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Agriculture biotechnology for management of multiple biotic and abiotic environmental stress in crops

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ABSTRACT

In current situation where dramatic changes in the environmental conditions are very common finding the alternate options in increasing crop productivity is main area that needs to be emphasized to feed the overwhelming populations and ensure their food security. Among environmental conditions like various biotic and abiotic stresses are playing major role in decreasing crop productivity. Abiotic stress includes high and low temperature, salinity, drought, flooding and heavy metals. These stresses reduced the yield of crops, depending on the type of crop and stress period. In many semi-arid and arid regions of the world, crop yield islimited due to increased rate of soil salinity. Salinity and drought are the two most complex stress tolerances to breed for as the type (combinations of drought and salinity), timing in relation to plant growth stage and intensity of stress can all vary considerably, which have severely affected plant growth and biomass production since long. Biotic stresses, mainly represented by pests and diseases, constitute the single greatest threat to crop production. These include many thousands of species and types of fungi, insects, bacteria, viruses, nematodes and other organisms. Modern farming practices, with their reliance on agrochemical pest and disease control, are responsible for considerable pollution and can have harmful effects on human health. Pests control strategies in crops included the fungicides and other cultural control measures, particularly against airborne fungi pathogens, are continually eroded in their effectiveness by adaptations in the pathogen. Resistance against pests and stress is one of the key factors for plant varieties used in production systems. The most prevalent tools to control plant, pests and enhance soil fertilely are the use of intensive agrochemicals irrespective of their high cost and deleterious impacts on health and environments. Variety selection and the use of fungicides are two management strategies that producers should consider to improve economic return. Multiple biotic and abiotic environmental stress factors affect negatively various aspects of plant growth, development, and crop productivity. Plants and animals share some response mechanisms to unfavorable environmental conditions; however, plants, being sessile organisms, have developed, in the course of their evolution, highly sophisticated and efficient strategies of response to cope with and adapt to different types of abiotic and biotic stress imposed by the frequently adverse environment.

INTRODUCTION

Drought stress is highly variable in its timing, duration and severity, and these results in high environmental variation and $G \times E$ variation. The whole-plant response to stress is complex because it is determined by component traits that interact and differ in their individual responses to the intensity and duration of water deficits and temperature. The use of managed stress environments can be very effective in breeding for drought tolerance, however, it is important to apply sufficient drought or salinity stresses intensity to maximize $G \times E$ Plant breeders are searching continuously for more effective and efficient selection procedure. Plants undergo a number of metabolic and physiological changes in response to salinity and water deficiency(drought). Plants are bestowed with the capability to respond via signal transduction pathways adjusting their metabolism. A defensive strategy of plants against such stressful conditions encompasses a cascade of signals ranging from primary (like changes in ionic/osmotic levels, stomatal closer, etc.) to secondary (e.g. phytohormones and secondary metabolites etc)responses. Salinity imposes ionic (mainly due to Na^+, Cl^-, and SO_4^{2-}), osmotic, and secondary stresses such as nutritional imbalances and oxidative stress for glycophytes. Drought affects the turgor pressure and biomass production, although drought is more pervasive and devastating than salinity; however, plants' response to both is closely related.

Exploiting naturally occurring host-plant resistance to biotic stress agents represents one means of addressing the problems associated with agrochemical control. However, the very nature of the selective pressure that resistance genes exert on pest and disease populations means that new forms are constantly evolving that need controlling with new gene combinations. For example, on wheat, the most prevalent leaf spotting diseases were rust (*Pyrenophoratritici-repentis*) and septoria complex (*Septoria* spp.) and on barley, net blotch (*Pyrenophorsteres*) and spot blotch (*Cochliobolus sativus*) [1], [2], [3]. Reduced photosynthetic area on the upper leaves from plants infected with these diseases result in reduced grain fill and yield that causes yield losses up to 50% and reduces grain quality. The fungal pathogen *Pucciniahordei* Otth is the causal agent of wheat and barley leaf rust, an economically important disease in temperate regions, which can considerably reduce the yield of susceptible cultivars up to about 60%. *Fusarium* head blight has emerged as a major threat to wheat and barley crops around the world. Wheat Aphid has been included world widely in the list of the important pests of cereals, particularly wheat plants. A recent study dealing with all production constraints (including diseases) for six major crops (rice, sorghum, chickpea, cassava, and cowpea) in 13 Asian and African farming systems showed that losses caused by diseases ranged from 3 to 14%, whereas yield losses due to all biotic stresses ranged from 16 to 37% and yield losses to all crop production constraints ranged from 36 to 65% [4]. The list of pathogens harmful to crops is large and extremely diverse. Crops can be attacked at different growth stages: at seedling establishment (root and seed rots), young seedlings (root and collar rots, seedling blights, wilts), pre-flowering (wilts, leaf blights, yellowing and mottling of the foliage, stunting), flowering (bud rots, flower blight), post flowering (rusts, blights) and post harvest (fruit rots). The same disease can induce diverse symptoms at different growth stages.

