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Scoping the Potential of Microorganisms for Increasing the Productivity in Agricultural System: An Overview

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Abstract

There is growing evidence that demonstrates the hazard of inorganic chemicals on the soil, ecosystem, and agriculture. The awareness of the public towards the health, environment, and economy prioritizes the search for alternate technology. The microbial world is the largest unexplored reservoir of biodiversity which performs variety of essential functions like nutrient recycling, environmental detoxification. Careful selection of the specific microbial species for the particular crop is integral for its biocontrol, bio fertilization, and phytostimulation. The beneficial microbes around the rhizosphere perform multiple functions like fixation of nitrogen, solubilization of phosphate, mobilization of potassium, improvement of the soil aggregation, resistance against pest and diseases, release of plant growth-promoting chemicals and hormones. The commercial administration of microbes inoculated bio effectors in the agriculture increases the productivity of the crop with no risk to the environment. Also, biotechnology applied with microbial genome widens the scope for developing resistance against a wide range of host specific pathogen. This review highlights the recent progress in the microbial world with the aim to increase the productivity of the crops maintaining a sustainable environment.

Keywords: Biocontrol; Bio fertilization; Phytostimulation; Productivity

Introduction

The modern agricultural system anticipates the use of mineral fertilizers, chemical pesticides, and herbicide. These practices are being re-evaluated due to the awareness of its consequences on the health and environment. The widely recognized menace of mineral fertilizers are underground water contamination by nitrate leaching, greenhouse gas emission, alteration in the ozone layer, and chemical residue in the food chain (Singh *et al*., 2017). The problems and concerns about inorganic fertilizers, pesticide, and fungicide have led to the search for alternative strategy i.e. microbial manipulation.

The microbial world is the largest unexplored reservoir of biodiversity and performs a variety of essential functions like nutrient recycling, environmental detoxification, and sustainability (Ahmad *et al*., 2011). The rise of agricultural biotechnology has developed microbial inoculants to enhance plant growth and suppress plant diseases which ultimately reduces reliance on chemical pesticides and herbicide (Adesemoye *et al*., 2009). Greater utilization of the microorganism in the agricultural system can improve crop productivity and increase crop resistance to biotic and abiotic stress. Plant growth and productivity are greatly affected by the interaction between plant roots and the soil, including the microbial population in the soil (Pereg & McMillan, 2015). Plant rhizosphere harbors different microorganism which has negative, positive, or no-effect to plant growth. The main mechanism for plant growth promotion by microbes includes biocontrol (suppression of disease), bio fertilization (enhancement of nutrient availability), and phytostimulation (production of plant hormones) (Martinez-Viveros *et al*., 2010).

The indigenous soil microbial population is greatly influenced by agricultural practices, crop species, cultivar, genotype, and soil type (Reeve *et al*., 2010). Microorganisms can play an integral role in enhancing the availability of nutrients to plants (e.g.: mycorrhizal association) and stimulate the root growth (Gomez-Munoz *et al*., 2017). The mycorrhizal association has been reported to increase the availability of especially nitrogen and phosphorus to the plants. This creates a mutually beneficial linkage between plants and fungi as the nutrients absorbed by the fungal hyphae are transported into plants (Opik & Rolfe, 2005). Thus, the selection of specific microbial species, natural or modified, may be of great significance for the benefit of society, environment, and agriculture.

Classification of Micro-Organism

Microorganisms are microscopic organisms that exist as unicellular or multicellular entities. Microorganisms are the group of naturally occurring beneficial organisms applied in the field as inoculants for the enhancement of plant growth (Ahmad *et al*., 2008). In the currently accepted biological classification, the microorganism is categorized under three domains: eukaryotes, bacteria, and archaea. The microorganism can further be classified as six major types: bacteria, fungi, protozoa, algae, archaea, and virus. Bacteria are the prokaryotic unicellular organism. They exist in different shapes: bacillus, vibrio, spirilla, and coccus. Fungi are the eukaryotic organism which may be multicellular or unicellular. The distinguishing feature of fungi is cell wall composed of chitin and their characteristic filamentous structure called hyphae. Protozoans are the unicellular aerobics eukaryotic. Algae are a unicellular or multicellular organism that obtains nourishment by photosynthesis. Archaea are a single-celled prokaryotic organism that shows the traits of both bacteria and eukaryotes.

