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Role of Biotechnology in Achieving Sustainable Environmental Development: A Comprehensive Review

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ABSTRACT

Recombinant DNA technology has significantly increased the yield of traditional crops and has broad prospects in helping plant growers meet the anticipated increase in food demand in the 21st century. In the past 20 years, significant progress has been made in manipulating genes from various exotic sources and their placement in microorganisms and crops to resist pests and diseases, herbicide tolerance, drought, soil salinity, and aluminum toxicity. Although the effective applications of biotechnology products are diverse, it is still necessary to make these benefits for the public truly and understandably to trigger a publicly impartial and irresponsible debate. Therefore, this study explained development concepts, sustainable development, and the environment and investigated the testing and release of agricultural products produced through biotechnology-based processes. Also, indicators of sustainability and environmental protection, as well as their impact on biosafety over the preceding decade, were taken into account. Finally, by expressing a dynamic and fluid regulatory structure, adequate strategies have been proposed to achieve sustainable development and bioremediation.
Keywords: Biotechnology, DNA technology, Bioremediation, Microorganism, Environment.

Introduction

The environment plays a crucial role in every aspect of life because all living things depend on the environment for their survival and needs. (Shimbar, 2021; Boz & Cetin-Dindar, 2021). Environmental management requires the present generation to manage all living and non-living components of the environment for present and future generations. Hence, environmental management requires setting and pursuing policies for sustainable use of the environment. Sustainable development is defined as development that meets the energy, food, and environment of the present without compromising the earth's resources or its future (Schuwirth et al., 2019).

Innovative solutions have moved towards biotechnology, whether to increase agricultural productivity, reduce greenhouse gas emissions, create a new therapeutic disease, or reduce the use of pesticides. Biotechnology is any technique that uses living organisms or parts of organisms to make/modify products (Zhang et al., 2019).

Biotechnology has played an important role in the attainment of environmental sustainability by using environment-friendly methods and techniques. Now, it has had a significant impact on various sectors such as health care. The International Society for Environmental Biotechnology defines environmental biotechnology as "the development, use, and regulation of biological systems for remediation of contaminated environments (land, air, water). On the other hand, the combination of biological knowledge and technology and their application to solving environmental problems using microorganisms and their products in the environment and in ecosystems is also defined as environmental biotechnology. The use of genetic engineering as a tool to obtain microorganisms and plants capable of efficient degradation of specific pollutants or enhancing such processes in native organisms with such capabilities has become a popular way to increase bioremediation efficiency. Bio-optimization using microorganisms and plants is generally regarded as a safe and inexpensive method of removing harmful substances from the environment and producing non-toxic by-products. The production of biotechnology products also provides completely new opportunities for the sustainable production of existing and new products and services (Degli Esposti et al., 2021).

Applications of Biotechnology to Renewable Fuel Production

Biotechnology applications using clean and sweetening bio-based technologies can play a vital role in making biofuels more sustainable. Even though various sources of alternative energy have been discovered, biofuel remains one of the most potential alternatives to cut down the dependency on fossil fuel by replacing it fully or partially (Jamwal et al., 2020).

Several strategies have been developed by which biotechnology is used to make improved biofuel products or processes, including making engineered or synthetic microorganisms to produce ethanol, biodiesel, or other genetically engineered fuels or plants as raw materials for improved fuels (Chen & Jiang, 2018).

There are different types of biofuels that are characterized by their sources of biomass (Majidian et al., 2018).

1. First-generation biofuels are made from sugar, starch and are easily fermented and extracted, and then fermented to produce ethanol. Alcohol can be produced by fermentation employing a number of microorganisms such as butanol. At present, liquid biofuels are based on biomass, ethanol from corn kernels, and sugarcane stalks. However, first-generation biofuel production often competes with food for the earth and can only meet a limited fraction of global fuel demand. The use of first-generation biofuels is expected to pose many challenges in the near future, forcing biotechnologies to seek replacement or advancement in biofuels, and thus with the help of advanced biotechnology, second-generation biofuels were created (Mihajlovski et al., 2020).

2. Second-generation biofuels are generally generated from lignocellulosic biofuels that appear to have greater potential for reducing greenhouse gas emissions, and the supply of these raw materials is higher than that of first-generation biofuels.

