Life Sciences: an International Journal (LSIJ) Vol. 1, No. 1, 2023

ROLE OF MICROBIAL TECHNOLOGY IN AGRICULTURE BY IMPROVING SOIL HEALTH, PLANT BROAD-MINDEDNESS, CROP QUALITY AND PRODUCTIVITY FOR SUSTAINING RAPID POPULATION

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ABSTRACT

Presently, soil management strategies (SMS) depend on inorganic chemical fertilizers (IOCFs), which pose a serious threat to human health and the environment. Harnessing beneficial microbes as biofertilizers has become of paramount importance in the agricultural sector because of their potential role in food security and sustainable agricultural production. The eco-friendly approaches inspire a wide range of applications of plant growthpromoting rhizobacteria (PGPRs), Endo and Ectomycorrhizal fungi, cyanobacteria, and many other useful microscopic organisms led to improved nutrient uptake, plant growth, and plant tolerance to abiotic and biotic stress. Exerting soil management strategies are dependent on inorganic chemical-based fertilizers, which cause a serious risk to human health, Soil ecology and the environment. The abuse of advantageous organisms as a biofertilizer has gotten to be of fundamental significance within the agriculture sector for their potential role in food and nourishment security and sustainable crop production. The eco-friendly approaches motivate a wide extent of applications of plant growth-promoting rhizobacteria (PGPRs), endo- and ectomycorrhizal microbes, cyanobacteria, and numerous other valuable microscopic microbes' forms driven to progressed nutrients uptake, plant development, and plant resistance to abiotic and biotic stress. The current manuscript highlighs biofertilizers (BF)PGPRs, mycorrhizae and others useful microbes interceded crops' functional trails characteristics such as plant development and efficiency, nutritional profile, plant defense, and protection with especial accentuation on its trigger-to-trigger different growth and defenece-related genes in signaling systems of cellular pathways to cause a cellular reaction and subsequently crops enhancement. The information picked up from the literature assessed in this will help us to get the physiological bases of biofertilizers towards sustainable agriculture in diminishing issues related to the utilization of chemical fertilizers (CFs).

KEYWORDS

Biofertilizer, Crop Improvement, Environmental stress, Mode of action,Biofertilizers, Sustainable Agriculture

1. INTRODUCTION

Conventional agriculture (CA) plays a key role in fulfilling the growing food needs of a growing human population, resulting in an increasing reliance on chemical pesticides (CPs) and CFs (1).CFs are industrially engineered substances composed of known amounts of nitrogen (N), phosphorus (P) and potassium (K), the use of which leads to air and groundwater pollution through eutrophication of water bodies (2). In this context, recent efforts have focused on producing "nutritious, high-quality food" on sustainable plots to ensure biosecurity. Innovative views on agricultural production have increased the demand for bio-organic fertilizers with no alternatives to pesticides (3). In agriculture, promotion of alternative methods of soil fertilization relies on organic inputs to improve nutrient delivery and protect crop management (4). Organic farming (OF) is one strategy that not only ensures food safety but also contributes to soil biodiversity (5). Further advantages of organic/bio fertilizers include long-term shelf life without negative ecological impacts (6).

Organic farming (OF) is largely dependent on the soil's natural microbiome constituting all kinds of beneficial bacteria and fungi, including arbuscular mycorrhizal fungi (AM fungi) known as plant growth-promoting rhizobacteria (PGPR). Biofertilizers (BF) keep the soil environment rich in all kinds of micro and macro nutrients through nitrogen fixation, dissolution or mineralization of phosphate and potassium, production of antibiotics, release of growth of plants and biodegradation of organic matter in the soil (7). When biofertilizers are used as seeds or soil inoculants, they multiply and participate in nutrient cycling and improve crop yields (8). Normally, 60-90% of the total fertilizer applied is lost and the remaining 10-20% is absorbed by the plants. In this regard, probiotics are of prime importance in integrated nutrient management systems (INMS) to support agricultural productivity and a healthy environment (9). Plant growth-promoting rhizobacteria or their enantiomers can increase the nutrient utilization efficiency of fertilizers. The synergistic interaction of PGPR and AMF was most consistent with 70% fertilizer plus AM fungi and PGPR for P uptake. The same trend was also reflected in tissue-wide N uptake, suggesting that 75%, 80% or 90% fertilizer plus inoculant is significantly equivalent to 100% fertilizer (10-14). Various manuscript is intended to meet the needs of agronomists and plant biologists, whose work is focused on creating clean and efficient ways to improve soil quality by nurturing and maintaining soil systems through natural and beneficial microorganisms. In addition, it presents recent development in field management that demonstrated the potential application of biofertilizers and increase nutrient composition, plant growth and yield, while improving tolerance. with environmental pressure, with special emphasis on bio-fertilizer extraction mechanism.

2. PLANT-MICROBES INTERACTIONS

Plants have complex interactions with various microorganisms found in the soil, including bacteria, fungi, and viruses. Some of these microorganisms form beneficial relationships with plants, providing them with essential nutrients, improving nutrient absorption, promoting growth, and protecting against disease and pests. Microbial biofertilizers (MBF) consist of specific beneficial microorganisms that are applied to plant roots or soil to improve nutrient uptake and delivery such as some strains of nitrogen-fixing bacteria (NFB) can form symbiotic relationships with legumes such as soybean (15-16) and peas, to convert atmospheric nitrogen into a form that plants can use. PGPRs are a group of beneficial bacteria that colonize the rhizosphere around the plant's roots and promote plant growth and productivity. They can stimulate root growth, produce growth promoters, solubilize nutrients, and improve plants' resilience to environmental stresses (ESs). Mycorrhizal fungi form a mutualistic relationship with plant roots, facilitating the absorption of nutrients, especially phosphorus (17). These fungi extend their mycelium into the soil, increasing the surface area for nutrient absorption and transferring nutrients to the plant in exchange for carbohydrates. Some soil microorganisms have the ability to inhibit plant pathogens, thereby reducing disease incidence and severity. These beneficial microorganisms (BMs) can compete with pathogens for resources, produce antimicrobial compounds, or induce plant defense mechanisms. Farmers can adopt practices that promote a diverse and healthy soil microbiome, such as minimizing the use of chemical pesticides and fertilizers, adopting crop rotation and cover cropping, and practicing conservation tillage. These practices create a more favorable environment for BMs to thrive. The utilization of BMs as a seed treatment can improve the establishment and early development of plants. Coating seeds with a microbial cultures provides a favorable environment for seed germination, protects against seed-borne pathogens, and strengthens the plant's immune system. Farmers can adopt practices that promote a healthy and diverse soil microbiome (SMB), such as minimizing the use of chemical pesticides and fertilizers, adopting crop rotations and cover crops as well. as conservation farming practices. These practices create a more favorable environment for the growth of BMs. Technological advances, such as high-throughput DNA sequencing and metagenomics, allow farmers to analyze the composition of the soil microbiome and understand its dynamics. This information can guide the selection of appropriate microbiological interventions and enable targeted management strategies. The microbiome approach to agriculture is a promising area, but it is still evolving. More research is needed to understand the complexities of plant-microbes interactions, optimize microbial formulations, and develop sustainable practices that maximize crop yields while at the same time and maintain soil health and ecosystem balance (15-16, 18-22).

3. RHIZOSPHERE MICROBIAL ORGANISMS TO ENHANCE PLANT GROWTH AND PRODUCTIVITY

The history of human civilization (HC) run parallels to agriculture. The domestication of plants was the first step in the long journey that transformed man from forager searcher to settler. Over the years, however, the man-made effects of conventional agriculture on the soil have been costly. Soil erosion, nutrient depletion and pollution by natural elements, compounds and even xenobiotics have accumulated in the cultivated soil. Agricultural intensification has increased the productive capacity of agro-ecosystems, but has had undesirable environmental consequences, including degradation of land and water resources and alteration of biogeographic chemical cycles (23-24). All of the resource depletion mentioned above is the result of focusing agricultural production on human needs without regard to the health or stability of the soil (19). The importance of soil health and quality in relation to sustainable soil management has been discussed by Prasad (25). When it comes to xenobiotics, a number of chemical pesticides have been shows to be useful in solving many problems affecting human health and food production. However, the use of such pesticides sometimes comes with potential risks to humans and the environment (26).

4. POTENTIAL SIGNIFICANCE OF BENEFICIAL MICROBES IN SUSTAINABLE AGRICULTURE

The rhizosphere, which is the restricted zone of soil encompassing the plant roots, can include up to 10^{11} microbial cells per gram of root (27) and more than 30k prokaryotic species (28) that in general, increase plant efficiency and productivity (28-31). The collective genome of the rhizosphere microbial community (RMC) encompassing plant roots is bigger compared to that of plants and is alluded to as microbiome (32), whose intuitive decide trim well being in common agro-ecosystem by giving various administrations to crop plants such as organic matter deterioration, supplement securing, water assimilation, nutrient recycling, weed control and biocontrol (33). The metagenomic study provide the individual with the core rhizosphere and endophytic microbiomes movement in Arabidopsis thaliana utilizing 454 sequencings (Roche) of 16S rRNA gene amplicons (34). It has been proposed that abusing tailor-made core microbiome exchange treatment in horticulture can be a potential approach in overseeing plant illnesses for diverse crops (35).