Microorganism for Agricultural Use

1. Bacteria

Bacteria have been widely reported for its bio fertilization, biocontrol, and phytostimulation property (Table 1). These bacteria are present in the soil and assist the farmer in one way or another. Bacteria can be divided into broad categories based on bio fertilization: symbiotic nitrogen-fixing bacteria, non-symbiotic nitrogen-fixing bacteria, phosphorous solubilizing bacteria, and potash mobilizing bacteria. Symbiotic nitrogen-fixing bacteria includes *Rhizobium leguminosarum*, *Rhizobium tripoli*, *Rhizobium phaseoli*, etc. These bacteria live in a mutualistic symbiotic relationship in the host crop and have the ability to fix free atmospheric nitrogen (Singh *et al*., 2017). Non-symbiotic nitrogen-fixing bacteria include *Azotobacter* species, *Glucanobacter diazotrophicus*, *Acetobacter xylinum*, etc. Non-symbiotic bacteria are free-living bacteria that fix the atmospheric nitrogen without symbiotic association with host plants (Kass *et al.*, 1971). Phosphorous solubilizing bacteria include *Bacillus megaterium*, *Pseudomonas putida*, etc. (Koberl *et al*., 2011). Phosphorous solubilizing bacteria are capable of solubilizing the inorganic form of phosphate into a soluble form. Potash mobilizing bacteria includes *Frateuria aurantia* which is capable of mobilizing the potassium in the vicinity of the plant root (Johansen *et al*., 2005). The bacteria which are responsible for the stimulation of the plant hormones are called plant growth-promoting rhizobacteria (PGPR). They are reported for their phytostimulation property. *Pseudomonas aeruginosa*, *Serratia marcescens* are some of the examples of PGPR that release indole-3 acetic acid which assists the plant growth and development. *Bacillus subtilis, Bacillus polymyxa*, *Pseudomonas fluorescens*, and *Pseudomonas putida* have been reported for their biocontrol against various pathogens. *Bacillus subtilis* is a spore-forming bacterium and it colonizes it the rhizosphere of the plant. The bacteria suppress the plant pathogenic fungal organisms like *Rhizoctonia*, *Fusarium*, *Aspergillus*, and others (Singh *et al*., 2017). *Pseudomonas fluorescens* is a non-pathogenic saprophyte that suppresses the plant disease in the field crops by the production of the secondary metabolites like antibiotics, siderophores, and hydrogen cyanide. This unique ability enables the *Pseudomonas* to acts as a systemic biocontrol agent against fungus and pathogenic bacteria (Espinosa *et al., 2000*). The bacteria *Bacillus thuringiensis* (Bt) is the world's most used and successful microbial insecticide. Bt produces insecticidal crystal protein during its sporulation which upon ingestion by the pest shows the effect. These microorganisms are responsible for their rhizosphere's competitive ability by their antagonistic ability on harmful pathogens and chemicals that interfere with the homeostasis of plants.

2. Fungi

Fungi have been involved in the promotion of plant growth in one mechanism or another (Table 2). Various instances of application of fungus in plant growth promotion can be observed for phosphate solubilization, production of growth regulators, secretion of extracellular enzymes, bio resistance against toxic chemicals, and biosorption ability for Ni, Cd, and Cr. Fungus as bio effector has the property of biocontrol, bio fertilization, and phytostimulation. Biofertilizers play a cogent role in the improvement of productivity of crops through nutrient recycling, seed germination, and enzyme secretion. One example of biofertilizers is arbuscular mycorrhizal fungi which increase uptake or absorption of nutrients, stimulates the plant growth by hormonal action or antibiosis, and by the decomposition of organic residues. Mycorrhizal fungi increased the water uptake and retention in severe drought conditions (Ruiz-Lozano & Aroca, 2010). Mycorrhizal fungi colonize with the plant roots and increase the stomatal efficiency of plants. A fungus; *Penicillium bilaii* helps to increase the phosphate availability to the plant by dissolution (Mosttafiz *et al*., 2012). Inoculum of fungi has been reported for their insecticidal, nematocidal, and fungicidal property. *Metarhizium anisopliae*; an entomopathogenic fungus has been used as an effective agent for the control of Grasshoppers, Termites, Thrips, Caterpillars, Aphids, and malaria inducing mosquitoes (Singh *et al*., 2017). *Beauveria bassiana* have been reported for their effective control against various pests such as whitefly, termites and other insects (Singh *et al*., 2017). *Paecilomyces lilacinus*, when applied on the soil effectively showed action against plant root nematode by infecting eggs, juveniles, and adult females (Singh *et al*., 2017). *Trichoderma* sp. is the antagonistic fungus which prevents the crop form a wide range of pathogen *like Pythium, Botrytis, Phoma, Sclerotinia, Fusarium*, *Ascochyta, Alternaria*, and others (Singh *et al*., 2017). Fungi serve as a primary and secondary agent in the process of food fermentation, preventing food spoilage. *Saccharomyces cerevisiae* is the most widely used fungi in the fermentation process.