Biotechnology and Stress

Biotechnology nowadays changing the agricultural and plant scene in three major areas: (1) growth and development control (vegetative and reproduction/ propagation), (2) protecting plants against the ever-increasing threats of abiotic and biotic stress, (3) expanding the horizons by producing specialty foods, biochemicals and pharmaceuticals [5]. Multiple biotic and abiotic environmental stress factors affect negatively various aspects of plant growth, development, and crop productivity. Plants, as sessile organisms, have developed, in the course of their evolution, efficient strategies of response to avoid, tolerate, or adapt to different types of stress situations. The diverse stress factors that plants have to face often activate similar cell signaling pathways and cellular responses, such as the production of stress proteins, upregulation of the antioxidant machinery, and accumulation of compatible solutes. Over the last few decades advances in plant physiology, genetics, and molecular biology have greatly improved our understanding of plant responses to abiotic stress conditions.

Biotechnology and Sustainable Agriculture

Biotechnology has been contributing to sustainable agriculture through the following ways:

- Increased resistance against biotic stresses (insect pests and diseases);
- Increased resistance against abiotic stresses (drought, cold, flooding, and problem soils);
- Bioremediation of polluted soils and biodetectors for monitoring pollution;
- Increased productivity and quality;
- Enhanced nitrogen fixation and increased nutrient uptake and use efficiency;
- Improved fermentation technology;
- Improved technologies for generating biomass-derived energy;
- Generation of high nutrient levels in nutrient-deficient staple crops such as rice.

The main biotechnological approaches to improve plant responses to stress are:

1. Breeding

Climate change threatens sustainable agriculture with its rapid and unpredictable effects, making it particularly difficult for agricultural scientists and farmers to respond to challenges from biotic and abiotic stresses. Global warming is causing changes in temperature at a rate unmatched by any temperature change over the last 50 million years making it all the more important how well agricultural production can be maintained. It calls for concerted efforts in sustaining food production to meet this challenge. Aspects of climate change that may affect future crop production include changes in both mean and extreme temperatures and changes to available water. Improving adaptation requires development of plants and associated production and management systems to cope with or avoid climate effects. Many complex processes and interactions determine crop yield under climate change and Crop simulation models combined with high resolution climate change scenarios may identify key traits that are important under drought and high temperature stress in crops. Climate change and associated strategies should build over adopting new technologies and farming policy and systems. Drought and high temperatures are considered as key stress factors where scientists should anticipate the effects of climate change on plants. With the knowledge and tools, plant breeders and biotechnologists that will begin to make the best use of the huge global effort to meet challenges posed by climate change.

