

Biotechnology: Role Of Microbes In Sustainable Agriculture And Environmental Health

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Abstract

Biotechnology is the rapidly growing segment in biological sciences. It has diversified applications in sustainable agriculture. The review deals with microbes in biotechnology and their diversified applications in agriculture as biofertilizers, bio-pesticides, bio-herbicides, bioinsecticides, fungal based bioinsecticides and viral based bioinsecticides. Further, precise descriptions have been made on Microbiology Ecology Biotechnology and Sustainable agriculture in the later part of the review. Finally, a brief highlight has been given on the role of Microbial Biotechnology on Environmental Health

INTRODUCTION

Biotechnology is the branch of biological science, which deals with the manipulation through genetic engineering of living organisms or their components to produce useful products for various applications in biological sciences.

The world's population is estimated to be double by the end of 2033. Food demand in Asia is expected to exceed the need by the end of 2010. This poses a great challenge to agricultural systems. Traditional farming equipment and practices are reaching their limits of effectiveness in increasing agricultural productivity. As countries develop, people are also demanding more and better food. These pressures are multiplied by shrinking farmland, rising labour costs and shortage of farm workers. Biotechnology offers an additional method to improve the sustainability of existing system to produce more and better quality of our agricultural products.. The potential benefits of plant biotechnology are numerous and include providing resistance to crop pests, increasing crop yield and reducing chemical pesticide usage. The processing of food and food ingredients using biotechnology provides a wide variety of fermented foods and food ingredients that are extensively used. Agricultural technologies that ensured a 'green revolution' in the middle of 20th century, causing now high ecological cost and contributing global pollution, unfavourable climate change and loss of biodiversity (Vance, 1998). The broad application of microbes in sustainable agriculture is due to the genetic dependency of plants on the beneficial functions provided by symbiotic cohabitants (Noble &

Ruaysoongnern, 2010). Therefore, microbial biotechnology and its applications in sustainable development of agriculture and environmental health are getting better attention. The purpose of the review is to further prioritize the importance in the scientific community as well as stakeholders.

MICROBES AND BIOTECHNOLOGY

Microbes / micro-organisms are mostly microscopic small creatures are placed in different groups such bacteria, fungi, protozoa, micro-algae and viruses. These organisms live in soil, water, food, animal intestines and other different environments. Various microbial habitats reflect an enormous diversity of biochemical and metabolic traits that have arisen by genetic variation and natural selection in microbial populations.

Men used some of microbial diversity in the production of fermented foods such as bread, yogurt, and cheese. Some soil microbes release nitrogen that plants need for growth and emit gases that maintain the critical composition of the Earth's atmosphere.

Other microbes challenge the food supply by causing yield-reducing diseases in food-producing plants and animals. In our bodies, different microbes help to digest food, ward off invasive organisms, and engage in skirmishes and pitched battles with the human immune system in the give-and-take of the natural disease process.

A genome is the totality of genetic material in the DNA of a

particular organism. Genomes differ greatly in size and sequence across different organisms. Obtaining the complete genome sequence of a microbe provides crucial information about its biology, but it is only the first step toward understanding a microbe's biological capabilities and modifying them, if needed, for agricultural purposes.

Microbial biotechnology, enabled by genome studies, will lead to breakthroughs such as improved vaccines and better disease-diagnostic tools, improved microbial agents for biological control of plant and animal pests, modifications of plant and animal pathogens for reduced virulence, development of new industrial catalysts and fermentation organisms, and development of new microbial agents for bioremediation of soil and water contaminated by agricultural runoff
(<http://microbialbiotechnology.puchd.ac.in>).

Microbial biotechnology is an important area that promotes for advances in food safety, food security, value-added products, human nutrition and functional foods, plant and animal protection, and overall fundamental research in the agricultural sciences.

MICROBIAL BIOTECHNOLOGY AND ITS APPLICATIONS IN AGRICULTURE

NATURAL FERMENTATION

Micro-organisms found in the soil to improve agricultural productivity. Men use naturally occurring organisms to develop biofertilizers and bio-pesticides to assist plant growth and control weeds, pests, and diseases.

Micro-organisms that live in the soil actually help plants to absorb more nutrients. Plants and these friendly microbes are involved in “nutrient recycling”. The microbes help the plant to “take up” essential energy sources. In return, plants donate their waste by-products for the microbes to use for food. Scientists use these friendly micro-organisms to develop biofertilizers.

BIOFERTILIZERS

Phosphate and nitrogen are important for the growth of plants. These compounds exist naturally in the environment but plants have a limited ability to extract them. Phosphate plays an important role in crop stress tolerance, maturity, quality and directly or indirectly, in nitrogen fixation. A fungus, *Penicillium bilaii* helps to unlock phosphate from the soil. It makes an organic acid, which dissolves the phosphate in the soil so that the roots can use it. Biofertilizer made from this organism is applied by either coating seeds with

the fungus as inoculation, or putting it directly into the ground. *Rhizobium* is a bacteria used to make biofertilizers. This bacterium lives on the plant's roots in cell collections called nodules. The nodules are biological factories that can take nitrogen out of the air and convert it into an organic form that the plant can use.

