crop by Employing Plant Growth Promoting Rhizobacteria (PGPR)

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Abstract:

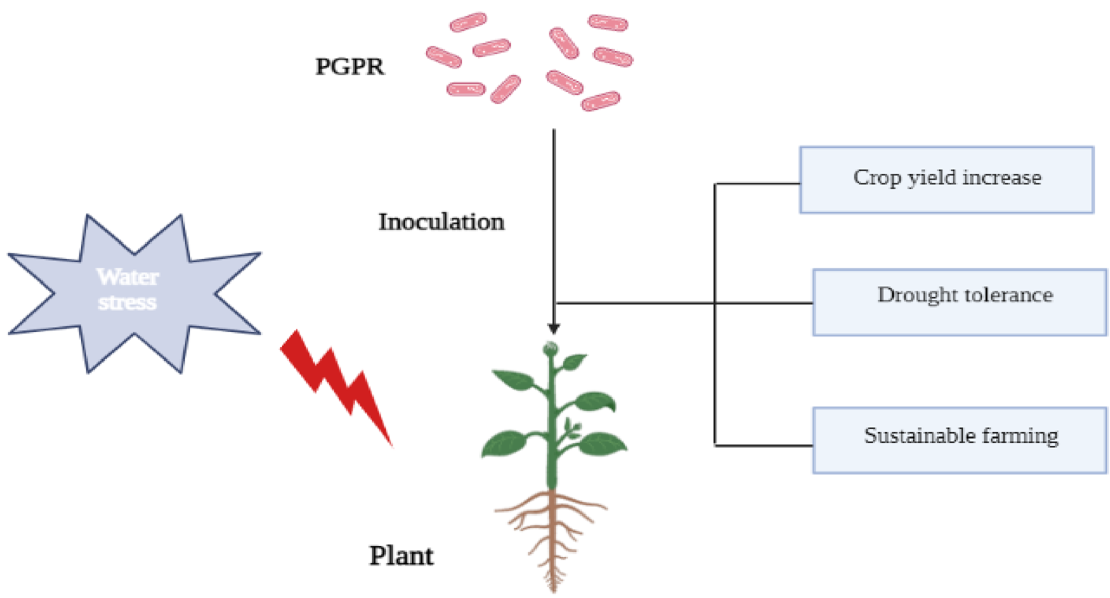
Drought constitutes among the most popular significant abiotic factors impacting dry land agricultural productivity. It results an increase in ROS, which disrupts oxidation-reduction equilibrium and triggers oxidative damage, thereby impacting the physiological state of plants. It also reduces crop yields by altering other biological molecules and growth hormones. As a result of this, the demand for sustainable options to safeguard the integrity of food supplies worldwide has shot up. Rhizobacteria are soil microbes that dwell near the roots of plants and are either directly or through indirect means involved in promoting the development and expansion of plants by producing and releasing a large number of regulatory chemicals. PGPR, via multiple processes such as osmotic modifications, enhanced antioxidant function, phytohormone synthesis, and so on, not just guarantees the plant's survival under drought but additionally enhances its development. The application of PGPR in the form of biofertilizer for crops is an effective method for increasing crop production and protecting crops from abiotic challenges to ensure sustainable farming. The many processes involving PGPR in drought stress resistance are thoroughly discussed in this paper.

Keywords: Drought tolerance, PGPR, water stress, biofertilizer.

Introduction:

It is expected that the number of people will exceed 9.7 billion people by 2050, with roughly 65% of the population relying primarily on agriculture for a living. In emerging nations, this figure is expected to rise to 90% (Ahluwalia et al., 2021). Among the primary problem in sustaining the world's expanding population is the need for superior quality food with a variety of essential components and a balanced diet (Khatoon et al., 2020). Uncontrolled application of chemical fertilizers to boost agricultural yield. is wreaking havoc on agricultural systems. (Alavaisha & Lindborg, 2022). Many researchers have used biofertilizers in the past few decades to lessen the harm to the environment caused by mineral fertilizers while also lowering their prices (de Andrade et al., 2023). Abiotic stressors are significant limits to agricultural output and worldwide food security, necessitating an early reaction (Goswami & Suresh, 2020). Drought severity has risen as a consequence of the actions of humans as well as global warming, posing a significant risk to production of crops (Sati et al., 2022). Drought constitutes among the biggest contributors to crop failures among all environmental factors (Shaffique et al., 2023). It is a multifaceted stress caused mostly by a decrease in rain as well as a subsequent dry spell (Slimani et al., 2023). Drought frequently causes cellular dehydration, a reduction of water-holding potential, decreased cell development, stem growth, impaired cell growth and synthesis of cell walls, as well as salt buildup surrounding stomata openings, which causes them to be dysfunctional (Ahmed et al., 2015).

Water scarcity occurs when a plant's need for water is unable to be completely fulfilled, which takes place when the quantity of water evaporated surpasses the



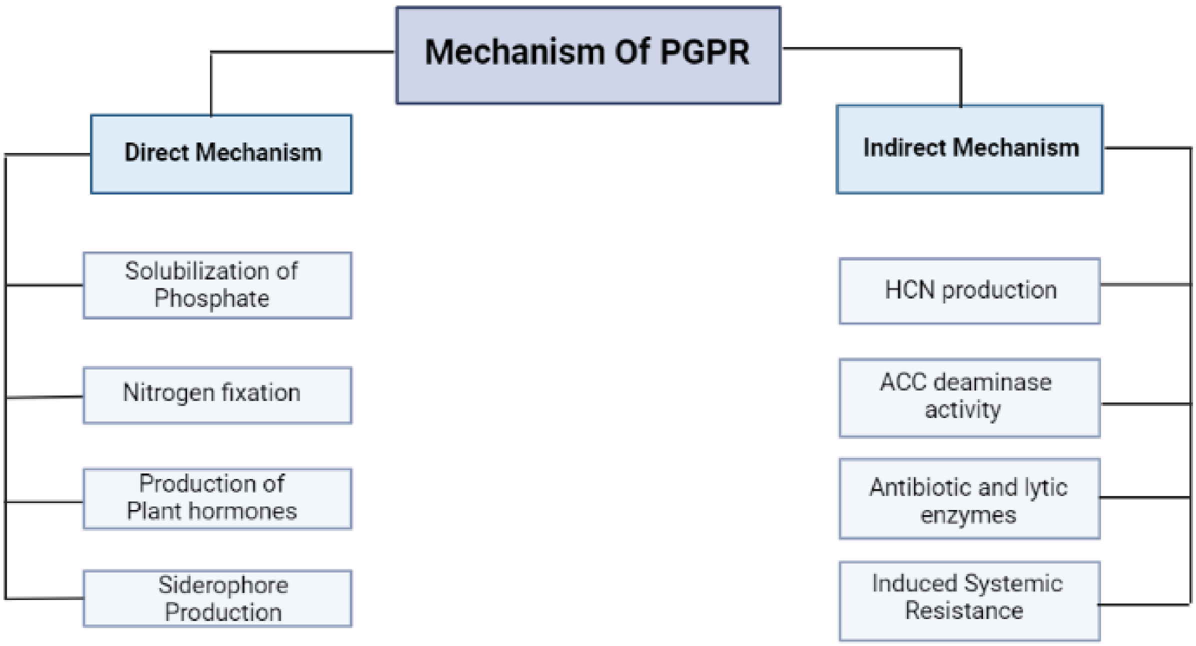
quantity of water used by the roots, this is caused by a lack of precipitation, reduced underground water level, or inadequate the accumulation of moisture by soil particles (Salehi-Lisar & Bakhshayeshan-Agdam, 2016). Drought not only impacts crop development and growth, but it also has a negative influence on crop plant production (Seleiman et al., 2021). Regarding drought stress, the cultivation of crops is a serious difficulty (Fathi & Tari, 2016). Drought stress causes changes in essential plant structure, physiology, and biochemistry (Iqbal et al., 2020). Water stress lowers the absorption of nutrients that are soluble in water such as magnesium, nitrates sulfate, silicon, and magnesium (Talebi Atouei et al., 2019). Water shortage causes a rise in ROS like superoxide radicals, reactive OH radicals, as well as H_2O_2, which causes oxidative stress. ROS may harm tissues, induce membrane erosion, and destroy nucleic acids and proteins by producing lipid peroxidation (Farooq et al., 2014). Drought reduces the availability of CO_2 for photosynthesis, which could lead to ROS generation by using misplaced electrons in electron transport chain. (Gaffney et al., 2015). Plants contain an antioxidant defense mechanism that protects the membranes of cells and DNA from oxidative harm caused by ROS through the transformation of ROS to harmless forms like water and oxygen (Nasim et al., 2018).