3. A new approach was proposed, in response to the problems of second-generation biofuels, with the solution of using algal biomass aided microbial enzymes to achieve a better and more efficient

quality of sustainable biofuels. Second-generation genetic and metabolic biofuels using non-edible feedstock such as lignocellulosic biomass or agricultural and municipal wastes convert cellulose to ethanol (Yadavet al., 2019). The sustainability of engineered strains and methods to achieve sustainable production in industrial microbial processes are recognized as important issues. Figure 4 describes the classification of biofuels based on their production source.

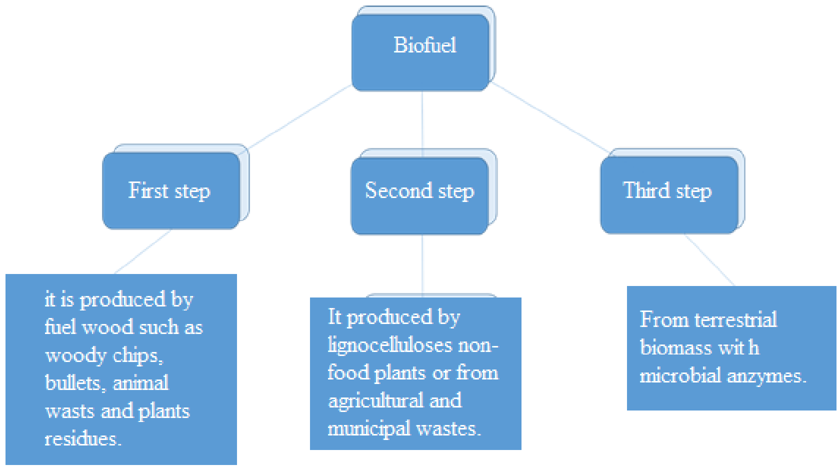

Figure 1- Classification of biofuels based on t their production source. (Alkagas et al., 2006)

Microbial biotechnology and its applications in agriculture

Apart from providing food security for the growing world population, the agricultural sector plays an important and vital role in improving the economic growth of developing countries. The awareness of plant biotechnology benefits seems to have increased among people. Now everyone is aware that biotechnology can benefit agriculture and increase food supply (Yadavet al., 2019). Even with the growing awareness of plant biotechnology, people have strong ideas about biotechnology. However, people's awareness of biotechnology and its potential benefits seems to have increased, and this information helps to form positive feedback and support (Yadav et al., 2019).

The potential benefits of plant biotechnology are numerous, including Pest-resistant crops, increasing crop yields, and reduced use of chemical pesticides. Microorganisms present in nature can be used as biofertilizers and biotoxins to help plant growth and control weeds, pests, and diseases. The development and use of microbial-based fertilizers have become important in an effort to reduce the negative environment. Given the effects of overuse and improper use of chemical fertilizers, biofertilizers and biopesticides present developing countries with an excellent opportunity to enhance their crop yields.

3- Bioremediation and biodegradation of environmental pollutants

Environmental pollutants may be organic or inorganic, like heavy metals, pesticides, toxic chemical fertilizers, and a variety of hydrocarbons, polychlorinated biphenyls, detergents, antibiotics, lubricants, nanoparticles, dyes, and disinfectants that can cause various diseases in humans and animals. Bioremediation involves the application of microbes to detoxify and degrade environmental pollutants. In other words, it is defined as the biologically catalyzed reduction in the complexity of chemical compounds (Chandra, 2019). Microorganisms have long been used for bioremediation and transformation of pollutants. Some microorganisms have the astonishing, naturally occurring microbial catabolic diversity to degrade, transform or accumulate a huge range of compounds, including hydrocarbons (e.g., oil), polychlorinated biphenyls (PCBs), radionuclides, and metals. (Yan et al., 2021; Hurtado-Bermudez et al., 2021). Mixed populations with overall broad enzymatic capacities are required to degrade complex mixtures of hydrocarbons such as crude oil in the soil, freshwater, and marine environments. The principles of bioremediation are based on natural attenuation, bioaugmentation, and biostimulation.

In biostimulation, some specific nutrients are injected into the soil (soil/groundwater) to stimulate and support the growth of native microorganisms. Biostimulation involving the addition of soil nutrients, trace minerals, electron acceptors, or electron donors enhances the biotransformation of a wide range of soil contaminants (Fan et al., 2020).