In the coming decades, the major focus would be on safe and environmentally friendly methods of harnessing beneficial microorganisms in sustainable agricultural production (36).The physico-chemicalproperties (PCP) of the soil as well as the biodiversity of the soil microbes (SMs), the overall health of the soil, the growth and development of the plants and the crop yields are improved through the inoculation of the microbes (6). Microbial populations (MPs) useful in agriculture include PGPRs, mycorrhizae, beneficial bacteria (BB), N_2-fixing cyanobacteria, stress-tolerant endophytes, and bio-degrading microbes (8). BFs are a complementary component to traditional crop and soil management, namely crop rotation, organic regulation, tillage maintenance, crop residue recycling, fertility restoration. soil fertility and biological control of pathogens and pests, an activity that can be significantly helpful in maintaining sustainability and crop production (6, 37). Nitrogen-fixing bacteria (NFB) such as Azospirillum, *Azotobacter, Cyanobacteria*, *Rhizobium* and phosphorus and potassium solubilizing (PBS) microbes are some of the PGPRs that, in addition to mycorrhiza, have been shown to increase in soil under mínimum tillage treatment (38-41). A considerable amount of nitrogen can be supplied to *Helianthus annuus* by effective strains *of Azotobacter, Azospirillum, Phosphobacter* and *Rhizobacter*. Similarly, in rice, the addition of Azotobacter, *Azospirillum* and *Rhizobium* promotes physiology and improves root morphology (42). *Azotobacter* plays an important role in the nitrogen cycle in nature because it has many metabolic functions (6). In addition to its role in nitrogen fixation (NF), *Azotobacter* is also capable of producing vitamins such as thiamin and riboflavin (43), and plant hormones, namely indole acetic acid (IAA), cytokinins (CK). and gibberellin (GA). *A. chroococcum* improves plant growth (PG) by improving seed germination and promotes root structure (44) by inhibiting pathogenic microorganisms around the root system of plants (45). The genus includes many different species, namely *A. chroococcum, A. vinelandii, A. beijerinckii, A. nigricans, A. armeniacus and A. paspali*. It is used as a biofertilizer for various crops, namely wheat, oats, barley mustard, fennel, rice, flaxseed, sunflower, castor, corn, sorghum, cotton, jute, sugar beet, tobacco, tea, coffee, rubber and coconut (46). *Azospirillum*, which promotes PG and development (47), is one of a group of free-living, gram-mutating, motile bacteria that can survive and thrive under various conditions. Beneficial soil microorganisms (BSM) support agricultural production (AP) as BF (48) or symbiotically (36).

5. CREATING SELF-IMPROVING ABIOTIC AND BIOTIC RHIZOSPHERE SOIL COMPLEXITY

Infertile soil is a very complex system consisting of a matrix of solids, gasses, water and minerals dissolved in pores spaces. Solid substrates contain inorganic particles of different sizes, shapes and chemical properties, as well as a composition of organic matter in different stages of decomposition (49). While the solid substrate (SS) provides physical space, the soil solution contained in the pores is an immediate source of plant nutrients (50). In short, farmland has not only great diversity but also marked physicochemical heterogeneity in pH, water content, hardness, oxygen concentration and nutrient concentration (51). However, this is not a static situation. Although the term "infertile soil" is often associated with the abiotic part, soil is not completely motionless or dormant. Over time, all soils undergo long-term structural and physicochemical changes that lead to the formation of a typical soil profile. In addition, soil properties are constantly changing due to shorter seasonal and environmental changes (EVC), such as changes occurring in soil mass density after freezing and thawing, grain effects, etc. precipitation and soil compaction. On the other hand, while barren soil itself is a very complex and constantly changing entity, living soil is much more complex and fickle. Almost every small part of the earth's surface can be inhabited by living systems. While plant roots, large and small animals, and arthropods are visible the most obvious biota, soil is densely populated with a multitude of diverse microorganisms. Furthermore, although it is difficult to imagine organisms growing anaerobically in the atmosphere, aerobic and anaerobic organisms coexist underground. Of all the subterranean coexisting systems, bacteria represent the largest community of biodiversity. Microbes are unevenly distributed, but form cluster around nutrients and organic matter. It is well established that plant roots and their associated biofilms can strongly influence soil chemistry (52-53), especially in determining availability of nutrients in the soil (54).

Furthermore, roots exert a significant influence on the microbial population living underground. In addition, plants are resistant to potential enemies through the production of antimicrobials, phytotoxins, nematode-killing compounds, and pesticides (55). However, the general trend seems to be to produce organic compounds that can be useful not only to guests but also to uninvited guests (55). In short, the relationship between organisms and roots is complex and highly variable, leading to beneficial, harmful, or neutral effects for a given plant (56).

6. Biofertilizers Exploitation and Nutrients Profile of Agriculture Crops

An important advantage of beneficial microorganisms is their ability to take up and utilize phosphorus, which is available insoluble form and in sufficient quantities in the soil. *Pseudomonas, Bacillus, Micrococcus, Flavobacterium, Fusarium, Sclerotium, Aspergillus* and *Penicillium* have been reported to be active in the solubilization process (57). Similarly, two fungi *Aspergillus fumigatus* and *A. niger* was isolated from rotten cassava husks and found to convert cassava waste into phosphate biofertilizer by a semi-solid fermentation technique (58). *Burkholderia vietnamiensis*, a stress-tolerant bacterium, produces gluconate and 2-ketogluconate involved in phosphate dissolution (59). *Enterobacter* and *Burkholderia* isolated from the rhizosphere of sunflowers were found to produce siderophores and indole compounds (ICs) capable of solubilizing phosphate (60). KSM, such as *Aspergillus, Bacillus,* and *Clostridium*, have been found to be effective in solubilizing K in soil (61). Reciprocal mycorrhizal symbiosis with plant roots satisfies the plant's nutritional needs (62), resulting in improved PG and development and protection against pathogen attack and environmental stress (ESs) (63). This results in the external to internal cortical mycelium uptake of phosphate by the hypha, ultimately transporting phosphate to the cortical root cells (64). Nitrogen-fixing cyanobacteria (NFC) such as *Aulosira, Tolypothrix, Scytonema,* Nostoc, *Anabaena* and *Plectonema* are commonly used as BFs (65-66). Cylindrospermum musicola increases root growth (RG) and rice yield (67).Constitutive expression of the hetR gene driven by a light-inducible promoter enhanced HetR protein expression, resulting in higher nitrogenase activity in *Anabaena* sp. (68).

7. Biofertilizers' Relevance and Plant Tolerance to Environmental Stress

Abiotic and biotic stresses are major constraints affecting crop productivity. Many tools of modern science (MS) are widely used to improve plants under stress, with the role of PGPR as a bioprotectant being of paramount importance in this regard (69). *R. trifolii* inoculated with *T. alexandrinum* showed higher biomass and increased nodule number under salt stress conditions (70). *P. aeruginosa* has been shown to tolerate biotic and abiotic stress (71). Paul and Nair (72)reveled *P. fluorescens* MSP-393 produces osmolytes and salt-stress-induced proteins that overcome the adverse effects of salt. *P. putida* Rs-198 increased the rate of K+, Mg2+, and Ca2+ uptake while decreasing Na+ uptake under alkaline and high-salinity conditions, thereby increasing germination rate and various growth parameters, namely plant growth. (69, 73-74). Several strains of the genus *Pseudomonas* have conferred plant tolerance via 2,4-diacetylphloroglucinol (DAPG) (75). Interestingly, the root fungus *Piriformospora indica* was found to protect host plants from salt stress (76). In one study, inoculation of PGPR alone or in combination with AMs such as *Glomus intraradices* and *G. mosseae* improved nutrient uptake and normal physiological processes in *Lactuca sativa* under conditions of stress. The combination of *A. brasilense* and AM improved plant tolerance to various abiotic stresses (50). The additive effects of *P. putida* or *B. megaterium* and AM fungi were effective in reducing DSs (77). The photosynthetic efficiency and antioxidant response of rice exposed to drought stress were found to increase after inoculation with AM fungi (78-80). Beneficial effects of mycorrhiza have been reported in both drought and saline conditions (29-31, 81).

8. AZOSPIRILLUM-PLANT INTERACTIONS

Considering that salt-stressed plants also suffer from water deficit, inoculation of root seedlings with 10^8 cfu of *A. brasilense* followed by exposure to mild and severe salt stress may contribute to some of the reversed adverse effects has been shown to be reduced. Wheat seedlings inoculated with azospirillum survived up to 320 mM NaCl when he was exposed for 3 days (82). Uniform *T. aestivum*cv. 'Buck Ombú' seedlings (1cm long) were inoculated with *A. brasilense* Sp245 by soaking the roots in a suspension of 10^8cfu ml^{-1} for 3 hours. The inoculum was then replaced with either distilled water, 160 mM NaCl, 320 mM NaCl, 20% PEG 6000, or 30% PEG 6000, and seedlings were grown in a dark growth chamber at 20°C for up to 3 days. rice field. Fresh weight, fresh weight/dry weight, moisture content, and relative moisture content were higher in shoots from inoculated plants than in stressed controls (82). These changes may partially explain the improved crop performance. Indeed, field experiments were performed with his *S. bicolor, Z. maize* inoculated with*A. aestivum* has shown significantly higher yields, accompanied by enhanced water and mineral uptake, reduced canopy temperature, and improved growth and yield (82-83). Early studies of the benefits that plants could achieve after inoculation with *Azospirillum* emphasized the importance of improving plant water status (84-85). In this sense, the *Azospirillum* inoculation technique may be extended to dry soils to protect crops from drought. Since the main action of *Azospirillum* is to promote a more developed radical system, plant adaptation to water stress may be enhanced in inoculated cultures. In this context, experiments on plant response mechanisms to water stress showed significantly higher water content, relative water content, water potential, apoplastic moisture content, and lower cell wall elasticity in drought-stricken *Azospirillum*-inoculated plants. It was shown that the coefficient was achieve. *Azospirillum*-inoculated *T. aestivum*cv. "Pro-INTA Oasis" and grain were clearly 38.4. 22.2 and 125% more Mg, K and Ca than uninoculated plants (82). In any case, it is agreed that the positive effects of *azospirillum* on plants depend on good root colonization. Root colonization (RC) is not only important as the first step in infection by soil-borne pathogens (SBPs), but also in beneficial relationships with microbes. The first event in the colonization process is bacterial attachment to the roots. The interaction of *Azospirillum* with roots is a two-step process consisting of adsorption mediated by bacterial proteins and fixation involving bacterial polysaccharides (82). Chemical attraction, or chemotaxis, of soil microbes to plant roots is a well-understood mechanism involved in triggering plant root-microbes interactions. Bacterium resides mainly on the surface of roots and is present in *A. lipoferum* and some strains of *A. lipoferm, A. brasilense* can colonize the internal apoplast and intercellular spaces of roots, but others cannot. This ability could mean less sensitivity to harsh soil and/or environmental conditions, which in turn could mean more efficient promotion of plant growth (86). In this context, rhizobia that colonize roots in close association with plants are considered endophytes. These microbes live outside the symplast and do not produce nodules, but produce signaling compounds that stimulate plant growth, increase plant resistance to disease, and enhance soil nutrient mobilization.