Drought and soil salinity are major abiotic stress factors affecting seriously crop production and food safety. They reveal adverse impacts on the socio-economic structure of many developing countries. Water scarcity, declining water quality for irrigation, and soil salinity are problems which are becoming really acute [6]. It was estimated that 20% of all cultivated land and nearly a half of irrigated land are affected by salt, greatly reducing the yield of crops below their genetic potential [7]. Breeding cultivars that combine drought and temperature resistance, yield potential, and yield stability are a prerequisite for stable productivity will require introgressing resistance genes from landraces and wild relatives to commercial cultivars and evaluating them in a matrix of stress environments. Achieving genetic increases in yield under abiotic stresses has always been a difficult challenge for plant breeders [8]. The accumulation of soluble salts in soil leads to an increase in the osmotic pressure of soil solution, which may limit the absorption of water by the seeds or by the plant roots. Salt damage to plants is attributed to the reduction in water availability toxicity or specific ions, and nutritional imbalance caused by such ions [9]. There has been an active debate in literature whether to breed primarily for yield potential or for improved yield under the stressful environments that prevail in most wheat-growing areas worldwide. One can find examples of both views: (i) improving yield potential constitutively improves yield under stress conditions; and (ii) breeding for yield potential produces lines of poorer behavior than landraces or lines selected for better performance under stress conditions. As the human population grows, the demand for animal products increases, thus requiring improved agriculture systems. Increases in crop yields have boosted the demand for human feed. To feed the increasing human population, more land will need to be devoted to crops, thereby reducing the land available for pasture and fodder. The limited land available for feed and fodder production and the decreasing quality of available pasture have given rise to the use of improved crop genotypes through breeding systems for increasing human demand for food makes feed improvement essential in order to avoid competition between animal and human feed requirements; feed improvement and use in developing targeted sites should therefore be based on farmer practices, production systems and participation; locally available and potential feed resources production systems and improved techniques appropriate to the farming system in use and economically and socially acceptable. Wheat and barley have evolved as grain structures, destined more to be double purpose grain crops rather than forage crops. These crops have high water-use efficiency and are well adapted to dry areas (abiotic stress). For instance, these crops also have a high degree of drought, salinity and heat tolerance [10]. Adaptation of these crops to soil problems and degraded lands further broadens their adaptation range. Elite breeding lines, open-pollinated varieties and hybrid parents have been identified in wheat, barley through classical breeding programs and selection methods for the most tolerant genotypes and that have performed well at high salinity levels (10dS m^{-1}).

Biotechnology has many potential uses in the campaign against pests and diseases, providing knowledge and tools useful to the plant breeder. However, the very complex nature of the relationships between pests, diseases, vectors, host plants and the environment means that integrated management methods are required. Biotechnology is certainly one component of an integrated management strategy along with resistant varieties, biocontrol, appropriate cultural practices and rational agrochemical use.

Host plant resistance is an important tool to control diseases of major food crops in developing countries, especially wheat, rice, potato, cassava, chickpea, peanuts and cowpea. The use of resistant varieties is very much welcomed by resource poor farmers because it does not require additional cost and it is environment-friendly. Rice varieties resistant to rice blast [11], bacterial blight [12], and brown spot [13] are widely used. Such success stimulated interest in extending the principles of genetic diversity for disease control to other crops in developing countries[14]. Rusts have been known to cause serious disease on wheat since its domestication. The use of genetic resistance is still the most economic and feasible mode of disease control. Genetic resistance is often based on a limited number of major genes that are readily overcome by evolving pathogen races. With the reduction of genetic diversity in the wheat cultivars planted over large areas globally, serious rust epidemics are being recorded whenever new aggressive virulent rust races emerge. A typical example is the yellow rust epidemics that spread from East Africa to Central and South Asia and North Africa during the 1980’s and 1990’s. Presently the breakdown of Yr27, a gene used to replace Yr9, and the emerging stem rust race Ug99 are threatening 80-90% of commercial wheat varieties grown worldwide.

2- Genomics

A gene by gene approach has been typically used to understand its function. Functional genomics allows large-scale gene function analysis with high throughput technology and incorporates interaction of gene products at cellular and organism level. Gene identification through physical and chemical mutagens has become amenable for large-scale analysis with the availability of markers [15], but gene tagging is more promising for functional analysis on a wider scale. Moreover, the understanding of the complexity of stress signaling and plant adaptive processes would require the analysis of the function of numerous genes involved in stress response. Numerous investigations show that plant defense response genes are transcriptionally activated by pathogens and also by different types of abiotic stress. It has been described that the induction of specific defense genes, in the response against certain pathogens, is dependent on specific environmental conditions, suggesting the existence of a complex signaling network that allows the plant to recognize and protect itself against pathogens and environmental stress[16]. Advances in plant genomics research have opened up new perspectives and opportunities for improving crop plants and their productivity. The genomics technologies have been found useful in deciphering the multigenicity of biotic and abiotic plant stress responses through genome sequences, stress-specific cell and tissue transcript collections, protein and metabolite profiles and their dynamic changes, protein interactions, and mutant screens.

3. Proteomics

The adaptation of plants to biotic or abiotic stress conditions is mediated through deep changes in gene expression which result in changes in composition of plant transcriptome, proteome, and metabolome. Since proteins are directly involved in plant stress response, proteomics studies can significantly contribute to elucidate the possible relationships between protein abundance and plant stress acclimation. Several studies [17] have already proven that the changes in gene expression at transcript level do not often correspond with the changes at protein level. The investigation of changes in plant proteome is highly important since proteins, unlike transcripts, are direct effectors of plant stress response.