Plant growth-promoting rhizobacteria (PGPR) is a type of bacteria that live freely, invade then help to stimulate plant development in plant roots (Bhanse et al., 2022). PGPR can boost growth in plants by utilizing its metabolic processes, directly impacting the metabolism of plants, improving the development of roots, boosting plant enzyme activity, "assisting" other helpful microbes to improve their effect on the plant, or reducing pathogenic bacteria (Vocciante et al., 2022). The growth of plants in arid and semi-arid regions might benefit from microbe inoculation to increase water retention techniques and drought resistance (Ngumbi & Kloepper, 2016). Phosphate solubilization, siderophore synthesis, biological fixation of nitrogen, and other processes can all be used by PGPR to boost plant development. The plant hormones synthesis, antifungal activity, VOC generation, systemic resistance induction, development of helpful plant-microbe mutually beneficial relationships, and interfering with the pathogenic production of toxins (Ali et al., 2017).

This review article is concerned with the strategies to find out how PGPR affects crops ability to regulate systemically developed resistance. In order to produce food over the long term, it is necessary to continuously identify and isolate suitable PGPR strains. The primary goal of the aforementioned study is to evaluate the strains' capacity to control the biochemical and physiological adaptations of potato crops in order to comprehend the defense mechanism under normal and drought conditions. The efficiency of PGPR is dependent on its growth period, soil ecological variation, and crop life span and species, but also modifies plant-soil biochemistry, promoting plant growth including well-being. To effectively use PGPR, it is crucial to comprehend the processes by which it affects and achieve feasible cultivation (Alori et al., 2017).

Mechanism Adopted by PGPR:

PGPR can improve development of plant by means direct or indirect means through a variety of ways (Mekonnen & Kibret, 2021). Direct mechanisms involve procedures including the solubilization and breakdown of phosphate, fixation of nitrogen, also the generation of plant hormones, siderophore and nutrient uptake, while indirect processes include processes which not only promote growth but participate in synthesis process. Indirect processes involve HCN, ISR, activity of ACC deaminase, antibiotic synthesis and lytic enzymes (Parewa et al., 2018).



Direct Mechanism:

Solubilization of Phosphate:

Phosphorus is a necessary ingredient for the growth of plants and production. The phosphorus content in soil is not frequently adequate for the proper plant development and growth because of soil fixation (Malhotra et al., 2018). The majority of the phosphorous in the earth's soil exists as both organic and inorganic insoluble phosphate. Phosphate-solubilizing bacteria are significant in this area because they release phosphates derived from organic materials or dissociate inorganic phosphate which is insoluble. (Gouda et al., 2018).

PSB generates acids that are organic with relatively low molecular weights like acetic acid, tartaric acid, succinic acid, citric acid, lactic acid, ketogluconate, oxalic acid, gluconic acid, and glycolic acid. The hydroxyl as well as carboxyl groups of these acids involve in cation chelation associated with the phosphate, eventually transforming it to form which is more soluble. These soluble forms are more readily absorb by the plants.(Patel & Minocheherhomji, 2018).