Recently, research has focused on the production of genetically modified microbes or consortia to detoxify environmental pollutants. A genetically engineered microorganism (GEM) or modified microorganism (GMM) is a microorganism whose genetic material has been altered using genetic engineering techniques inspired by the natural genetic exchange between microorganisms. The use of genetically modified (GM) bacteria represents a research frontier with broad implications. Genetically engineered microorganisms (GEMs) have shown potential for bioremediation applications in soil, groundwater, and activated sludge environments, exhibiting enhanced degradative capabilities encompassing a wide range of chemical contaminants.

There are at least four principals to GEM development for bioremediation application, these include (Tripathi et al., 2013):

- Modification of enzyme specificity and affinity
- Pathway construction and regulation
- Bioprocess deelopment, monitoring, and control
- Bioaffinity bioreporter sensor applications for chemical sensing, toxicity reduction, and endpoint analysis.

Two genetically modified strains of Pseudomonas aeruginosa and Pseudomonas sputididae were first discovered in the early 70s and contained genes for the degradation of camphor, octane, naphthalene, salicylate. Genetic engineering is a modern technology, which can design microorganisms that have the ability to degrade specific pollutants and provide an opportunity to create an artificial combination of genes that do not exist together in nature (Pang et al., 2019).

Biotechnology as a sustainable alternative for the chemical industry

Biotechnology is "the application of scientific and engineering principles to the processing of materials by biological agents." Some of the defining technologies of modern biotechnology include genetic engineering; culture of recombinant microorganisms, cells of animals and plants; metabolic engineering; protein engineering; transgenic animals and plants; immunological assays; proteomics and bioreactor technologies (Czapar & Steinmetz2017). The objective of "industrial sustainability" is to achieve sustainable production and processing within the framework of environmental and social sustainability. The World Commission on Environment and Development (WCED) refers to the phrase “sustainable development” to mean development that meets the needs of the present without compromising the ability of future generations to meet their needs. Sustainable development is clearly one of the most difficult challenges that humanity has ever faced. Biotechnology refers to an array of powerful technologies that can be used in various parts of the industry and is also considered a key technology for the sustainable chemical industry. Industrial biotechnology, also known as white biotechnology, is the application of modern biotechnology to the sustainable production of chemicals, materials, and fuels from renewable sources, using living cells and/or their enzymes. Environmental concerns help the use of biotechnology in the industry to prevent pollution in the first place, in addition to removing pollutants from the environment. In addition, biotechnology has been very influential in health care, medical diagnosis, agriculture, and food processing (Muller et al., 2020).

The chemical industry has used traditional biotechnological processes for many years (e.g., microbial production of enzymes, antibiotics, amino acids, ethanol, vitamins; enzyme breakdown, fermented foods, and residues, etc.) (Kruis et al., 2019). Human unsafe activities will result in an undesirable change in the environment. As a result, the whole of humanity must think about the deteriorating environmental conditions. The greater the human effort to control nature, the greater the pollution of the environment, and the future becomes more and more insecure. Environmental protection day is the most important concern for the future of humanity. Biotechnology clearly holds promise as a solution to environmental problems. Environmental biotechnology has recently gained credibility due to the hard work of skilled and dedicated scientists. Biotechnology has played an important role in various fields by using environment-friendly techniques and products to eliminate environmental pollution.

Biotechnology Application in Environmental and Pollution Abatement

Biotechnology is not a new science, but rather it is a new term given to the recent evolution of genetic knowledge. This science has its origins in the pioneering work by Gregor Mendel at the end of the nineteenth century. During the 1970s, scientists developed new methods to combine fragments of DNA (deoxyribonucleic acid, a biochemical substance in all living cells that provides instructions for regenerative properties) and make fragments from one organism to another. These techniques are used as organic engineering of recombinant technology. The last two decades have seen a dramatic increase in the number of significant advances in genetics.

The increase in new techniques for understanding and genetically modifying existing organs in living organs has raised the interest and investment in biotechnology over the past two decades. The main effect of new modern biotechnology in agriculture is a wide range of inherited materials that can be used with common breeding programs to produce new types of plants, animals, and microbes that are widely used. The applications developed by these new methods place them entirely within the framework of the techniques used in industry, agriculture, and food processing throughout human history. Thus, while modern biotechnology provides completely new tools, these tools are used to produce products that complement the main roles of those produced by traditional methods. Proper relationships between these products are not fundamentally different from what you are already familiar with. The most striking difference between modern biotechnology techniques and those that have been used for years is the increased accuracy using the first method and less time to produce results. New recombinant technology (genetic engineering) allows plant growers to work with molecular biologists to transfer just one or two genes needed to transfer a new trait, such as a specific type of pest resistance, to a popular, highly advanced crop.