Proteomics studies could thus lead to identification of potential protein markers whose changes in abundance can be associated with quantitative changes in some physiological parameters related to stress tolerance [18].

4. Metabolomics

The possibility of monitoring a complete set of metabolites could largely improve the understanding of many physiological plant processes. It is systematic study, defined as “metabolomics,” is intended to provide an integrated view of the functional status of an organism. Besides its use as a breeding or selection tool, metabolomics techniques have also been used to evaluate stress responses in barley [19], Citrus [20] and *Arabido psisthaliana* [21]. Some of the metabolites that have been involved in the plant responses to stress.

4. Crop Genetic Improvement

Use of modern molecular biology tools for elucidating the control mechanisms of stress tolerance and for engineering stress tolerant plants is based on the expression of specific stress-related genes. To date, successes in genetic improvement of environmental stress resistance have involved manipulation of a single or a few genes involved in signaling/regulatory pathways or that encode enzymes involved in these pathways [22]. The plant hormone abscisic acid (ABA) regulates the adaptive response of plants to environmental stresses such as drought, salinity, and chilling via diverse physiological and developmental processes [23]. The ABA biosynthetic pathway has been deeply studied, and many of the key enzymes involved in ABA synthesis have been used in transgenic plants to improve abiotic stress tolerance [24]. Transgenic plants overexpressing the genes involved in ABA synthesis showed increased tolerance to drought and salinity stress [24].

A variety of insects, mites and nematodes significantly reduce the yield and quality of the crop plants. The conventional method is to use synthetic pesticides, which also have severe effects on human health and environment. The transgenic technology uses an innovative and eco-friendly method to improve pest control management. About 40 genes obtained from microorganisms of higher plants and animals have been used to provide insect resistance in crop plants

The success of the transgenic approach led to the development of Bt crops, transgenic crops are used worldwide to control major pests of cotton, corn and soybean. Cotton (*Gossypium hirsutum*) tolerant to lepidopteran larvae (caterpillars), maize (*Zea mays*) tolerant to both lepidopteran and coleopteran larvae (rootworms) and soya bean (*Glycine max*) both lepidopteran and coleopteran larvae have become widely used in global agriculture and have led to reductions in pesticide usage and lower production costs [25],[26].

5. Elicitors for Management of Abiotic and Biotic Stresses

Plant environmental stress such as drought conditions, high water or soil salinity or too cold or too hot temperatures represents the most important economic problem for crop production worldwide. In plants, abiotic stress is often accompanied by an excess in ROS levels that leads to oxidative damage. Thus, plant tolerance to abiotic stresses involves adaptive changes in plant morphology, physiological and biochemical processes to minimize stress-induced oxidative injury [27]. ROS play a dual role in plant stress response: they are toxic by-products that accumulate in cells but they are also important signal transduction molecules. The signal perception of an abiotic stress by the plasma membrane is followed by the generation of second messengers such as calcium, ROS and inositol phosphates. These messengers modulate the calcium level in the cells. This change is recognized by calcium sensors, resulting in the expression of major stress responsive genes, and finally leading to a physiological response. Certain chemical treatments can induce an increase of plant stress responses in monocotyledonous plants. Application of secondary messengers such as calcium or inositol to plants enhances their tolerance towards abiotic stress. Seed priming with $CaCl_2$ reduced chilling injury of maize. Plant growth was improved, antioxidant activity was enhanced and soluble sugars accumulated to a higher level after calcium treatment [28]. Ascorbic acid pretreatment of sugarcane results also in higher salt tolerance triggered by enhanced antioxidant enzymes activities [29]. It is now established that polyamine biosynthesis can inhibit the growth of a wide range of fungi by exerting fungicidal activity, thereby reducing the infection of a range of plant pathogenic fungi [30]. Polyamines are essential for normal growth and development, the regulation of several cellular and molecular functions, as well as during the plant's response to stress. Polyamine levels are also known to change in plants in response to biotic stress in the form of pathogen infection [31]. Antioxidants are known to play an important role in the resistance of plants against pathogen attack[32]