8.1. Azospirillum 'S Mechanism of Growth Promotion

Besides the BNF mentioned above, several mechanisms have been hypothesized to explain how *Azospirillum* promotes plant growth and development, including phytohormone production and nitrate reduction. However, to date, no clear mechanism has been established that could explain the growth-promoting ability of these bacteria. Rather, the most common hypothesis is that the sum of events is responsible for the overall effect of PG promotion. Genus *Azospirillum* is not considered a classical biocontrol agent against soil-borne plant pathogens (SBPPs). However, there are reports that *A. brasilense* has moderate ability to biologically control crown gall-producing *Agrobacterium*. In addition, *A. brasilense* may limit the growth of other non-pathogenic rhizobacteria. *Azospirillum's* antibacterial activity may be related to its ability to generate known bacteriocins and siderophores (87). Furthermore, it was recently reported that A. brasilense can synthesize phenylacetic acid (PAA), an auxin-like molecule (ALM) with antibacterial activity (ABA). PAA was detected by concentrating the culture supernatant only in the presence of 0.5 mM phenylalanine added to the medium as a precursor molecule. It has also been detected at the onset of secondary metabolism. Widely accepted hypothesis also states that as root surface area increases, so does nutrient uptake over time. From this point of view, PGPR fortification could be an indirect consequence of its effect on root development (88-89). In addition to its physiological activity on root membranes, there is evidence that the fatty acid composition of the major root phospholipids is affected by A. brasilense inoculation (85, 90-94). Although the effects mediated by PGPRs have been fairly well characterized, the underlying signaling mechanisms that these bacteria cause in plants remain to be identified. It was assumed that all effects of *Azospirillum* on plants depended on the plant species and cultivar inoculated and the inoculum concentration used (71). Regarding the latter factor, inoculation of many different plant species with *Azospirillum* resulted in root elongation ranging from 10^6 to 10^8 cells per seedling (82). Furthermore, *Azospirillum*-inoculated tomato roots incubated with NO-specific fluorescent probes showed higher fluorescence intensity compared with uninoculated roots. Fluorescence was mainly localized to vascular tissue and root subepidermal cells (82). Furthermore, treatment of inoculated seedlings with the NO scavenger (4-carboxyphenyl)-4,4,5,5-tetramethylimidazoline-1-oxyl 3-oxide completely reversed this effect, suggesting that azospirillum-induced LRF Induction is believed to be NO dependent. blocked (82)

9. SOIL EROSION AND NUTRIENT LOSS

A study on soil aggregate stabilization (SAS) under field conditions (FCs) was recently published (95). In fact, *Lactuca sativa, L. calcareous* soil containing 10^{10}cfuof *Pseudomonas mendocina* inoculated. In the 'Focea' plants, a clear increase in the proportion of stable aggregates was observed with each application (approximately 84% increase over the control soil). Fertilized and control soils without inoculation had the lowest aggregate stability. The use of inoculants and subsequent fertilization practices to reduce the burden of soil nutrient depletion in cultivated land suggests that a variety of microorganisms may enhance plant uptake of essential macronutrients. (96-102). Several example have been reported of simultaneous growth enhancement and increased phosphorus and nitrogen uptake by plants as a result of inoculation with PSB. Inoculation with two strains of *Rhizobium leguminosum,* selected for their ability to solubilize phosphorus, improved root settlement and growth promotion and significantly increased phosphorus levels in lettuce and maize (96). *R. leguminosumby. trifolii* also increased nitrogen uptake in rice.

10. MYCORRHIZAL FUNGAL BIOFERTILIZER

10.1. AM Fungi for Soil Highway for Nutrient Transfer & Chemical Communication

Mycorrhizal relations involve ∼50,000 taxa of soil fungi and ∼340,000 land plants approximately 70–95% of all species (25, 29-31,103-106). Based on the fisil record and molecular estimases, the evolutionary history of AM fungi originates as far back as 460 million years ago. Four main types of mycorrhizae have been described based on their structure and function: a. The AM fungus has 240 species of Glomeromycota, accounting for <0.5% of the relative abundance of fungal communities found in soil b. Ectomycorrhiza (ECM) - reservad for shrubs and perennials (about 2% of all terrestrial plants), compare to Ericoid mycorrhiza (ERM) - invasive only plants of the family Ericaceae d. Orchid mycorrhizae (ORM) - invades only plants of the Orchidaceae family A single fungus that can connect different plants underground to form a common mycorrhizal network (CMN). CMNs can serve as highways for transferring nutrients and chemical signals between plants. Soil bacteria and other fungi reside in cavities, attracted and nourished by plant secretions and mycelium. Specific plant and root microbial flora facilitate the release of nutrients (N and P) from soil organic matter (29, 91, 107-114).

Mycorrhizae are the connections between fungi and the roots of higher plants. AM fungi must be one of the most amazing things to see under a microscope. With good root staining, the internal and external structures of the host root look very nice. The arbuscules where the magic happens look like little trees inside individual cell. Branched structures form inside the plant cell but the plant's cell membrane remains intact and forms around the arbuscule. Thus, expanding the exchange zone between plants and fungi. The fungus provides the plant with nutrients obtained from its fine network of mycelium in the soil while the plant provides sugar for the fungus to exchange. The mycelium can be seen growing intracellularly in the roots up to the appresoria, where it leaves the roots and spreads into the soil. A large network of mycelium forms around the plant's roots. This network of mycelium can absorb nutrients from soil particles much more efficiently than plant roots alone. This is mainly because the diameter of the mycelium is very small compared to the root hairs. Other mycorrhizal structures include vesicles that are the storage organs of mycorrhizae. Here energy can be stored before being used by mycorrhiza. At the end of the growing season of the annual plant, the energy stored in the vesicles is used to form spores. These spores ensure the survival of mycorrhizae in the soil (91).

10.2. Arbuscular Mycorrhizal Phosphate Acquisition

Phosphate is an essential nutrient and limits PG in many environment (91, 103-116). Phosphate exists in soil in the form of inorganic orthophosphate (Pi), which readily binds with cations, especially under acidic conditions. Of the cations, iron, aluminum and calcium are the most common. The mobility of sequestered phosphate is reduced, resulting in a rapid depletion of available phosphate near the root system upon plant uptake, creating a local depletion zone (115). In modern agriculture, the problem of phosphate limitation is addressed through the widespread use of phosphate additives, with over 4,000,000 tons per year in the US alone (www.fao.org). However, as reserves dwindle, phosphate extraction becomes increasingly difficult and costly. In addition, phosphate uptake efficiency may be as low as 20% (91), and much of the added phosphate will leach into adjacent waterways, adversely affecting the environment. increase. Plants in wild ecosystems have been shown to derive much of their phosphate from mycorrhizal fungi (117). Investigating the current importance and potential future benefits of mycorrhizal colonization on phosphate uptake by crops remains a major focus of current mycorrhizal research.