Rising the plant (and animal) modification accuracy, in turn, means greater safety. In addition, modern biotechnology products must undergo extensive testing for performance, economic characteristics. Quality is assessed at various sites over several seasons in the same way as the products of the Convention's racial programs. Concerns have been raised about new biotechnology techniques because of their huge potential and so many new products. Providing appropriate monitoring mechanisms to ensure the safety of products made using new techniques is as important as traditional biotechnology products.

Bioremediation is a process of optimization by selecting options among a number of biological, chemical, and physical factors. These include correctly matching the degrading microbes to conditions, understanding and controlling the movement of the contaminant (microbial food) so as to come into contact with microbes, and characterizing the abiotic conditions controlling both of these factors. Optimization can vary among options, such as artificially adding microbial populations known to break down the compounds of concern. Only a few species can break down certain organic compounds. Two major limiting factors of any biodegradation process are toxicity to the microbial population and the inherent biodegradability of the compound. Numerous bioremediation projects include in situ (field treatment) and ex-situ (sample/laboratory treatment) waste treatment using biosystems. Table 2 shows the application of bioremediation in various environmental processes.

Table 2. Environmental process and bioremediation procedures involved. (Ezeonu et al., 2012).

Environmental condition	Biosystem/microbes used	Bioremediation benefit
Wastewater and industrial effluents	Sulfur-metabolizing bacteria	(1) Microorganisms in sewage treatment plants remove common pollutants (heavy metals and sulfur compounds) from wastewater before it is discharged into rivers or the sea. (2) Production of animal feed from fungal biomass after penicillin production in penicillin industries. (3) Useful biogas (methane, etc.) production from anaerobic wastewater treatment
Drinking and process water	Organic degrading microbes (Bacteria, fungi, and algae)	(1) Reclamation and purification of wastewaters for reuse and provision of portable recyclable drinking water for public consumption and for livestock use. (2) Remove wastes for organic fertilizer agric use
Air and waste gases	Bacteria, fungi	Biofilter application of pollutant purifying bacteria. Application of bioscrubbers, immobilized microorganisms in the inert matrix, and nutrient film trickling devices for better air and gas purification. For example, bioscrubber based system for removal of nitrogen and sulfur oxides from flue gas of blast furnaces in place of limestone gypsum process, and elimination of styrene from the waste gas of polystyrene processing industries by a fungi biofilter model
Soil and land treatment	Fungi, *Rhodococcus*, *Acinetobacter*	Both in situ (in its original place) and ex-situ (somewhere else) are commercially exploited for the cleanup of soil and groundwater. Use of microorganisms (bioaugmentation, ventilation, and/or adding nutrient solution (biostimulation), that is, petroleum decontamination, can involve use of plants phytoremediation). Bacteria in association with roots of plants (Rhizobacterium), and so forth. Use of bioreactors for ex-situ treatment with the introduction of suitable microbes and environmental factors

Implications for biosafety

Biotechnology products

Modern biotechnology products are used in the agriculture, environment, and human consumption (Yadav et al., 2020; Rischer et al., 2020). Here, the product specifications are responsible for their safety. The processes used to make products are important only because they describe the quality or specifications of the product. This principle has been replicated in several extensive studies that have examined the implications of the use of modern biotechnology in medicine, agriculture, and the environment. Modern biotechnology products in agriculture include plants, animals, and microbes (Yadav et al., 2019).

Modern biotechnology products have essentially their origin in materials with which we have extensive experience in agriculture, industry, and commerce (Torres & Santos-Ordóñez, 2020). However, given the challenges in producing genetically engineered organisms that survive long enough in the environment to perform the desired functions, researchers have a strong incentive to work with well-defined systems and organisms as much as possible. The evolution of regulatory policies in the countries with the most experience in biotechnology products follows a strict and prudent pattern, and following the reassuring experiences, it follows from the fewer disciplinary needs. This has been the case with health guidelines, which are widely used for laboratory research with recombinant DNA (Carriere et al., 2020).