Nitrogen fixation:

Nitrogen constitutes among the primary nutrients restricting plant development in agricultural ecosystems (Mahmud et al., 2020). Nitrogen-based fertilizer is used to deliver nitrogen for crop development and production. But only about half of the nitrogen supplied to plants is properly absorbed, with the remainder lost via volatilizing or leaching and therefore damaging the surroundings (Aloo et al., 2019).

Nitrogen-fixing organisms utilize a sophisticated enzyme named nitrogenase which turn nitrogen into ammonia which is the plant-utilizable form (Shaikh et al., 2018). The fixation of nitrogen by biological means contributes to over two-thirds of global nitrogen fixing and takes place either symbiotically or freely among microorganisms and plants (Gouda et al., 2018).

Plant hormones Production:

Plant hormones are organic compounds that are necessary for controlling plant development and yield, as well as for promoting the tolerance of plants to diverse both abiotic as well as biotic stimuli (Khan et al., 2020). These hormones are produced in one site in a plant and then transported to another site where they are used and increase plant growth. Physical reactions to these hormones cause the development of roots as well as leaves (Rehman et al., 2020). PGPR produces a variety of plant hormones, including auxins, gibberellins, cytokinin, ethylene, as well as abscisic acid (Egamberdieva et al., 2017).

Auxins Production:

80% of PGPR create **IAA**, among the most biologically active auxins, that supports various growth as well as development processes including division of cells, elongation of the stem as well as cell differentiation (Ahmed et al., 2017). Auxins influences several growths as well as physiological processes in plants, such as responses of growth to environmental parameters, organogenesis, leaves, root systems, and the formation of vascular tissues in leaves, as well as the maintenance of vascular tissue in leaves (Khan et al., 2020).

Ethylene Production:

Ethylene occurs naturally and plays a role in a variety of physiological activities, including the development of shoots as well as roots, apex meristem activity, root as well as root hair formation (Vandenbussche & Van Der Straeten, 2012). Plant ethylene regulation can be influenced by PGPR by regulating the activity of genes expressing ethylene production enzymes, ACC-synthase as well as ACC-oxidase (Poupin et al., 2016).

Cytokinin Production:

Cytokinins are plant hormones shown to induce cell division, cell expansion, and tissue growth in many plant sections (Nasir, 2016). Plants and microbes both manufacture Cks, which vary in form and functioning (Akhtar et al., 2020). Cytokinins produce by bacteria also help plants fight stressors that are both abiotic along with biotic (Großkinsky et al., 2016).

Gibberellins Production:

Gibberellins are kind of plant hormone that serve a variety of roles for plants. They have critical roles in the building and growth of reproductive organs, as well as the maturation of fruit along with viable seeds (Plackett & Wilson, 2018). The most dangerous scenario occurs during periods of drought when gibberellin synthesis is limited. PGPR, like other plant hormones, can regulate the quantity of naturally occurring gibberellin in plants (Bottini et al., 2004).

Abscisic acid production:

ABA is a widely recognized plant hormone because of its function in water stress. High ABA concentration during water stress situations results in closure of stomata, minimizing loss of water (Bauer et al., 2013). It turns on the stress genes that show resistance against drought. Several PGPR strains produce Abscisic acid (Rehman et al., 2020).

Production of Siderophore:

Siderophore are PSM-produced small metabolites which are secondary in nature with high sensitivity for inorganic iron that acts as metal chelators (Silva et al., 2023). Siderophore are formed under iron-restricted circumstances in which Fe 3+ accomplishes a particular action. It acts as a conduit necessary for the entry of Fe (III) inside microbiological cell. Iron availability for microbes uptake in the root zone is highly limited (Jain et al., 2022). So, to survive, organisms release ligands which bind iron known as siderophore that may attach the ferrous ion thus making it accessible to the recipient. Fe (3+) is converted to Fe (2+)., which is subsequently excreted by the cell siderophore. Siderophore synthesis functions as a biological control strategy because PGPR starves other microbes of iron. PGPR also employs siderophore to extract additional toxic substances from the environment and avoids heavy metals from causing toxicity in crops (P. Kumar et al., 2018).