Table 1: Growth promoting substances released by important plant growth-promoting bacteria.

SN	Microorganism	Growth- promoting substances/properties	References
1	*Pseudomonas* sp.	ACC deaminase, IAA, siderophore Biocontrol against pathogenic fungus and bacteria	Poonguzhali *et al*. (2008)
2	*Bacillus subtilis*	IAA, siderophore, antifungal activity Biocontrol against *Rhizoctonia, Fusarium, Aspergillus*, and others	Singh *et al*. (2008)
3	*Enterobacter* sp.	ACC deaminase, IAA, siderophore Phosphate solubilization, N_2 fixation	Kumar *et al*. (2008)
4	*Pseudomonas jessenii*	ACC deaminase, IAA, siderophore, heavy metal solubilization	Rajkumar and Freitas (2008)
5	*Azotobacter* sp.	IAA, siderophore, antifungal activity,	Ahmad *et al*. (2008)
6	*Bacillus amyloliquesfaciens*	Increase root and shoot growth of rice	He *et al*. (2013)
7	*Rhizophagus intraradices*	Increase the plant growth, number of leaves, plant height, shoot and root length and weight of tea	Sharma & Kayang (2017)
8	*Rhizobium leguminosarum*	Increase nodulation, nitrogen fixation in lentils, pea, *Vicia*	Singh *et al*. (2017).
9	*Rhizobium japonicum*	Nitrogen fixation in soyabean	Singh *et al*. (2017).
10	*Rhizobium meliloti*	Increase nodulation, nitrogen fixation in melilotus, Lucerne, fenugreek.	Singh *et al*. (2017).
11	*Bacillus megaterium*	Produce cytokinin, produce root growth	Koberl *et al*. (2011).
12	*Glucanobacter diazotrophicus*:	Nitrogen fixation in sugarcane	Singh *et al*. (2017).
13	*Azospirillum lipoferum*:	Produce various phytohormones	Singh *et al*. (2017).
14	*Pseudomonas aeruginosa*	Siderophores and phenazines	Rane *et al*. (2008)
15	*Rhizobium* sp.	Increase nodulation, HCN, ammonia, IAA, exo-polysaccharides, siderophores	Singh *et al*. (2017)
16	*Bradyrhizobium* sp.	Heavy metal mobilization	Singh *et al*. (2017)
17	*Pseudomonas fluorescens*	ACC deaminase, phosphate solubilization	Singh *et al*. (2017)
18	*Bacillus thuringiensis*	Decrease volatile emissions and increase photosynthesis	Timmusk *et al*. (2014)
19	Erwinia sp	Efficient uptake of insoluble phosphate from soil	Muleta *et al*. (2013)

Note: IAA stands for indole-3-acetic acid, HCN stands for hydrogen cyanide, ACC stands for 1-aminocyclopropane-1-carboxylate

Table 2: Growth promoting substances released by important plant growth-promoting fungi.

SN	Microorganism	Growth-promoting substances/properties	References
1	*Penicillium bilaii*	Increase root length and P-content Increase grain yield	Mosttafiz *et al*. (2012).
2	*Trichoderma* spp.	Biocontrol against a wide range of pathogen	Singh *et al*. (2017)
3	*Trichoderma harzianum*	Increase systemic resistance, root length, growth Improve germination and seedling growth of wheat	Gupta *et al*. (2016)
4	*Aspergillus flavus*	Control of aflatoxin-producing fungi	Singh *et al*. (2017)
5	*Trichoderma virens*	Control of Rhizoctonia, Fusarium, and Pythium spp.	Singh *et al*. (2017)
6	*Penicillium oxalicum*	Malic acid, gluconic acid, oxalic acid	Shin *et al*. (2006)
7	*Metarhizium anisopliae*	control several pests such as grasshoppers, termites, thrips, caterpillars, aphids	Singh *et al*. (2017)
8	*Beauveria bassiana*	biological insecticide for termites, whiteflies,	Singh *et al*. (2017)
9	*Verticillium lecanii*	biological pesticide	Singh *et al*. (2017)
10	*Paecilomyces lilacinus*	control nematodes that attack plant roots	Singh *et al*. (2017)
11	*Arthrobotrys spp.*	biological indicator of nematodes	Niu and Zhang (2011).
12	*Saccharomyces cerevisiae*	Integral for fermentation	Singh *et al*. (2017)