This fertilization method has been designed by nature. With a large population of the friendly bacteria on its roots, the legume can use naturally-occurring nitrogen instead of the expensive traditional nitrogen fertilizer.

Biofertilizers help plants use all of the food available in the soil and air, thus allowing farmers to reduce the amount of chemical fertilizers they use. This helps preserve the environment for the generations to come.

BIO-PESTICIDES

Microorganisms found in the soil are all not so friendly to plants. These pathogens can cause disease or damage the plant. As scientists developed biological “tools,” which use these disease-causing microbes to control weeds and pests naturally.

BIO-HERBICIDES

Weeds are the problem for farmers. They not only compete with crops for water, nutrients, sunlight, and space but also harbor insect and disease pests; clog irrigation and drainage systems; undermine crop quality; and deposit weed seeds into crop harvests.

Bio-herbicides are another way of controlling weeds without environmental hazards posed by synthetic herbicides. The microbes possess invasive genes that can attack the defence genes of the weeds, thereby killing it.

The benefit of using bioherbicides is that it can survive in the environment long enough for the next growing season where there will be more weeds to infect. It is cheaper than synthetic pesticides thus could essentially reduce farming expenses if managed properly. Further, it is not harmful to the environment compared to conventional herbicides and will not affect non-target organisms.

BIOINSECTICIDES

Biotechnology can also help in developing alternative controls to synthetic insecticides to fight against insect pests. Micro-organisms in the soil that will attack fungi, viruses or bacteria, which cause root diseases. Formulas for coatings on the seed (inoculants) which carry these beneficial organisms

can be developed to protect the plant during the critical seedling stage.

Bioinsecticides do not persist long in the environment and have shorter shelf lives; they are effective in small quantities, safer to humans and animals compared to synthetic insecticides; they are very specific, often affecting only a single species of insect and have a very specific mode of action; slow in action and the timing of their application is relatively critical.

FUNGAL- BIOINSECTICIDES

Fungi cause diseases in some 200 different insects and this disease producing traits of fungi is being used as bioinsecticides.

Fermentation technology is used to mass production of fungi. Spores are harvested and packaged so these are applied to insect-ridden fields. When the spores are applied, they use enzymes to break through the outer surface of the insects' bodies. Once inside, they begin to grow and eventually cause death.

Fungal agents are recommended by some researchers as having the best potential for long-term insect control. This is because these bioinsecticides attack in a variety of ways at once, making it very difficult for insects to develop resistance.

VIRUS-BASED BIOINSECTICIDES

Baculoviruses affect insect pests like corn borers, potato beetles, flea beetles and aphids. One particular strain is being used as a control agent for bertha army worms, which attack canola, flax, and vegetable crops. Traditional insecticides do not affect the worm until after it has reached this stage and by then much of the damage has been done.

MICROBIOLOGY ECOLOGY BIOTECHNOLOGY AND SUSTAINABLE AGRICULTURE

Now increasing attention has been paid to the development of sustainable agriculture in which the high productivities of plants and animals are ensured using their natural adaptive potentials, with a minimal disturbance of the environment (Noble & Ruaysoongnern, 2010). It is our view that the most promising strategy to reach this goal is to substitute hazardous agrochemicals (mineral fertilizers, pesticides) with environment-friendly preparations of symbiotic microbes, which could improve the nutrition of crops and livestock, as well as their protection from biotic (pathogens, pests) and abiotic (including pollution and climatic change)

stresses (Yang et al., 2009).

Therefore, agricultural microbiology is the present paramount research field responsible for the transfer of knowledge from general microbiology and microbial ecology to the agricultural biotechnologies. The present review is focussed on plants, but also emphasises the importance of micro-organisms in relation to agriculture and environmental health (Wang et al., 2009) and to the biocontrol of phytophagans (Mohammed et al., 2008).

The broad application of microbes in sustainable agriculture is due to the genetic dependency of plants on the beneficial functions provided by symbiotic cohabitants (Noble & Ruaysoongnern, 2010). The agronomic potential of plant-microbial symbioses proceeds from the analysis of their ecological impacts, which have been best studied for N₂ fixing (Franche et al., 2009). This analysis has been based on 'applied co-evolutionary research' (Arnold et al., 2010), addressing the ecological and molecular mechanisms for mutual adaptation and parallel speciation of plant and microbial partners. For plant-fungal interactions, it has been demonstrated that the host genotype represents the leading factor in the biogeographic distribution of mycobionts and for their evolution within the mutualist-antagonist and specialist-generalist continua (Peay et al., 2010).

