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Climate Change Triggered Abiotic Stress Mitigation in Crops through Plant Growth Promoting Microbes

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***Abstract:** Sustainable food and feed crop production to match with the needs of the growing population is a major challenge. Besides many limiting factors on plant health, growth and yield, management of abiotic stress in a sustainable manner will play an important role in meeting this challenge. Abiotic stresses negatively affect plant growth and development and are responsible for crop losses. Among the many alternatives being worked out to combat abiotic stress, using PGPMs to enhance stress tolerance and productivity are emerging as a viable and sustainable practice.*

***Keywords:** Plant Growth Promoting Microbes (PGPMs), Abiotic Stresses, soil salinity, Water Stress*

1. INTRODUCTION

As the process of changes caused by global warming plays out in the coming decades, abiotic stress for crops (and other flora) is going to challenge the already achieved yields and nutrient content of crops, besides proving as a challenge for further improvement in output and production. While climate change caused desertification will limit and even shrink the arable area available for crop production, even in available arable areas climate change is going to mean excess of abiotic stresses.

Every crop grows in unique microecosystem characterized by soil conditions, natural weather in terms of temperature variability across seasons and water in by way of precipitation, ground water availability or through manmade irrigation systems. Any changes in any or all of these factors of crop production can trigger changes in growth rate and harvest time, stalk to grain/fruit ratio, yield, cellular metabolism, altered gene expression and sometimes absolute unsuitability because of multiple factors combined. Most plants have ability to adapt to any of the external condition changes, but this is a slow evolutionary scale process whereas the changes being brought about by human actions in the last few decades, especially the GHG originated warming and consequent climate change is much too fast and unpredictable.

The food and feed crops are already of limited and gradually reducing genetic diversity and the annual output barely manages the survival usage for the current population of the world that any unpredictable external environmental shock can be cause of widespread famine.

In the current era of rapidly changing climate, while genetic research towards development of abiotic stress tolerance in plants is of prime importance, but the timescale of genetic research outcome is unknown and unreliable.

One of the suggested mechanism is to use Plant Growth Promoting Microbes (PGPMs), and more particularly rhizobacteria (PGPRs), to enhance the ability of crops (and generally all plants) to tolerate abiotic stress in the era of climate change and preserve the ability of the current crop lands to meet the protein energy requirements of the growing population of the world.

2. ABIOTIC STRESSES

Air and soil temperature, both low and high - cold, frost and heat

Excess Heat: Drop in percentage of seed germination, photosynthetic efficiency and yield; disruption in function of tapetal cells and anther

Excess Cold and Frost. Although the overall trend is towards warming – temperatures going up, the cold weather conditions in are also becoming extreme, unpredictable, and harsh. The chilling and freezing conditions affect the cellular functions of plants

Air and Soil temperature, at different times of the day and night and during different seasons is a key determinant of physiological processes and plant development. A gradual and small increase in temperature accelerates the sowing to harvesting period and the green mass output will be higher [2]. Climate change temperature change is neither gradual nor small – it is erratic and substantial , and is thus damage plant cells with resulting yield drop [2,3]. Some studies have established yield losses in maize, wheat, rice and soybean from 3.1% to 7.4% per one degree Celsius increase in global mean temperature [6]. Studies in other biomes indicated a 6% and 4% drop in wheat and maize yields, respectively, over three decade period of continued warming [8]. High temperature stress limits photosynthesis outcome generally, more particularly in C3 crops such as rice and wheat besides maize and sugarcane [2,4,5,7]. Temperature increase has a positive feedback for changes in atmospheric humidity which causes excessive water loss from the plants with stomata closing as a reaction and photosynthesis efficiency changes.

Water Stress:

Humidity, soil moisture and deficient or excessive precipitation, variability in rainfall and extreme weather events, resulting Droughts, floods, in quick run off and water logging

Climate change is affecting the rainfall distribution pattern in its spread and intensity. As a reaction to water deficiency plants reduce their metabolism rate and the growth of shoot is stunted.

There is threat of both hydrological and meteorological water stress as effects of climate change and intensive agriculture pan out. Less precipitation and higher temperatures combined with low humidity will also increase the risk of wildfires and parched land not even suitable for grazing of livestock.

Currently employed yield raising practice of groundwater irrigation and chemical fertilizers is only increasing the problem in the long run.

Water stress signaling via ABA activates the plant's threat response by way of closing of stomata

Soil water shortage usually inhibits proper growth and development. Less access to water increases the concentration of ions. Both water scarcity and high salinity can create hypertonic conditions leading to osmotic stress, thus disturbing the nutrient and water balance, the permeability of membranes, and reducing the activity of selected enzymes.

ABA is a plant stress hormone which makes the plant drought and salinity tolerant. Presence of in appropriate quantity, while improving water intake and root length, determines the shoot length to root length ratio. Other abiotic stress busters are osmoprotectants like proline, extracellular polymeric substances, volatile organic compounds (VOCs)

Drought tolerance is usually the result of many biochemical and physiological adaptations, which consequently allow the plant to maintain its desired size and yield despite unfavorable environmental conditions. However, in the case of long-term or sudden changes, the plant is unable to cope and needs external help to survive

High soil salinity, mineral toxicity and atmospheric air pollution heavy metals in soil and air

Osmotic stress and ion toxicity are the two immediate outcomes of soil salinity, limiting the water and mineral intake and secondary effects like assimilate production, impaired cell expansion, membrane function and cytosolic metabolis. The topography of the soil, natural ground water availability and depth, and precipitation determines the extent of natural alt accumulation in soil. Excessive irrigation without drainage causes salinity as well.