3. Protozoa

Protozoa occupy a wide range of ecological niches and they hold a pivotal stance in nutrient cycling and energy flow**.** It plays an integral role in the mineralization of the soil nutrients, making it available to the plants and other soil organisms. Amoebae and heterotrophic flagellates are numerous in the agricultural soil. It was reported that these organisms played an important role as bacterial consumers and fungal consumers. Protozoan activity directly or indirectly stimulates the process of mineralization of the nitrogen, carbon, and other mineral nutrients (Ekelund and Ronn, 1994).

4. Algae

Algae are a large and diverse component of microorganism which can perform photosynthesis. Algae can be used as biofertilizers and soil stabilizers. Cyanobacteria can fix nitrogen and carbon. Seaweed being a biostimulant contains many chelating compounds (mannitol) that increase the nutrient availability in the field. Besides, foliar application of seaweed extract increases the Ca uptake in the leafy vegetables. Cyanobacteria can be used as biological fertilizers in wetland rice cultivation and lentil seedling (Ibraheem, 2007). Algae are the important source of organic matter in the soil as the debris formed from the death and decay of algae bind with the soil and increase the humus content of the soil (Marathe and Chandhari, 1975). Algae play an important role in soil reclamation by increasing soil fertility and improve the plant response to stress. Blue-green algae excrete a variety of growth regulators, antibiotics, amino acids, exopolysaccharides, antifungal, and antibacterial substances (Abdel-Raouf *et al*., 2012). *Ascophyllum nodosum* has been reported to produce plant growth stimulants which is important for the increase in crop productivity.

5. Archaea

Archaea are ubiquitous in the harsh climatic habitat and have been reported in a wide range of environments like sea, marshlands, and ocean. There are many reports on the contribution of archaea in nutrient recycling, solubilization and mobilization of nutrients, indole-3 acetic acid production, and nutrients fixation. Few reports are available which shows archaea as growth-promoting organism, phosphorous solubilization by haloarchaea, nitrogen fixation by methanogens, and IAA production (Yadav *et al*., 2017). The archaea biota plays a vital role in the establishment of habitat in the extreme climatic environment.

6. Virus

The development of biotechnology in agriculture has made a tremendous impact on the diagnosis and control of plant disease with the use of the virus genome. The discovery of *Cryphonectria hypovirus* 1 developed the way of making viruses as a biocontrol agent. The data a few years back showed that twenty-nine phages/ virus species have been used as biopesticide. The example of the beneficial virus includes tomacco mosaic virus, cucumber mosaic virus, tobacco rattle virus which permit tolerance against drought and freezing temperature in certain crops. Various research has shown that some host attacked by viruses do not develop any ill symptoms at all. The persistent virus; white clover cryptic virus suppresses the nodulation process if the nitrogen content in the soil is maximum (Roossinck, 2011). Virus can also affect insect that feed on the plant tissues. Whitefly feeding on the plants infected with tomato spotted wilt virus has been found to have lower fecundity and slower development (Pan *et al*., 2013). The various mild strain of viruses has been inoculated in the crop as a means of cross-protection against severe strain. Viruses have a great deal of potential for the benefit of agriculture but we need to discard the ubiquitous bias for the negative effect of viruses.

Conclusion

The excessive and injudicious administration of chemical fertilizers, pesticide strikes serious threat to the microbial diversity, microbial communal structure, soil fertility, and ecosystem. In contemporary agricultural practices, the application of microorganisms is the only way to achieve the goal of sustainable agriculture. Today's technological era is revealing a whole new way of looking at microbes. Unexplored microbial diversity and technological advancement are the main resources to be exploited to solve the problems and concerns of the twenty-first century. The research on the microbial habit and habitat showed that it can assist the farmers by the process of bio fertilization, phytostimulation, and biocontrol against variety of virulent pathogens. The action of microbes can also be observed in numerous novel practices such as biofuel, biosensor, and probiotics. Further, this microbial biotechnology on introduction in the field are long-lasting and perpetual.

Our future targets should be more action-oriented for the exploration the microbial diversity, exploitation of microbial genome for bioremediation and plant health. We need to applicate this knowledge for the novel cause such as sustainable agriculture, bumper productivity and environmental rehabilitation.

Conflict of Interest

The author declares that there is no conflict of interest with present publication.

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