The major impact of agricultural microbiology on sustainable agriculture would be to substitute agrochemicals (mineral fertilizers, pesticides) with microbial preparations. However, this substitution is usually partial and only sometimes may be complete, e.g. in recently domesticated leguminous crops, which retain a high potential for symbiotrophic N nutrition, typical for many wild legumes (Provorov & Tikhonovich, 2003). The application of nutritional symbionts could be based on plant mixotrophy, e.g. on a simultaneous symbiotrophic and combined N nutrition. This is why the maximal productivity of the majority of crops is reached using an optimal (species- and genotype-specific) combination of both nutritional types because of which a high sustainability of legume production may be achieved (Provorov et al., 1998). Moreover, the energy costs for N₂ fixation and for assimilation of combined N differ by less than 10% (Andrews et al., 2009). The balance between symbiotrophic and combined N nutrition may be improved by a rapid removal of N-compounds from the actively N₂-fixing symbioses, as has been suggested for tropical forest ecosystems (Hedin et al., 2009).

This approach is most promising in legume-rhizobia

symbioses where the strong correlations between the ecological efficiency of mutualism and its genotypic specificity are evident (Provorov & Vorobyov, 2010b)

At present, a wide spectrum of preparations of diverse microbial species may be used to enhance crop production (Andrews et al., 2010). However, different approaches for improving the nutritional and defensive types of microbial mutualists need to be developed. For the nutritional types, an effective colonisation of plants in a host-specific manner is optimal and the impacts of beneficial symbionts are increased in parallel with their host specificity (Provorov & Vorobyov, 2009).

The application of microbial symbiotic signals or their derivatives for remodelling plant developmental or defensive functions may represent a promising field for agricultural biotechnology.

The prospects for a future development of agricultural microbiology may involve the construction of novel multipartite endo- and ecto-symbiotic communities based on extended genetic and molecular (metagenomic) analyses. The primary approach for such construction is to create composite inoculants, which simulate the natural plant-associated microbial communities. For balancing the host plant metabolism, a combination of N- and P-providing symbionts would appear promising, including the endosymbiotic rhizobia + VAM-fungi (Shtark et al., 2010),

The further development of agricultural microbiology faces several important ecological and genetic challenges imposed by the broad application of symbiotic microbes. Some of these challenges are associated with opportunistic or even regular human pathogens, which are frequently found in endophytic communities, including *Bacillus*, *Burkholderia*, *Enterobacter*, *Escherichia*, *Klebsiella*, *Salmonella* and *Staphylococcus* species (Ryan et al., 2008).

An increased knowledge of microbe-based symbioses in plants could provide effective ways of developing sustainable agriculture in order to ensure human and animal food production with a minimal disturbance of the environment. The effective management of symbiotic microbial communities is possible using molecular approaches based on the continuity of microbial pools which are circulating regularly between soil-, plant- and animal-provided niches in natural and agricultural ecosystems (Kupriyanov et al., 2010; Analysis of this circulation could enable the creation of highly productive microbe-based

sustainable agricultural system, whilst addressing the ecological and genetic consequences of the broad application of microbes in agricultural practice

ENVIRONMENTAL HEALTH AND MICROBIAL BIOTECHNOLOGY

Bruce Rittmann, director of the Center for Environmental Biotechnology in the Biodesign Institute at ASU, addressed the challenges and solution of environmental health by manipulation of microbes (<http://www.biodesign.asu.edu>)

Their solution: a synergistic marriage of two distinct disciplines, microbial ecology and environmental biotechnology. "Together, they offer much promise for helping society deal with some of its greatest challenges in environmental quality, sustainability, security, and human health," Rittmann stated in an excerpt from the paper (<http://www.biodesign.asu.edu>)

Leading the marriage are revolutionary changes in compiling vast amounts of genetic information on microbial organisms through state-of-the-art DNA-based techniques. Identifying just a single microbial specimen is a daunting task, considering, that there may be trillions of bacteria in every litre of water.

To aid in the identification and function of individual micro-organisms and communities, the first use of modern molecular biology tools began in the early 1980s, with the advent of polymerase chain reaction (PCR) amplification of microbial DNA and a new view of the evolution of organisms based on their ribosomal RNA.

These technologies have advanced into high-throughput genomic and proteomic protocols that can detect specific genes and their metabolic functions with great precision and detail. Other methods can now reconstruct entire genomes of what were once "uncultivable" microbes.

With recent advances in biology, materials, computing, and engineering, environmental biotechnologists now are able to use microbial communities for a wealth of services to society. These include detoxifying contaminated water, wastewater, sludge, sediment, or soil; capturing renewable energy from biomass; sensing contaminants or pathogens; and protecting the public from dangerous exposure to pathogens.

"Scientifically, it might be easiest to let the microbes convert the energy in organic wastes directly to electricity. However, they also can generate useful fuels, such as methane and

hydrogen, and we are pursuing research on all of these renewable-energy forms.”

Rittman hoped the success in capturing the energy out of waste materials, this would be a world-transforming technology and a real step forward to using more renewable forms of energy and much less reliance on fossil fuel.”

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