Bio-elicitors -for Management of Abiotic and Biotic Stresses in Crop

Recently, great attention has been devoted to cultivate field crops in new reclaimed sandy soils. In general, under such unfavorable conditions and in soil characterized as low fertile, low organic matter content and high leaching rate thus the production of most crops is not economic and farmers have to apply high rates of chemical fertilizers to maintain satisfactory yield. Improvements in its yield have been established due to a large number of factors. Soil microbial populations are immersed in a framework of interactions, which are known to affect plant fitness and soil quality. Beneficial free-living bacteria in the plant rhizosphere are usually referred as plant growth promoting rhizobacteria (PGPR) which promote the plant growth by means of direct and indirect mechanisms. To rescue plant growth in such stressful conditions, PGPR have been known to play an essential role in the growth and metabolism of plants. Many PGPR contain the enzyme 1-aminocyclopropane -1- carboxylate (ACC) deaminase and promote plant growth by sequestering and cleaving plant produced ACC, the immediate precursor of the plant hormone ethylene and thereby lowering the level of ethylene in the plant. Some microorganisms and the molecules they produce are able to biocontrol plant pathogens by inducing SAR and thus can be defined as biocontrol microorganisms(BCMs) [33]. Some fungal BCMs are able to promote plant growth and development, so acting as PGPMs, that in turn determines a higher tolerance of the plants against abiotic stresses, such as drought and salinity. Both BCMs and PGPMs can be defined as "biostimulant microorganisms", able to foster plant growth and defense against pathogens throughout the crop life cycle, from seed germination to plant maturity. Indeed, BCMs, whose main action is to prevent or inhibit the growth of pathogens by SAR, exercise" indirect" benefits on plant growth by antibiosis based on the production of hydrolytic enzymes or inhibiting substances. These indirect effects have been clarified only in part, and even less is known regarding the "direct" effects of BCMs on the improvement of plant growth through production of siderophores and phytochelatins, which chelate metals and make them available to the roots. The most interesting PGPMs are those able to colonise the rhizosphere. This latter is particularly richin nutrients and supports a microbial population that can exert positive effects on the physiological state of the roots, on the absorption of nutrients and on plant tolerance to environmental stresses. A wide range of abiotic stresses such as flooding, drought, salt, heavy metals and organic contaminants; high and low temperature can induce synthesis of stress ethylene which causes severe damage to the plants and affecting the crop production. ACC deaminase containing PGPR can be exploited as successful strategy for protecting the plants against the deleterious effects caused by these stresses. Amongst the biotic stresses, phytopathogens can reduce crop yield which is an enormous potential loss to crop productivity. Development of superior or novel PGPR strains by improving above traits can be possible using genetic manipulations [34]. These PGPR-biotechnologies can be exploited as a low-input, sustainable and environment-friendly technology for the management of plant stresses. PGPR are able to increase plant tolerance via different mechanisms such as lowering ethylene concentration in plants, producing phytohormones, regulating nutrient uptake, inducing and augmenting stress-response gene expression or the production of antioxidants.

Beneficial effects of drought tolerant *Pseudomonas* strains on drought-stressed maize plants were observed at the morphological and physiological level. Interestingly, antioxidant enzyme activities were lower in bacteria-inoculated plants compared to control plants. This shows that the biochemical response of inoculated plants correspond to a less stressed plant [35]. In wheat, salt-tolerant rhizobacteria induced phenolics and quercetin accumulation leading to an enhancement of plant growth under saline stress [36]. PGPR containing ACC-deaminase can improve maize plant growth under salt stress conditions through better nutrient uptake [37] and exopolysaccharides produced by PGPR allow maize plants to tolerate salt stress by binding Na^+, resulting in a reduced salt uptake by the plant [38]. The bacteria belonging to *Bacillus* spp. are ubiquitous microorganisms, present inthe soil and in the phylloplane, and they are also able to live as endophytes. They have been studied for their antagonistic activity and induction of plant resistance against stresses. In the last years, endophyte isolates of *B. subtilis*, able to control several diseases caused by leaf and soil pathogens, have been identified[39]. Many *Bacillus* isolates can promote plant vegetative development by producing several extracellular substances, so acting as PGPMs. *Paenibacillus polymyxa*, a common soil bacterium, belongs to this group. A range of activities has been found to be associated with *P. polymyxa* treatment, some of which might be involved in plant growth promotion [40].

Most mechanisms proposed to explain indirect growth promotion suggest that the active principle may be a secondary bacterial metabolite that antagonizes pathogens as HCN, side rophores, and antibiotics. *P. polymyxa*is known to produce antibiotic compounds, and inoculation with *P. polymyxa* suppresses several plant pathogens [41]. Inoculation by the PGPR *P. polymyxa* can protect *A. thaliana* against a bacterial pathogen and drought stress in a gnotobiotic system. This effect correlates with an increase in the expression not only of genes associated with biotic stress (*PR-1, HEL,ATVSP*) but also of those associated with drought stress (*ERD15, RAB18*).