The increased dependence of agriculture on chemical fertilizers and sewage waste water irrigation and rapid industrialization has added toxic metals to agriculture soils causing harmful effects on soil-plant environment system

Salinity stress results in drop in dry mass and biomass accumulation, weak spread of the root system, low output and impaired seed germination. Salinity causes improper and unbalances pH of soil, reducing the bioavailability of essential nutrient elements as they are present in water-insoluble form. High salinity impacts ion/electron transport, phosphorylation and photorespiration, besides an unstable photosynthesis. Unchecked salinity increase results in salt accumulation increasing the dispersion and swelling capacity, and reduced soil water permeability. Over a period of time land becomes uncultivable.

These abiotic stresses affect the survival, growth, yield and seed quality of the plants. The abiotic stresses are interlinked in the sense that the effect of a particular stress on a plant may reduce its tolerance to another abiotic stress. Every plant has a very narrow tolerance range for these abiotic stresses and some adaptation potential over multiple seasons, normally decades.

This luxury of time is not available now as the fast changing climate and other human activity introduced environmental pollutants are making each of the above abiotic stresses too harsh, have arisen together and too quick on time scale. The natural defenses of most of plants, especially the food and feed crops are unable to cope and tolerate, resulting major crop yield losses and output. Excessive use of chemical fertilizers without adequate drainage and less than adequate time for the soil to renew its natural nutrient base is causing beyond tolerance salinization of arable land worldwide. High salinity is resulting in multiple damages like osmotic stress, ion distribution malfunction and cell homeostasis. The changed gene expression causes growth stunting. this salinity damage is getting further aggravated because of deficient water stress.

Plant Growth Promoting Microbes as Saviours

Genetic engineered solutions to make plants, especially essential plants like food and feed crops, resilient to the fast increasing abiotic stresses have, by the nature of the process of genetic modification of years of trial and error, will take uncertain time. As one of the few pathways of making plants more tolerant to the abiotic stress is the possible use of Plant Growth Promoting Microbes (PGPMs).

Type of soil, other than the plant itself, is the key determinant of the intensity of abiotic stress experienced. They adversely impact the physical-chemical soil properties and microbial communities. Different studies on plants have indicated PGPR playing a major supportive role against abiotic stress, having evolved and adapted to survive higher stress better and faster than the plant itself. These microbes have been specifically categorised as abiotic stress tolerant growth promoting bacteria (AST-PGPB). Some AST PGPBs have been shown to be better performing under severe stress. Within the AST PGPBs group specific bacteria have evolved to tolerate a specific stress in normally multi-stress field situations. Secondary metabolites like osmoprotectants production by PGPBs act as stress fighters. PGPBs like Azospirillum spp. accumulating glycine betaine, glutamate, proline and trehalose improve osmotic stress tolerance.

Strains of P. aeruginosa have been observed to improve Exopolysaccharide (EPS) secretion. EPS has been shown to store nutrients and aid formation of microconsortia and promote colonization of root. Some PGPBs under environmental stress conditions produce lipohilic indicator compounds like VOCs. In one study. PGPR reduced the toxic effect of cadmium pollution on barley plants with the bacteria through a binding mechanism brought down cadmium availability in the soil. By using Bacillus lentimorbus nutrient content and antioxidant capacity augmentation was observed in usable parts of spinach, carrot and lettuce. PGPRs have been observed to have improved the stomatal aperture performance under saline and scanty water stress, making the plant more water efficient Inoculation of Bacillus megatertum and Pantoea agglomerans into maize roots improved the water absorption by maize roots under saline conditions .Azospirillum brasilense and A. brasilense improved the saline tolerance of Jojoba [8] Azospirillum brasilense inoculated lettuce could withstand the high saline stress and also improve its shelf life [9] The most common and successful PGPB belong mainly to the genera Agrobacterium, Azospirillum, Azotobacter, Bacillus, Burkholderia, Pseudomonas, Streptomyces and Serratia[1].

PGPM to be inoculated is based on expected characteristics, extent of stress exposure and host plant bacteria. PGPB usage can follow many alternate methods like carrier based inoculation, soil application and/or seed treatment. Dipping the root in bacterial suspension or drip irrigation methodology can also be deployed. PGPB to be inoculated must not be rejected by the immune response of the plant and should be able to successfully colonize plants. A cocktail approach is also suggested to avoid in missing links and as some studies have indicated synergetic actions of some PGPRs together

3. CONCLUSION

Food and non food crops have always been exposed to different abiotic stresses year on year. Only rarely more than one abiotic stress would dominate together or in a persistent manner year after year. Climate change and air and water pollution in the last few decades are making crops face with a possibility of multiple/consortium, persistent and permanent abiotic stresses.

The gains of green revolution which banished famine from the earth are all going to get wiped out and food shortages and famine could make a comeback unless measures are taken to address the stresses the food and feed crops are likely to face.

PGPMs present a viable, sustainable, and renewable means to make plants tolerate the abiotic stresses better. This also can only be a immediate measure as in the long run we will have to use genetic modification to bring about more tolerant variety of crop varieties.

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