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Role of Pink Pigmented Facultative Methylotrophic (PPFM) Bacteria on Drought Tolerance in Plant

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Plant growth-promoting microorganisms (PGPMs) supports plant to survive extreme environmental condition moreover to improving plant growth by establishing beneficially interaction with plants. These PGPMs are associated with different compartments of plants includes rhizosphere, phyllosphere, and endophytes. The plant phyllosphere supports a large and complex microbial community and bacteria are viewed to be the dominant microbial inhabitants of the phyllosphere. Mainly, leaves comprise a significant microbial habitat, which includes methylotrophs. Plant phyllosphere is an ecological niche that shelters highly abundant Methylobacterium species of 104–107 colony forming units per leaflet. Bacteria belonging to the genus Methylobacterium are commonly known as Pink-pigmented facultative methylotrophic bacteria (PPFMs). They are strict aerobes, Gram-negative, facultative methylotrophic rods. They can grow on C1 compounds like methanol, formaldehyde, and methylamine and also on a variety of C2, C3, and C4 compounds (Green, 2006).

PPFMs are known to improve plant growth by adopting various mechanisms viz., nitrogen fixation and nodule formation, phosphate solubilization, plant growth regulators production (auxins, cytokinins, gibberellic acid), production of urease enzyme, vitamin B12 production, synthesis of siderophores. PPFM accountable for a diverse beneficial effect on plant includes fasten seed germination and seedling growth, accelerate vegetative growth by producing phytohormones, increase leaf area index and chlorophyll content, earliness in flowering, fruit set, and maturation, improves fruit quality, color, and seed weight, yield increase by 10% and Mitigate drought. Methylotrophic bacteria adapt to survive in stress conditions such as low nutrient, drought, and high temperature by producing biofilm, aggregate formation, and producing ultraviolet (UV)-protecting compounds. Additionally, PPFMs promote plant growth by producing an enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase is responsible for drought management during the beneficial interaction with plants (Chinnadurai et al., 2009).

Drought Tolerance Promoting Mechanisms of PPFMs

Under drought conditions, plants produce higher amounts of ethylene and reactive oxygen species and, besides increase the frequency of stomata closure and membrane damages, which leads to yield loss. Methylotrophic bacteria produce 1-aminocyclopropane-1-carboxylate (ACC) deaminase and induce the production of antioxidant enzymes and osmolytes in plants, which helps in mitigating drought stress.

ACC Deaminase and Hormone Production

Ethylene in plants interrupt the number of processes involved in plant growth and yield and plays a major role in plant biotic and abiotic responses. Increased concentrations of ethylene in plants have detrimental effects. Ethylene affects the photosynthesis process and stomata conductance in addition to it interacts with other plant hormones such as auxin and abscisic acid. Plants that are treated with PPFMs that synthesize the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase break down the ACC to ammonia and alpha ketobutyrate. Because of the bacterial ACC deaminase enzyme, ethylene production in plants is reduced under stress conditions. Besides, it also able to produce phytohormones like auxins, cytokinins, and gibberellic acid, which promotes cell division in shoots and roots (Chinnadurai *et al*., 2009).

Stomatal Regulation

Drought stress triggers the production of abscisic acid (ABA), which in turn induces the stomatal closure and accumulation of compatible solutes. PPFMs control stomata closure through direct and indirect ways. As regards the direct ways, volatile compounds, or microbial-associated molecular pattern (MAMP), activate plant defense-related plant hormones, such as salicylic acid (SA) and jasmonic acid (JA), and trigger ABA-independent stomatal closure through nitric oxide (NO) and open stomata 1 (OST1) signal cascade. In the indirect method, the negative effect of ethylene on the ABA in drought stress is reduced by ACC deaminase producing PPFMs.

Prevention of Reactive Oxygen Species Accumulation

Plants produce reactive oxygen species (ROS) under stress, which react with proteins, lipids, and deoxyribonucleic acid (DNA) causing oxidative damage and affect the normal functions of plants. To overcome the negative effect of ROS, plants develop antioxidant defense systems, comprising both enzymatic and non-enzymatic components that serve to prevent ROS accumulation and alleviate the oxidative damage occurring during drought stress. PPFM spray induces the synthesis of various enzymatic (superoxide dismutase, catalase, ascorbate peroxidase, and glutathione reductase) and non-enzymatic (cysteine, glutathione, and ascorbic acid) components in plants against ROS and thereby relieves the plant from drought stress (Sivakumar et al., 2017).

Method of Application

The liquid formulation of PPFMs recommended for application through seed treatment (imbibe seed in 1.0 % PPFM solution for 5-10 min depending on seed size), and foliar spray (1% PPFM spray during morning or evening, recommended for all crops, spray at the critical stage of crop growth (or) 30 days interval).

Role of PPFM on Drought Mitigation in Rice Crop

PPFM is widely used in rice crops by recommended spraying of bacteria to mitigate drought and save crops. The evidence of that spraying of PPFM helps the rice crops remain green for 15 to 20 days and it's helpful only during the terminal stages of the crops such as boot leaf stage and flowering stage after which panicle initiation would take place. The recommendation of the rice crop is 1000ml / acre by foliar application. Apart from that wetland rice contributes up to 20% of the global CH_4 emissions. CH_4 emissions will need to be reduced by microbial CH_4 oxidation (as happens with *Methylobacterium*). More research is being done on methanotrophs to understand their systems and ecological preferences to utilize them in facilitating attempts to reduce CH_4 emissions in the future.

Conclusion

The application of methylotrophs as bio-inoculants is common, and their use as an alternative to chemical fertilizers is also increasing. Their association with plant growth can be exploited for eco-friendly and cost-effective practices to promote sustainable agriculture. They employ multiple mechanisms to promote plant growth like phytohormones production, nodulation, nitrogen fixation, and nutrient acquisition. Similarly, methylotrophic bacteria also offer drought-tolerant mechanisms by nitrogen fixation, phytohormones production, ACC deaminase production, and phosphate solubilization. PPFMs could be potential bio-inoculants to increase plant growth and drought stress tolerance in sustainable agricultural systems.

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