10.3. AM Fungi Control Agricultural Crops Disease

Plant diseases (PD) can be controlled by engineering natural microbes or by introducing antagonists to reduce disease-causing bacteria (63). AM fungi and their associated interactions with plants mitigate damage caused by plant pathogens (118). Given the rising cost of pesticides and the environmental and public health hazards associated with pathogens resistant to pesticides and chemical pesticides (CP), AM fungi are more suitable and environmentally friendly for sustainable agriculture and forestry. It could be an alternative. Interactions between various AM fungi and plant pathogens vary depending on the host plant and culture system. Moreover, the protective effect of AM vaccination is either systemic or local in nature. Plant parasitic nematodes are found in agricultural soils worldwide and most crops are susceptible to damage by these parasites. Yield losses of up to 50% can occur when host plants are infested with nematodes, and these losses can be exacerbated if the plants are susceptible to other pathogens. Diseases caused by fungal pathogens (FP) persist in the soil matrix and soil surface residues. Root and crown tissue damage is often hidden in the soil. As a result, the disease may go unnoticed until the above-ground parts of the plant are heavily infected. RC by AM fungi reduces the severity of diseases commonly caused by plant pathogens. Less damage to mycorrhizal plants may be due to changes in root growth and morphology. Histopathological changes in host roots. Physiological and biochemical changes within plants. The mycorrhizosphere influences the microbial population. Competition over settlement sites and photosynthesis. Activation of defense mechanisms. and nematode parasitism by AM fungi (25, 31, 100). Of the various mechanisms proposed for biological control of plant diseases, effective defense is the cumulative result of all mechanisms acting individually or together. Challenges in achieving biological control through the use of AM fungi include the essential nature of AM fungi, limited understanding of the mechanisms involved, and the role of environmental factors in these interactions. increase. AM fungi are rarely found in commercial nurseries due to the use of composted soilless media, high levels of fertilizer, and regular application of fungicide solutions. The potential benefits of AM fungi in horticulture, agriculture and forestry are not considered significant in these industries. This perception may be due in part to inadequate methods for large-scale production of the inoculum. Planting sequence, fertilization, and plant pathogen control practices influence both the prevalence of AM fungi in soil and their impact on plants (119). Knowledge of factors such as fertilizer use, pesticide use, and soil management practices that affect AM fungi is essential for the use of AM fungi in sustainable agriculture (119-120). Additionally, effective vaccines should be identified and used as biofertilizers, bioprotectants and biostimulants for sustainable agriculture and forestry.

10.4. AM Fungal Communities Improve Yield Production

Population growth, urban sprawl, and growing interest in using biofuels are putting significant pressure on a portion of high-quality agricultural soils in many countries. Growing cereals and oilseeds such as barley, corn, soybean and wheat has been an important part of the agricultural economy for many years, and the continued rise in demand and prices has led farmers to grow high-intensity crops to: began to adopt agricultural management. Increased production increases crop productivity. Tillage, crop rotation, fallow, varietal rotation, and pesticide application are common practices in large-scale crops, and all these practices have environmental impact (103-114). Fertilizer use is a common agricultural management practice, but there is growing evidence that fertilizer use has many adverse effects on ecosystems. Regardless of the type of fertilizer applied (organic or mineral), conventional agriculture produces large excesses of nitrogen and phosphorus that can lead to phosphorus losses through nitrogen leaching and leaching from the soil profile (121). Not only does this loss result in high economic costs for farmers, this phenomenon also leads to soil contamination. Furthermore, excessive fertilizer application can pose a significant threat to aquatic ecosystems through surface water and groundwater degradation (122). Recently, it has been noted that fertilizer runoff from agricultural lands is one of the causes of cyanobacterial overgrowth and potentially harmful bloom growth, resulting in restricted access to lakes. Low-input farming systems are gaining traction in many developed countries due to growing concerns about conserving natural resources, reducing environmental degradation, and rising fertilizer costs. Conventional cropping systems with reduced fertilizer and pesticide application rates have been developed, but are rarely used in North American cereal production, probably due to a lack of understanding of agricultural soil dynamics (123). Many biological, chemical and physical factors affect soil quality. Among them, the rhizosphere microbial community (RMC) has been shown to directly affect soil fertility by contributing to nutrient cycling (NC) and performing essential processes that improve soil structure and PG and health. (124). Therefore, the extent to which these communities interact is of great importance, and this includes phenomena such as hormone production (HP), enhanced nutrient availability, and reduced root disease. Mycorrhizal symbiosis (MS) has been shown to favor the growth of many crops, mainly due to extensive development of mycelial networks in the soil, more efficient use of nutrients, and improved plant uptake. (117). MS also increases resilience to biotic and abiotic stresses and reduces disease incidence, a key component of sustainable agriculture (124). Proper management of mycorrhizal fungi in agriculture should ultimately lead to significant reductions in chemical consumption and production costs. Soils generally contain natural AM fungi that colonize plant roots (91). Growth promotion and phosphorus uptake in plants colonized by AM fungi are well-known processes (29, 31, 103-114). With the current trend to reduce pesticide use, research is focused on improving crop yield and yield sustainability. This is a promising approach to achieve high yields with low fertilizer use and support sustainable agricultural systems.

10.5. AM Fungi for Sustainable Agriculture

Sustainable agricultural systems (SASs) use natural processes (NPs) to achieve acceptable levels of productivity and food quality (FQ) with minimal negative environmental impact (118). By definitivo, sustainable agriculture (SA) must be ecologically sound, economically viable and socially responsible. Similarly, sustainable forest management (SFM) refers to a holistic approach to environmental protection (EP) that combines the production and planting of trees for useful products, the protection of soil, air, water quality, wildlife and aesthetics. Sustainable agriculture relies on long-term solutions that use proactive rather than reactive system-level measures. Mycorrhizal fungi, especially AM fungi, are ubiquitous in soil and form symbiotic relationships with most terrestrial plants, including agricultural crops, cereals, vegetables and horticultural crops (91). In agriculture, several factors, such as the host plant's dependence on mycorrhizal root colonization (MRC), tillage system, fertilization, and mycorrhizal inoculation (MI) potential, influence plant response and the benefits of mycorrhizae to the plant. Due to their role in promoting plant health and improving soil fertility and soil assemblage stability, there is increasing interest in propagating AM fungi for sustainable agriculture (SA). Effective utilization of these fungi can increase yields while minimizing the use of pesticides and inorganic fertilizers (103-114). The intensive use of CFs, the introduction of organic matter, the use of soil management techniques such as fallow cultivation and the cultivation of legumes can improve soil conditions, improve soil bioactivity and avoid external influences. It has been used to improve crop production in poor soils to optimize nutrient cycling. Minimize input and maximize utilization (125-126). This approach was developed for soil biota management using earthworms and microsymbionts. These soil organisms account for over 90% of soil biological activity and contribute to nutrient cycling, soil fertility, and symbiotic processes in the rhizosphere. The diversity and activity of soil fungi is poorly studied and understood (127). Mycorrhizae constitute an important group as they are widespread and potentially important contributors to plant microbial biomass and soil nutrient cycling processes (128). Mycorrhizal association has beneficial effects on plants and thus on crop productivity for SA (129). These improve the absorption of nutrients, especially P, and also improve the absorption of micronutrients such as zinc and copper. They can stimulate the production of PG substances and reduce stress, disease, or pest infestations (130 -131) Proper use of this technique requires the selection of optimal inoculum cultures adapted to the specific environmental factors that limit plant productivity.

10.6. Mycorrhizal Fungi Tolerance Plant Stress Resilience

Mycorrhizal fungi (MF) facilitate interactions between plants and soil microbiota, which in turn helps promote PG, improve nutrient uptake, and increase resilience to pathogens to biotic and abiotic stresses. Factors that contribute to the increased ability of plants invaded by AM fungi to resist abiotic stresses such as drought and salinity include a. Depletes osmotic pressure by creating accumulation of proline and soluble sugars. b. Increases photosynthetic efficiency by increasing stomatal conductivity and chlorophyll concentration. c. Compared to increase root length and sucker hair density to increase water absorption as well as strigolactone secretion to promote AM symbiosis under water stress conditions. d. Prevent excessive Na+ absorption to maintain ionic homeostasis under the influence of salt. e. Combats oxidative stress by increasing the activity of antioxidant enzymes (AOE) such as CAT, SOD and POD to eliminate ROS. Under biological stress condition (BSC), AM fungi protect host plants against pathogen infection by increasing the systemic defense response (SDR) of the host plant and induces PR gene expression. Increases biosynthesis and secretion of phenols and citrates that repel pathogens and formation of deposits on the cell wall to limit the invasion of mycelium. Expression of ENOD11 and several defense-related genes, as well as root remodeling genes, are upregulated during invasion. This then allows the formation of a pre-permeabilization device or PPA (115). The biology behind the development of arbuscules is unknown, but turning off a gene called vapillin reduces arbuscule growth (132). Many other genes are known to be involved in tree formation, including subtilisin protease 65, phosphate transporter 66, or two ABC transporters 67 (133-134). Nitrogen-fixing genes (NFG) are now commonly used by scientists to create genetically engineered plants that can fix atmospheric nitrogen (FAN). Induction of the nif gene occurs in NFB with low nitrogen and oxygen concentrations in the rhizosphere. Interestingly, sugarcane seedlings inoculated with wild strains of *G. diazotrophicus* showed radioactive N2 fixation compared to *G. diazotrophicus* mutants with nif-D gene mutations, proving the importance of the nif gene. The efficiency of nitrogen fixation depends on the use of carbon (135-136). Bacteria such as *Bacillus subtilis* (UFLA285) can differentially induce 247 genes in cotton plants compared to controls that did not receive PGPR (137). A few disease resistance genes that act through osmotic regulation via jasmonate/ethylene signaling and proline synthesis genes were differentially expressed upon UFLA285 induction (137). Several differentially expressed genes, including metallothionein-like protein type 1, NOD26-like integral membrane protein, ZmNIP2-1, thionin family proteins, oryzalin gamma chain precursor, stress-associated protein 1 (OsISAP1), and probenazole has been identified. Inducible protein PBZ1, auxin- and ethylene-responsive genes (138). The expression of the defense-associated proteins PBZ1 and thionine was found to be repressed in rice H-seropedicae association, suggesting regulation of plant defense responses during establishment (138).