In recent years, the induction of the plant defense response by fungi and bacteria that normally colonize living plants without causing visual damage, has received ample attention. Endophytic microorganisms that reside in the intercellular spaces of higher plants can also induce the plant defense response. In some cases, endophytes directly accelerate seedling emergence, promote plant establishment under adverse conditions and enhance plant growth and development [42],[43]. There are many examples of compounds produced as a result of endophyte infection which accumulate to higher levels than normal. In *Hordeum,* both proline and ergot alkaloids have been identified [44]. Microbial elicitors derived from some fungal endophytes promote biomass and induce terpenoid biosynthesis and production in plant suspension cells [45]. As sustainable and renewable agricultural production increases in prominence, endophytic microorganisms will increasingly play important roles and offer environmentally-friendly methods to increase productivity while reducing chemical inputs. A particular attention should be given to endomycorrhizal(*Glomus*spp.) and rhizosphere (*Trichoderma* spp.) coloniser that could allow plants to achieve optimum yields. The SAR represents a valid opportunity in plant natural protection. Therefore, the research activities should be oriented to the use of BCMs as inducers of SAR in agronomically important species against some of their most severe pathogens. *Trichoderma* spp. and *Glomus*spp. are some of the most abundant fungi found in many soil types, able to colonise plant roots and plant debris [46].They are agriculturally and industrially important, being the major source of manycommercial biostimulants and biofungicides. On the contrary, many *Trichoderma* and *Glomus* species are strong BCMs against bacteria, fungi and nematodes, and for this reason more than 60 % of all registered biostimulants used for plant disease control are *Trichoderma*- and/or *Glomus*–based[47].

Trichoderma spp. are also important for their ability to synthesisepeptaibols, a family of peptides with antibiotic function [48]. Their antibiotic functionarises from their membrane-insertion and pore-forming abilities, and it has been shown that peptaibols produced by *T. pseudokoningii* can induce programmed cell death in plant fungal pathogens [49].

Moreover,the crosstalk between the different plant hormones, whose levels change after plantinoculation with PGPMs, results in synergetic or antagonistic interactions that play crucial roles in response of plants to abiotic stress, such as drought, salinity and toxic metals [50]. Thus, plant hormones play central roles in the ability of plants to adapt changing environments by mediating growth, development, nutrient allocation and source/sink transitions.

PGPR-NEMATODES INTERACTIONS

The PGPR-nematodes interactions have been extensively studied with the aim to manage plant-parasitic nematodes. These studies involve the selection of bacteria that can be used as biocontrol agents against nematodes. The genera involved include *Agrobacterium, Alcaligenes, Bacillus, Clostridium, Desulfovibrio, Pseudomonas, Serratia*and *Streptomyces*[51]. These bacteria were characterized for production of hydrolytic enzymes, HCN, phenol oxidation and antifungal activity [52].

Organic fertilizers are safe for both the environment and human health. It is used to improve soil properties making the soil easier to cultivate by encouraging root development, providing plant nutrients and enabling their increased uptake by plants. Abou-Aly and Gomaa (2002) found that dual inoculation of coriander seeds with *Azotobacter* and phosphate solubilizers increased the vegetative growth and photosynthetic characteristics.

CONCLUSION

Environmental stresses which include both abiotic and biotic stresses are the major force that governs the food production in tropics. Drought, high and low temperature, flood, salinity and air pollution are most frequent abiotic stresses which are caused by various environmental factors, and phytopathogens, insect pests, nematodes and weeds act as biotic stresses which affecting the agricultural production. To achieve sustainable crop production to feed growing human population, strategic measures should be taken in management of these environmental stresses. One of the approach/strategy is the application of plant growth promoting rhizobacteria in agriculture. Large-scale application of PGPR to crops as inoculants would be attractive to increase crop yield as it would substantially reduce the use of chemical fertilizers and pesticides, which often pollute environment and contaminate the foodstuffs. Research and field trials of PGPR over decade have opened up new horizons for the agricultural bioinoculants industry. Development of superior or novel PGPR strains with improved plant growth promotion traits and development of transgenic crop plants expressing PGPR gene with increased resistance to various abiotic and

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