Indirect Mechanism:

HCN production:

Rhizobacteria that are poisonous can function for biological control. The bacteria invade crop root surfaces and inhibit growth. Many microbes, including bacteria, algae, and fungi, including plants, generate cyanide, which is hazardous. They compete with one another as a method of survival. HCN limits the ETC as well as the cell's energy supply. Cell death occurs as a consequence of this disruption. The inoculation of bacterial strains which produce cyanide has no harmful effects on the host plants. (Rehman et al., 2020).

ACC deaminase activity in plants by PGPR:

Soil microbes trigger plants to synthesize additional ACC than they would normally require and promote ACC discharge from the roots of plants, while additionally providing microbes with an unusual supply of nitrogen (ACC), and as a result, microorganisms proliferate with ACC deaminase increases in the vicinity of the roots of plants in contrast with standard soil microbes (Saleem et al., 2007). When ACCD-producing bacterial strains colonize the plant's root surfaces of a challenged plant, the bacteria operate as reservoirs of ACC, lowering levels of ethylene and speeds up growth of roots. Plants treated with ACCD containing PGPR may be more resistant to a range of environmental difficulties due to their broad root development (Shahid et al., 2023).

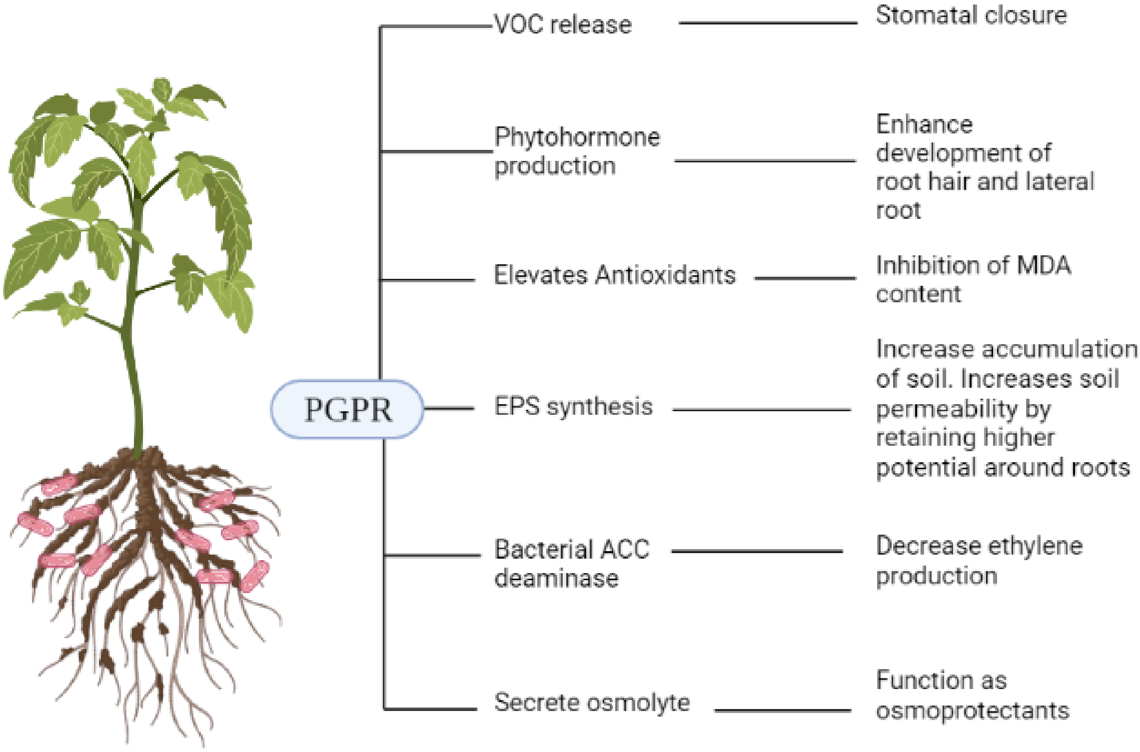
Antibiotic and lytic enzymes Synthesis:

It is generally known that microbes compete fiercely for resources and colonize sites in their native environments. Numerous PGPR species are capable of and possess numerous mechanisms for reducing competition, including the release of antibiotics and lytic enzymes into their surroundings (Tariq et al., 2017). As a result, PGPR is a significant weapon that may be employed against plant-borne pathogens. A rise in the utilization of PGPR can lead to the emergence of resistant strains of plant pathogens. Pathogens are excreted via the enzymes released by PGPR (Kenneth et al., 2019).