11.CONCLUSION

Environmental constraints are a major problem for declining productivity. Our reliance on CFs and CPs has fueled the growth of industries that produce potentially lethal chemicals that are not only dangerous to humans, but also dangerous to soil ecology, environmentand upset the ecological balance. BFs can help to solve the problem of feeding a growing world population at a time when the agricultural sector is facing a lot of environmental pressures. It is important to recognize the useful aspects of BFs and to implement their uses in modern agricultural practices (MAP). Cutting-edge innovation creates utilizing effective tools of molecular biotechnology can improve biological pathways of phytohormone production. Beneficial PGPRs, mycorrhizae and other microbes can help alleviate environmental stress. However, the lack of awareness of improved protocols for field biofertilizer applications (FBFA) is one of the few reasons to manyeffective PGPRs and microbes remain beyond the reach of conservationists and farmers. Nevertheless, recent technology related to microbiology, plant-pathogen interactions, and genomics can help optimize the required protocols. The success of BFs depends on the invention of innovative strategies regarding the function of PGPRs, other microbes and their appropriate application in the agricultural. The major challenge in this area of research lies in the fact that, in addition to identifying the PGPR strains and their characteristics, dissecting the actual mechanism of action of PGPR to reach the extraction efficiency in agriculture sustainability is essential. Microbes that promote PG in vegetable production (VP) have received little attention from the scientific community. However, several lines of evidence suggest that PGPM can improve crop yields in anthropogenically degraded environments. Overall, they can help reduce the burden of soil nutrient loss in arable land, counteract some of the negative effects of water and salt pressure on crop growth, and help PG and productivity and avoid or minimize the absorption of contaminants along with CFs. In addition, common practices in VP are soil sun drying, transplanting, sample seeding, drip irrigation combined with fertilizing and the use of soilless supports. All of this can be improved by using PGPM. New evidence has elucidated the mechanism of PG promotion induced by useful bacterium and fungi. Research needs to be conducted in different localities in different parts of the world and with different soil types to validate the beneficial impact of PGPR and AM fungi on soil fertility, PG, productivity and develop fact-based recommendations for its use in worldwide. Additionally field trials on other plant species and soil types are also needed to fully understand the benefits of this microbial technology. Lastly, carbon flow in soil plant systems treated with PGPR and AM fungi are needed to fully determine their effect on the physico-chemical properties of soils and environment.

RECOMMENDATION

SH plays an important role in the ability of plants to produce food, fuel and fiber for the growing world population. The efficient and diverse adoption of soil microbiota supported by these new technologies can facilitate and promote sustainable agriculture and can effectively contribute to meet the triple requirements of economic, social and environmental sustainability.

REFERENCES

[1] Santos VB, Araujo SF, Leite LF, Nunes LA & Melo JW. (2012) Soil microbial biomass and organic matter fractions during transition from conventional to organic farming systems. Geoderma. 70: 227-231.

[2] Youssef MMA & Aissa MFM. (2014) Biofertilizers and their role in management of plant parasitic nematodes. A review. E3 J Biotechnol. Pharm Res. 5: 1-6.

[3] Raja N. (2013) Biopesticides and biofertilizers: ecofriendly sources for sustainable agriculture. J Biofertil Biopestici. 2013, 1000e112: 1000e112.

[4] Araujo ASF, Santos VB & Monteiro RTR.(2008) Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piauistate, Brazil. Eur J Soil Biol. 2008, 44: 225-230.

[5] Megali L, Glauser G & Rasmann S. (2013) Fertilization with beneficial microorganisms decrease tomato defenses against insect pests. Agron Sustain Dev. doi:10.1007/s13593-013-0187-0.

[6] Sahoo RK, Ansari MW, Pradhan M, Dangar TK, Mohanty S & Tuteja N. (2014) Phenotypic and molecular characterization of efficient native Azospirillum strains from rice fields for crop improvement. Protoplasma. doi:10.1007/s00709-013-0607-7

[7] Sinha RK, Valani D, Chauhan K & Agarwal S. (2014) Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: reviving the dreams of Sir Charles Darwin. Int J Agric Health Saf. 1: 50-64.

[8] Singh JS, Pandey VC & Singh DP. (2011) Efficient soil microorganisms: a new dimension for sustainable agriculture and environment development. Agric Ecosyst Environ. 140: 339-353.

[9] Adesemoye AO & Kloepper JW (2009) Plant-microbes interactions enhanced fertilizer-use efficiency. Appl Microbiol Biotechnol. 2009, 85: 1-12.

[10] Adesemoye A, Torbert H & Kloepper J. (2009) Plant growth promoting Rhizobacteria allow reduced application rates of chemical fertilizers. Microbial Ecology 58 (4): 921-929.

[11] Prasad, K., Khare, A &RawatP. (2021) Quality and Yield Performance of Turmeric (*Curcuma longa* linn.) in Response to Glycoprotein Producing Arbuscular Mycorrhizal Fungal Biostimulant and Traditional Fertilizers Utilization. Current Investigations Agriculture and Current Research. 9(5) 1291-1298.

[12] Prasad K., Khare, A & Rawat P. (2021). Microbial Functions Improve Agricultural Soil Health, Quality Productivity and Environmental Sustainability for Future Generation. Gulf Journal of Molecular Biology (Gjmb) 1(1): 24-37.

[13] Prasad, K., Khare, A & Rawat P. (2021) Glycoprotein Producing AM Fungi Intensification Organic Carbon and Alteration Microbial Community in Rhizosphere Ecosystem, Potential Utilization for

Crops Improvement and Changing Global Environment towards Sustainable Development. Aditum Journal of Clinical and Biomedical Research. 3(1):1-16.

[14] Prasad K, Khare A & Rawat P. (2022) Glomalin Arbuscular Mycorrhizal Fungal Reproducción, Lifestyle and Dynamic Role in Global Sustainable Agriculture for Future Generation. In: Fungal Reproduction and Growth. Intech Open. Pp1-22.

[15] Prasad K & Meghavanshi MK. (2005) Interaction between indigenous Glomus fasciculatum (AM fungus) and Rhizobium and their stimulatory effect on growth, nutrient uptake and nodulation in *Acacia nilotica* (L.) Del. Flora and Fauna 11(1): 51-56.

[16] Prasad K, Meghavanshi MK, Harwani D, Mahna SK & Werner D. (2005) Synergistic effect of arbuscular mycorrhizal fungi and *Bradyrhizobium japonicum* on growth, yield and nutrient status of soybean [Glycine max (L.) Merrill] Anusandhan 1(1):13-19.

[17] Prasad, K. (202l) Growth and Yield Response of Indica Paddy Cultivars Cultivated Through Organic Agriculture System of Paddy Intensification and Conventional Technique under Wetland Conditions in East Uttar Pradesh, India. International Journal of Scientific Engineering and Applied Science (IJSEAS) 8(5):109-128.

[18] Prasad K & Meghavanshi MK. (2009) Legume Rhizobia Technology: Aspects and Prospects. Amravati University Research Journal IV (1):1-13.

[19] Prasad K & Pandey AK. (2012) Mycorrhizal symbiosis: A new dimension for agriculture and environmental development to improve production in sustainable manner. In: Bagyaraj DJ, Tilak KVBR, Kehri HK. eds. Microbial Diversity and Function. New Delhi, New India Publishing Agency, New Delhi, India pp389- 402.

[20] Prasad K, Warke RV & Khadke K. (2019) Management of soilborne pathogens to improve productivity of pulses using organic technologies for sustainable agriculture. International Journal of Research and Analytical Review 6(2): 82-101.

[21] Prasad K & Warke RV. (2018) Arbuscular mycorrhizal fungi plays a promising role towards green technology and soil health Management, In: Plant and soil health management: New Challenges and Opportunity, ICAR- Indian Institute of Pulse Research, Kanpur, ppules192.

[22] Prasad K&Warke RV. (2018) Biology, diversity and promising role of microbial inoculation especially mycorrhizae in agriculture and natural ecosystems to improve productivity for sustainable development In: Vishnoi VK. ed. Microbial inoculants for agriculture and environmental sustainability, National Conference, GKV, Haridwar, pp. 7-8.

[23] Gautam, SP & Prasad K. (2001) VA mycorrhiza Importance and biotechnological application. In: Maheshwari DK and Dubey RC eds. Innovative Approaches in Microbiology. Bishon Singh Mahendra Pal Singh, Dehradun, India, Pp83-114.

[24] Abou-Shanab RA, Ghanem K, Ghanem N & Al-Kolaibe A. (2008) The role of bacteria on heavy-metal extraction and uptake by plants growing on multi-metal-contaminated soils. World J. Microbiol. Biotechnol. 24: 253-262.

[25] Prasad K. (2017) Biology, Diversity and Promising Role of Mycorrhizal Entophytes for Green Technology. In: Maheshwari DK ed. Endophytes: Biology and Biotechnology, Vol-1, Series Sustainable Development and Biodiversity 15. Springer International Publishing AG, Switzerland, pp267- 301.

[26] Menjivar RD, Cabrera JA, Kranz J & Sikora RA. (2012) Induction of metabolite organic compounds by mutualistic endophytic fungi to reduce the greenhouse whitefly *Trialeurodes vaporariorum* (Westwood) infection on tomato. Plant Soil. 352: 233-241.

[27] Egamberdieva D, Kamilova F, Validov S, Gafurova L, Kucharova Z & Lugtenberg B. (2008) High incidence of plant growth stimulating bacteria associated with the rhizosphere of wheat grown on salinated soil in Uzbekistan. Environ Microbiol. 10: 1-9.

[28] Mendes R, Garbeva P & Raaijmakers JM. (2013) The rhizosphere microbiome: significance of plant beneficial plant pathogenic and human pathogenic microorganisms. FEMS Microbiol Rev. 37: 634-663.

[29] Prasad K. (2013) Arbuscular mycorrhizal fungus plays a major role in agriculture and natural ecosystems to improve production in sustainable manner. In: Jamaluddin, Singh AK Eds. Microbes and Sustainable Plant Productivity. Scientific Publication (India) Jodhpur, India, pp113-138.

[30] Prasad K (2015) Biofertilizers: A new dimensión for agriculture and environmental development to improve production in sustainable manner. Journal of Basic and Applied Mycology 11 (1& II): 5-13.

[31] Prasad K. (2020) Positive Importance of Arbuscular Mycorrhizal fungi for global Sustainable Agriculture and Environment Management for green technology. Current Investigations in Agriculture and Current Research 9(2): 1182- 1184.

[32] Bulgarelli D, Schlaeppi K, Spaepen S, Loren V, van Themaat E & Schulze-Lefert P. (2013) Structure and functions of the bacterial microbiota of plants. Annu Rev Plant Biol. 64: 807-838.

[33] Berg G, Zachow C, Müller H, Phillips J & Tilcher, R. (2013) Next-generation bio-products sowing the seeds of success for sustainable agriculture. Agronomy. 3: 648-656.

[34] Hirsch PR & Mauchline TH. (2012) Who’s who in the plant root microbiome? Nat Biotechnol. 30: 961-962.

[35] Gopal M, Gupta A & Thomas GV. (2013) Bespoke microbiome therapy to managed plant diseases. Front Microbiol. 5: 15-18.

[36] Nina K, Thomas WK & Prem SB. (2014) Beneficial organisms for nutrient uptake. VFRC reports 2014/1, virtual fertilizer research center. 2014, 63-Washington, DC: Wageningen Academic Publishers.

[37] AnjumMA, Sajjad MR, Akhtar N, Qureshi MA, Iqbal A, Jami AR & Mahmud-ul-Hasan (2007) Response of cotton to plant growth promoting Rhizobacteria (PGPR) inoculation under different levels of nitrogen. Journal of Agricultural Research 45 (2):135-143.

[38] Antoun H, Beauchamp CJ, Goussard N, Chabot R & Lalande R. (1998) Potential of Rhizobium and Bradyrhizobium species as plant growth promoting rhizobacteria on non-legumes: Effect on radishes (*Raphanussativus* L). Plant and Soil 204 (1): 57-67.

[39] Barriuso J, Solano BR, Lucas JA, Lobo AP, Villaraco AG & Manero FJG. (2008) Ecology, Genetic Diversity and Screening Strategies of Plant Growth Promoting Rhizobacteria (PGPR). Ahmad I, Pichtel J, Hayat S, eds. WILEYVCH VerlagGmbH& Co. KGaA, Weinheim, pp1-17.

[40] Dogan K, KamailCelik I, Mustafa Gok M & Ali C. (2011) Effect of different soil tillage methods on rhizobial nodulation, biyomas and nitrogen content of second crop soybean. Afr J Microbiol Res. 5: 3186-3194.

[41] Ane JM, Kiss GB, Riely BK, Penmetsa RV, Oldroyd GE, Ayax C, Levy J, Debelle F, Baek JM, Kalo P, Rosenberg C, Roe BA, Long SR, Denarie J &CookDR. (2004) Medicago truncatula DMI1required for bacterial and fungal symbioses in legumes. Sci. 2004, 303: 1364-1367.

[42] Choudhury MA &Kennedy IR. (2004) Prospects and potential for system of biological nitrogen fixation in sustainable rice production. BiolFertil Soils. 39: 219-227.

[43] Revillas JJ, Rodelas B, Pozo C, Martinez-Toledo MV & Gonzalez LJ. (2000) Production of B-Group vitamins by two Azotobacter strains with phenolic compounds as sole carbon source under diazotrophicand adiazotrophic conditions. J Appl Microbiol. 89: 486-493.

(44) Gholami A, Shahsavani S &Nezarat S. (2009) The Effect of Plant Growth Promoting Rhizobacteria (PGPR) on Germination seedling Growth and Yield of Maize. Int J Biol Life Sci. 5: 1-11.

[45] Mali GV, Bodhankar MG. (2009) Antifungal and phytohormone production potential of *Azotobacter chroococcum* isolates from Groundnut (*Arachis hypogea* L.) rhizosphere. Asian J ExpSci. 23: 293-297.

[46] Wani SA, Chand S & Ali T. (2013) Potential use of *Azotobacter chroococcum* in crop production: an overview. Curr Agric Res J. 1: 35-38.

[47] Bhattacharyya PN &Jha DK. (2012) Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World J Microbiol Biotechnol. 28: 1327-1350.

[48] Sahoo RK, Bhardwaj D & Tuteja N. (2014) Biofertilizers: a sustainable eco-friendly agricultural approach to crop improvement. Plant Acclimation to Environmental Stress. Eds: Tuteja N, Gill SS. 2013b, 403-432. LLC 233 Spring Street, New York, 10013, USA: Springer Science plus Business Media

[49] Egamberdiyeva D. (2005) Plant-growth promoting rhizobacteria isolated from a Calcisol in a semiarid region of Uzbekistan: biochemical characterization and effectiveness. Journal of Plant Nutrition and Soil Science 168 (1): 94-99.

[50] Joe MM, Jaleel CA, Sivakumar PK, Zhao CX & Karthikeyan B. (2009) Co-aggregation in *Azospirillum brasilensense* MTCC-125 with other PGPR strains: Effect of physical and chemical factors and stress endurance ability. J Taiwan InstChemEngg. 40: 491-499.

[51] Weller DM, Mavrodi DV, van Pelt JA, Pieterse CM, van Loon LC & Bakker PA. (2012) Induced systemic resistance in Arabidopsis thaliana against Pseudomonas syringae pv. tomato by 2, 4-diacetylphloroglucinol-producing *Pseudomonas fluorescens*. Phytopathology. 102: 403-412.

[52] Higa T. (1994) Effective Microorganisms: A new dimension for Nature Farming. In: Parr JF, Hornick SB, Simpson ME. eds. Proceedings of the Second International Conference on Kyusei Nature Farming. U.S. Department of Agriculture, Washington. D.C., USA, pp20-22.

[53] Warke RV, Prasad K & Khadke K. (2018) Impact of arbuscular mycorrhizal fungi (ROC-WA329) and phosphate solubilizing bacteria (WA302) on *Zea Mays* cultivated at Satara district of Maharashtra, India, In: Plant and soil health management: New Challenges and Opportunity, ICAR-Indian Institute of pules Research, Kanpur, p179

[54] Sieberer BJ, Chabaud M, Timmers AC, Monin A, Fournier J & Barker DG. (2009) A nuclear-targeted cameleon demonstrated intranuclear Ca2+ spiking in *Medicago truncatula* root hairs in response to rhizobial nodulation factors. Plant Physiol. 151: 1197-1206.

[55] Bais HP, Prithiviraj B, Jha AK, Ausubel FM & Vivanco JM. (2005) Mediation of pathogen resistance by exudation of antimicrobials from roots. Nature 434:217–221.

[56] Murphy JF, Zehnder GW, Schuster DJ, Sikora EJ, Polstan JE & Kloepper JW. (2000) Plant growth promoting rhizobacteria mediated protection in tomato against tomato mottle virus. Plant Dis. 84: 79-84.

[57] Pindi PK & Satyanarayana SDV. (2012) Liquid microbial consortium- a potential tools for sustainable soil health. J Biofertil Biopest. 3: 4-8.

[58] Ogbo FC. (2010) Conversion of cassava wastes for biofertilizer production using phosphate solubilizing fungi. Bioresour Technol. 101: 4120-4124.

[59] Park J, Bolan N, Megharaj M & Naidu R. (2010) Isolation of Phosphate-Solubilizing Bacteria and characterization of their Effects on Lead Immobilization. Pedologist. 53: 67-75.

[60] Ambrosini A, Beneduzi A, Stefanski T, Pinheiro F, Vargas L & Passaglia L. (2012) Screening of plant growth promoting Rhizobacteria isolated from sunflower *Helianthus annuus* L. Plant & Soil. 356: 245-264.

[61] Mohammadi K & Yousef Sohrabi Y. (2012) Bacterial Biofertilizers for sustainable crop production: A review. J Agric BiolSci. 7: 307-316.

[62] Kogel KH, Franken P& Huckelhovenl R (2006) Endophyte or parasite- what decides. Curr Opin Plant Biol. 9: 358-363.

[63] Lamabam PS, Gill SS & Tuteja N. (2011) Unraveling the role of fungal symbionts in plant abiotic stress tolerance. Plant Signal Behav. 6: 175-191.

[64] Smith, SE & Read DJ. (1997) Mycorrhizal Symbiosis. 2nd Edition, Academic Press, London.

[65] Ashrafuzzaman M, Hossen FA, Ismail MR, Hoque MA, Islam MZ, Shahidullah SM&Meon S. (2009) Efficiency of plant growth- promoting Rhizobacteria (PGPR) for the enhancement of rice growth. African Journal of Biotechnology 8 (7):1247- 1252.

[66] Roy M, Srivastava RC. (2013) Assembling BNF system in rice plant: frontier areas of research. Curr Sci. 104: 3-10.

[67] Venkataraman GS &Neelakantan S. (1967) Effect of cellular constituents of nitrogen fixing blue-green algae. *Cylindrospermum nusciola* on the root growth of rice seedlings. J General Appl Microbiol. 13: 53-61. 10.2323/jgam.13.53.

[68] Chaurasia AK &Apte SK. (2011) Improved eco-friendly recombinant Anabaena sp. strain PCC7120 with enhanced nitrogen biofertilizer potential. Appl Environ Microbiol. 77: 395-399.