ISR in Plants by PGPR:

Plants' evolved defensive systems are known as induced systemic resistance against pathogens. ISR is a kind of response that is activated by the PGPR. When a PGPR inoculum is administered to a plant, the PGPR induces tolerance in that plant toward several bacterial diseases. As a result, ISR is generated (ur Rehman[1] et al., 2020). It has been extensively documented that PGPR causes ISR via phytohormones (Sharifi & Ryu, 2018). The most well-known PGPR-produced plant hormones implicated in ISR stimulation are jasmonic acid (JA) as well as ET, which are also important for controlling the cascade of defense gene expression (Romera et al., 2019).

PGPR as a Biofertilizer:



Biofertilizers are inoculants of microbes that include cells that are dormant or active having efficient N-fixing, P as well as K solubilizing bacterial strains (Fasusi et al., 2021). Beneficial microbial agents used as biofertilizers help to enhance the number of nutrients by (i) affecting the rate of metabolism of plants and thus changing the chemical makeup of exudates from the roots, (ii) affecting nutrient mobility and the availability, as well as (iii) improving communication with other soil bacteria (Kumar et al., 2022). The association of PGPR with soil particles or rhizosphere bacteria indirectly increases plant development rates, thus PGPR may be classified as a biofertilizer (Sheirdil et al., 2023). Plants and other photosynthetic creatures form the basis for all life on Earth by generating carbohydrates and capturing carbon dioxide and the energy of light.

There is proof that the use of biofertilizers enhances crop growth, fruit quality, and production by enhancing photosynthesis through elevated chlorophyll and carotenoid-like pigments, water usage efficiency, enhanced oxidative state, and so on (Yapa et al.). Using a nitrogen-fixing process, biofertilizers may fix atmospheric N_2, solubilize minerals necessary for plants like zinc, phosphate, and potassium, and produce plant growth-boosting chemicals such as different hormones (M. S. Kumar et al., 2018). They've been demonstrated to improve seedling survival., increase root system development, extend the life of the root system and remove toxic compounds, and decrease blooming time (Youssef & Eissa, 2014).

Microbial inoculants have various benefits over conventional fertilizers (Meena et al., 2020). They are ecologically friendly, sustainable sources of the sustainable nutrients are required. for soil life and health (Sun et al., 2020). In addition, they having antimicrobial activity against a range of crop disorders and are effective towards abiotic stressors (Ilangumaran & Smith, 2017). Based on their capacity to acquire nutrition from the soil, fixation of atmospheric N_2, drive nutrient solubility, and operate as biocontrol molecules, certain microbial species have been widely exploited as biofertilizers that work (Schütz et al., 2018).

Conclusion:

This article provides an in-depth examination of how water stress affects agricultural plants and advocates the application of PGPR for the growth of plants as an environmentally benign technique for coping with drought and attaining sustainable agriculture. Nature's fury in the form of water shortage hurts plant development and growth. Drought stress has been demonstrated to have a significant impact on root systems as well as plant-associated microbiomes. It has an impact on root exudates such amino acids, sugars, flavonoids, and plant hormones., and so on. PGPR as biological fertilizers are both appealing and cost-effective for environmentally friendly agriculture. PGPR improves soil as well as crop health in a variety of ways. Identifying the biological systems that govern drought-related processes mediated by PGPR in plants is critical for increasing agricultural crop production and addressing future worldwide food security concerns. The economic execution of PGPR, on the other hand is highly dependent on its affordability, strain resilience, and formulated product lifespan.

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