[69] Yang JW, Kloepper JW &Ryu CM. (2009) Rhizosphere bacteria help plants tolerate abiotic stress. Trends Plant Sci. 14: 1-4.

[70] Antoun H & Prevost D (2005) Ecology of plant growth promoting rhizobacteria. PGPR: Biocontrol and Biofertilization. Edited by: Siddiqui ZA. Dordrecht: Springer, pp1-38.

[71] Pandey PK, Yadav SK, Singh A, Sarma BK, Mishra A & Singh HB (2012) Cross-Species Alleviation of Biotic and Abiotic Stresses by Endophyte Pseudomonas aeruginosa PW09. J Phytopathology. 160: 532-539.

[72] Paul D & Nair S. (2008) Stress adaptations in a plant growth promoting Rhizobacterium (PGPR) with increasing salinity in the coastal agricultural soils. J Basic Microbiol. 2008, 48: 1-7.

[73] Vessey JK. (2003) Plant growth promoting rhizobacteria as biofertilizers. Plant and Soil 255 (2): 571–586.

[74] Whitelaw MA, Harden RJ &Helyar KR. (1999) Phosphate solubilization in culture by the soil fungus *Penicillium r*adicum. Advances in Agronomy 31:655-665.

[75] Schnider-Keel U, Seematter A, Maurhofer M, Blumer C, Duffy B, Gigot-Bonnefoy C, Reimmann C, Notz R, Defago G, Haas D &Keel C. (2000) Autoinduction of 2, 4-diacetylphloroglucinol

biosynthesis in the biocontrol agent Pseudomonas fluorescens CHA0 and repression by the bacterial metabolite's salicylate and pyoluteorin. J Bacteriol. 182: 1215-1225.

[76] Ansari MW, Trivedi DK, Sahoo RK, Gill SS & Tuteja N. (2013) A critical review on fungi mediated plant responses with special emphasis to Piriformospora indica on improved production and protection of crops. Plant Physiol Biochem.70: 403-410.

[77] Marulanda A, Barea JM &Azcon R. (2009) Stimulation of Plant Growth and Drought Tolerance by Native Microorganisms (AM Fungi and Bacteria) from Dry Environments: Mechanisms Related to Bacterial Effectiveness. J Plant Growth Regul. 28: 115-124.

[78] Ruiz-Sanchez M, Aroca R, Munoz Y, Polon R & Ruiz-Lozano JM. (2010) The arbuscular mycorrhizal symbiosis enhances the photosynthetic efficiency and the antioxidative response of rice plants subjected to drought stress. J Plant Physiol. 167: 862-869.

[79] Prasad K. (2022) Growth and Yield Response of Indica Paddy Cultivars Cultivated Through Organic Agriculture System of Paddy Intensification and Conventional Technique under Wetland Conditions in East Uttar Pradesh, India. International Journal of Scientific Engineering and Applied Science (IJSEAS) – 8(5): 109-128.

[80] Prasad K. (2022) Utilization of Siderophore Producing Plant Growth Promoting Rhizobacteria to Improve Crucial Nourishment and Management of Phytopathogen in Cash Crops for Sustainable Development. American Journal of Sciences and Engineering Research. 5(2):15-23.

[81] Aroca R, Ruiz-Lozano JM, Zamarreno AM, Paz JA, García-Mina JM, Pozo MJ & Lopez-Raez JA. (2013) Arbuscular mycorrhizal symbiosis influences strigolactone production under salinity and alleviates salt stress in lettuce plants. J Plant Physiol. 170: 47-55.

[82] Creus CM, Graziano M, Casanovas EM, Pereyra MA, Simontacchi M & Puntarulo S. (2005) Nitric oxide is involved in the Azospirillum brasilense-induced lateral root formation in tomato. Planta. 221: 297-303.

[83] Okon Y & Labandera-Gonzalez CA. (1994) Agronomic applications of Azospirillum. In: Ryder MH, Stephens PM, Bowen GD, eds. Improving plant productivity with rhizosphere bacteria. Commonwealth Scientific and Industrial Research Organization, Adelaide, Australia, Eds. pp274–278.

[84] Bar-Ness E, Hadar Y, Chen Y, Shanzer A & Libman J. (1992) Uptake by plants from microbial siderophores-A study with 7-nitrobenz-2-oxa-1,3-diazole-dessferrioxamine as fluorescent ferrioxamine b-analog. Plant Physiol. 99: 1329–1335.

[85] Parr JF & Hornick SB. (1994) Assessment of the Third International Conference on Kyusei Nature Farming: Round GULF JOURNAL OF MOLECULAR BIOLOG Table Discussion by USDA Scientists, October 7, 1993. Published by the Nature Farming Research and Development Foundation, Lompoc, California, USA.

[86] Farzana Y, Saad ROS & Kamaruzaman S. (2009) Growth and storage root development of sweet potato inoculated with rhizobacteria under glasshouse conditions. Australian Journal of Basic and Applied Sciences 3(2): 1461-1466.

[87] Stefan M, Mihasan M &Dunca S. (2008) Plant growth promoting Rhizobacteria can inhibit the in vitro germination of *Glycine Max* L seeds. Scientific Annals of University Alexandru Ioan Cuza Iasi, Section Genetics and Molecular Biology T. IX, 3: 105-110.

[88] Yasmin F, Othman R, Saad MS &Sijam K. (2007) Screening for beneficial properties of Rhizobacteria isolated from sweet potato rhizosphere. Journal of Biotechnology 6 (1): 49-52.

[89] Zaidi Khan MS, Ahemad M & Oves M. (2009) Plant growth promotion by phosphate solubilizing bacteria. Acta Microbiologicaet Immunologica Hungarica 56(3):263-284.

[90] Garcia JL, Probanza A, Ramos B & Manero FJG. (2001) Ecology, genetic diversity, and screening strategies of plant growth promoting rhizobacteria. Journal of Plant Nutrition and Soil Sciences 164:1-7.

[91] Prasad K. (1993) Studies on ecological factors affecting vesicular arbuscular mycorrhizal infection in Sugarcane. Ph.D. Thesis, B.R. Ambedkar Bihar University, Muzaffarpur, Bihar, India

[92] Prasad K. (1998) Effect of Glomus fasciculatum VAM form and Rhizobium on biomass yield and nutrient uptake of *Dalbergia sissoo* L. Journal of Tropical Forestry 14(111):143-148.

[93] Prasad K. (2000) Growth responses of Acacia nilotica (L.) Del. inoculated with Rhizobium and *Glomus fasciculatum* VAM fungi. Journal of Tropical Forestry 16(1): 22-27.

[94] Prasad K. (2000) Occurrence of vesicular-arbuscular mycorrhizal fungi in some cultivated crop plants. In: Microbes: Agriculture, Industry, and Environment. D. K. Maheshwari, R. C. Dubey, G. Prasad, and Navneet (eds.), Bishen Singh Mahendra Pal Singh Publishers, Dehra Dun, pp 5-69.

[95] Kohler J & Caravaca F. (200) An AM fungus and a PGPR intensify the adverse effects of salinity on the stability of rhizosphere soil aggregates of Lactuca sativa Roldan. Soil Biol Biochem. 2010, 42: 429-434.

[96] Rahimzadeh S & Pirzad A. (2019) Pseudomonas and mycorrhizal fungi coinoculation alter seed quality of flax under various water supply conditions. Industrial Crops and Products, 129:518-524.

[97] Prasad K & Deploey JJ. (1999) Incidence of arbuscular mycorrhizae and their effect on certain species of trees. Journal of the Pennsylvania Academy of Science 73 (3): 17-122.

[98] Prasad K. (2022) Influence of PGPR, AM Fungi and Conventional Chemical Fertilizers Armament on Growth, Yield Quality, Nutrient's translocations, and Quercetin Content in Onion Crop Cultivated in Semi-Arid Region of India. *Open Access Journal of Microbiology & Biotechnology (OAJMB)*: 7(1): 1-18.

[99] Prasad K. (2022) Productivity and Quality of Horticultural Crop Capsicum (Capsicum Annum L) Through Co-Inoculation of Novel Microbial Consortium Plant Growth Promoting Rhizobacteria, Glycoprotein Producing AM Fungi and Chemical Fertilizer under Low-Cost Protected Cultivation. Open Access Journal of Microbiology & Biotechnology *(OAJMB)*. 7(2):1-18.

[100] Prasad K. (2022) Potential Impression of Arbuscular Mycorrhizal Fungi on Agricultural Growth, Productivity, and Environment Towards Global Sustainable Development for Green Technology. In: *Applied Mycology*. Springer Nature, Switzerland AG. A. C. Shukla (ed.), pp. 111-136.

[101] Prasad K. (2022) Glycoprotein Producing AM Fungi Lifestyle and Energetic Role in Global Sustainable Agriculture to Green Technology for Future Generation. 7th Asian PGPR International Conference for Sustainable Agriculture held in Kuala Lumpur, Malaysia on 23-26 August 2022. Pp.120-121.

[102] Prasad K. (2011) Effect of Glomus intraradices AM fungi on the shoot dry matter, seed dry yield, and nitrogen and phosphorus uptake of soybean (*Glycine max* (L.) Merrill) inoculated with cultivar specific Bradyrhizobium japonicum. Mycorrhiza News 23(3): 13-18.

[103] Prasad K. (2010) Ectomycorrhizal Symbiosis: Possibilities and Prospects In Progress in Mycology, Rao MK, Kovices G (Eds), Springer Science, The Netherlands and Scientific Publisher, Jodhpur, India pp290-308.

[104] Prasad K. (2021) Arbuscular mycorrhizal fungi and plant collaborations influences ecology and environmental changes for global sustainable development. Journal of Ecology and Natural Resources 5(1): 1-16.

[105] Prasad K. (2021) Diversification of Glomermycota form arbuscular mycorrhizal fungi associated with vegetable crops cultivated underneath natural ecosystems in arid region of Rajasthan, India. Current Investigations in Agriculture and Current Research 9(2): 1205-1212.

[106] Prasad K. (2021) Glycoprotein Producing AM Fungi life cycle and Potential Role in Agricultural Plant Lifespan and Global Environmental Changes for Sustainable Green Technology. *Journal of Ecology and Natural Resources*. 5 (2): 1-18.

[107] Prasad K. (2021) Effect of dual inoculation of arbuscular mycorrhiza fungus and cultivar specific Bradyrhizobium japonnicum on the growth, yield, chlorophyll, nitrogen and phosphorus contents of Soybean (*Glycine max* (L.) Merrill.) grown on Alluvial Soil. Journal of Innovation in Applied Research 4(1): 1-12.

[108] Prasad K. (2021) Impact of biological fertilizer arbuscular mycorrhizal fungi and conventional fertilizers mobilization on growth, yield, nutrients uptake, quercetin and allin contents in allium crops cultivation under field conditions in semi-arid region of India. South Asia Journal of Experimental Biology 11 (1):15-26.

[109] Prasad K. (2021) Influence of arbuscular mycorrhizal fungal biostimulants ad conventional fertilizers on some solanaceous crops for growth, productivity, and nutrient stoichiometry under field conditions in semi- arid region of Maharashtra, India. Journal of Experimental Biology and Agricultural Sciences 9(1):75-86.

[110] Prasad K. (2021) Potential Impact of Seed Coating with Beneficial Microorganisms to Meticulousness Sustainable Organic Agriculture for Quality Nutritive Food Production for Modern Lifestyle, Improve Global Soil and Environmental Health towards Green Technology. Aditum Journal of Clinical and Biomedical Research. 2(4):1-9.

[111] Prasad K. (2021) Stimulation Impact of Rhizosphere Microbe's Glomeromycota AM Fungi and Plant Growth Promoting Rhizobacteria on Growth, Productivity, Lycopene, B-Carotene, Antioxidant Activity and Mineral Contents of Tomato beneath Field Condition Cultivated in

Western Ghats Covering Semi-Arid Region of Maharashtra, India. Journal of Bioscience & Biomedical Engineering. 2(3): 1-14.

[112] Prasad K. (2022) Stimulation Effect of Rhizospheric Microbes' Plant Growth Promoting Rhizobacteria. Glycoprotein Producing AM Fungi and Synthetic Fertilizers Application on Growth, Yield, Nutrient's acquisition and Alliin Content of Garlic Cultivation Under Field Conditions in Southeast Region of Rajasthan, India. Advances in Earth and Environmental Science. 3(2): 1-15.

[113] PrasadK. (2022) Potential Impression of Arbuscular Mycorrhizal Fungi on Agricultural Growth, Productivity, and Environment Towards Global Sustainable Development for Green Technology. In: Applied Mycology, Fungal Biology, Shukla, AC (ed.), Springer Nature Switzerland AG, pp. 111-136.

[114] Prasad K. (2022) Influence of PGPR, AM Fungi and Conventional Chemical Fertilizers Armament on Growth, Yield Quality, Nutrient's translocations, and Quercetin Content in Onion Crop Cultivated in Semi-Arid Region of India. Open Access Journal of Microbiology & Biotechnology. 7(1):1-18

[115] Bucher M, Wegmüller S & Drissner D. (2009) Chasing the structures of small molecules in arbuscular mycorrhizal signalling. Curr Opin Plant Biol. 12: 500-507.

[116] Cordell D, Drangert JO & White S. (2009) The story of phosphorus: global food security and food for thought. Global Environmental Chang 19:292-305.

[117] Smith S, Lakobsen I, Gronlund M & Smith FA. (2011) Roles of arbuscular mycorrhizas in plant phosphorus nutrition: interactions between pathways of phosphorus uptake in arbuscular mycorrhizal roots have important implications for understanding and manipulating plant phosphorus acquisition. Plant Physiol. 156: 1050-1057.

[118] Harrier LA & Watson CA. (2004) The potential role of arbuscular mycorrhizal (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or other sustainable farming systems. Pest Manag Sci 60(2):149-57.

[119] Bethlenfalvay GJ & Linderman RG. (1992) Mycorrhizae in Sustainable Agriculture. American Society of Agronomy Special Publicación No. 54. American Society of Agronomy, Madison, Wisconsin, USA. 124 p.

[120] Allen MF. (1991) The Ecology of Mycorrhizae. Cambridge University Press, Cambridge. Pp184.

[121] Brady NC & Weil RR. (2002) The Nature and Properties of Soil. 13th Edition, Prentice Hall, Upper Saddle River, New Jersey.

[122] Kirchmann, H & Thorvaldsson G. (2000) Challenging Targets for Future Agriculture. European Journal of Agronomy, 12, 145-161.

[123] Ryan MH & Graham JH. (2002) Is there a role for arbuscular mycorrhizal fungi in production agriculture? Plant and Soil 244: 263-271.

[124] St-Arnaud M & Vujanovic V. (2007) Effect of the arbuscular mycorrhizal symbiosis on plant diseases and pests, In C. Hamel and C. Plenchette, eds. Mycorrhizae in crop production. Haworth Press, Binghampton, New York, pP 67-122.

[125] Schwintzer R & Tjepkema JD. (1990) The Biology of Frankia and Actinorrhizal Plants. Academic Press Inc. San Diego, USA, 99.

[126] Sanchez JC, Gimenez R, Schneider A, Fessner WD, Baldoma L, Aguilar J & Badia J. (1994) Activation of a cryptic gene encoding a kinase for L-xylulose opens a new pathway for the utilization of L-lyxose by Escherichia coli. J.Biol.Chem. 269:2 9665- 29669

[127] Hawksworth DL. (1991) The fungal dimension of biodiversity: Magnitude, significance, and conservation, Mycological Research, 95, 641-655.

[128] Harley JL & Smith SE. (1983) Mycorrhizal Symbiosis. Academic Press, London, New York, 483.

[129] Gianinazzi-Pearson V & Diem HG. (1982) Endomycorrhizas in the Tropics. In: Microbiology of Tropical Soils. Implications in Soil Management, Eds. Y R Dommergues and H G Diem. Martinus Nijhoff, The Hague, pp 209–251.

[130] Salvioli A, Zouari I, Chalot M & Bonfante P. (2012) The arbuscular mycorrhizal status has an impact on the transcriptome profile and amino acid composition of tomato fruit. BMC Plant Biol. 12: 44-56.

[131] Sylvia, DM & Williams SE. (1992) Vesicular-Arbuscular Mycorrhizae and Environmental Stress. In: Bethlenfalvay, G.J. and Linderman, R.G., Eds., Mycorrhizae in Sustainable Agriculture, Special Publication 54, ASA, Madison, 101-124.

[132] Bapaume L & Reinhardt D. (2012) How membranes shape plant symbiosis: signaling and transport in nodulation and arbuscular mycorrhiza. Biology Frontiers in Plant Science. Vol. (3): https://doi.org/10.3389/fpls.2012.00223.

[133] Zhang Q, Blaylock LA & Harrison MJ. (2010) Two *Medicago truncatula* Half-ABC transporters are essential for arbuscule development in arbuscular mycorrhizal symbiosis. Plant Cell. 22: 1483-1497.

[134] Tromas A, Parizot B, Diagne N, Champion A &Hocher V. (2012) Heart of endosymbioses: transcriptomics reveals a conserved genetic program among arbuscular mycorrhizal, actinorhizal and legume-rhizobial symbiosis. PLoS ONE. 7: e44742-5

[135] Sevilla M, Burris RH, Gunapala N & Kennedy C. (2001) Comparison of benefit to sugarcane plant growth and 15n2 incorporation following inoculation of sterile plants with *Acetobacter diazotrophicus* wild-type and Nif–mutant strains. Mol Plant-Microbe Interact. 14: 358-366.

[136] Bertalan M, Albano R, de-Pádua V, Rouws L, Rojas C, Hemerly A, Teixeira K, Schwab S, Araujo J, Oliveira A, França L, Magalhães V, Alquéres S, Cardoso A, Almeida W, Loureiro MM, Nogueira E, Cidade D, Oliveira D, Simão T, Macedo J, Valadão A, Dreschse M, Freitas F, Vida M, Guedes H, Rodrigues E, Meneses C, Brioso P&Pozzer L. (2009) Complete genome sequence of the sugarcane nitrogen-fixing Endophyte Gluconacetobacter diazotrophicus Pal5. BMC Genomics. 10: 450-460.

[137] Baharlouei K, Pazira E &Solhi M. (2011) Evaluation of Inoculation of plant Growth-Promoting Rhizobacteria on Cadmium. Singapore: International Conference on Environmental Science and Technology IPCBEE vol.6 IACSIT Press.

[138] Brusamarello-Santos L, Pacheco F, Aljanabi S, Monteiro R, Cruz L, Baura V, Pedrosa F, Souza E &Wassem R. (2012) Differential gene expression of rice roots inoculated with the diazotroph Herbaspirillum seropedicae. Plant Soil. 356: 113-125.

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