Risk Assessment

A study conducted by the American Environmental Association provides a list of important criteria for considering the safety of planned arrangements (Keith, 2017). They also examined risk assessment criteria and showed how these criteria might be linked in a flexible review plan that should be highly valued from a regulatory perspective. The US National Academy of Sciences (NAS) and the National Research Council (NRC) have presented a report on a framework pertinent to making decisions about the introduction of genetically modified microorganisms and plants into the environment. This study was done to identify criteria for defining risk categories and to recommend ways to assess the potential risks associated with introducing these modified organisms (Arpaia et al., 2017).

The NRC report evaluates the fundamental principle enunciated in the prior document that is the safety assessment of a recombinant DNA-modified organism. The organism "should be based on the nature of the organism and the environment in which it is introduced, not on the method by which it is modified." The discussion also points out that although genetic modification by molecular methods may be more powerful and capable of producing a wider range of phenotypes, “no conceptual distinction exists between genetic modification of plants and microorganisms by classical methods or by molecular methods that modify DNA and transfer genes.” (Que et al., 2019).

"The NRC also discusses the long history of utility and safety in the use of plants and microorganisms." Society has benefited greatly from the use of genetically modified microorganisms and plants, and field testing is essential if we are to increase our knowledge about the relative safety or risk of large-scale use of genetically modified organisms and to determine the potential utility of the modified organisms. ”The NRC report given the field testing of genetically modified plants concludes that: (Devos et al., 2018).

- Plants modified by classical genetic methods are judged safe for field testing on the basis of experience with hundreds of millions of genotypes field-tested over decades. The current means for making decisions about the introductions of classically bred plants are entirely appropriate, and no additional oversight is needed or suggested.
- Crops modified by molecular and cellular methods should pose risks no different from those modified by classical genetic methods for similar traits. As the molecular methods are more specific, users of these methods will be more certain about the traits they introduce into the plants. Traits that are unfamiliar to a specific plant will require careful evaluation in small-scale field tests where plants exhibiting undesirable phenotypes can be destroyed.
- The potential for enhanced weediness is the major environmental risk perceived for introductions of genetically modified plants. The likelihood of enhanced weediness is low for genetically modified, highly domesticated crop plants on the basis of our knowledge of their morphology, reproductive systems, growth requirements, and unsuitability for self-perpetuation without human intervention.
- Confinement is the primary condition for ensuring the safety of field introductions of classically modified plants.
- Depending on the crop species, proven confinement options include biological, chemical, physical, spatial, environmental, and temporal isolation, as well as the size of the field plot.
- Plants are grown within field confinement for experimental purposes rarely if ever, escape causing problems in the natural ecosystem

- Established confinement options are as applicable to field introductions of plants modified by molecular and cellular methods as to introductions of plants modified by classical genetic methods

NRC report given the field testing of genetically modified organisms concludes that:

- The precision of many of the molecular methods allows scientists to make genetic modifications in microbial strains that can be fully characterized, in some cases to the determination of specific alterations of bases in the DNA nucleotide sequence.
- The molecular methods have great power because they enable scientists to isolate genes and transfer them across biological barriers.
- Although field experience provides considerable information about some microorganisms—for example, rhizobia, mycorrhizae, and many plant pathogens and biocontrol agents—in general, information regarding the ecology of microorganisms and experience with planned environmental introductions of genetically modified microorganisms is limited compared with that regarding plants. However, no adverse effects have developed from the introductions of genetically modified microorganisms. Ecological uncertainties can be addressed scientifically with respect to the genetic and phenotypic characterization of the microorganisms as well as by consideration of environmental attributes such as nutrient availability. Field tests of genetically modified organisms can go forward when sufficient information exists to permit evaluation of the relative safety of the test
- The likelihood of possible adverse effects can be minimized or eliminated by appropriate measures to confine the introduced microorganism to the target environment, for example, by introducing "suicide" genes, as they become practicable, into the organisms.

Eventually, as our knowledge increases, entire classes of introductions may become familiar enough to require minimal oversight. Familiarity does not necessarily mean safe. Rather, to be familiar with the elements of an introduction means to have enough information to be able to judge the introduction's safety or risk when knowledge of the type of modification, the species being modified, or the target environment is insufficient to meet the familiarity criteria.

Possible types of risks posed for agricultural biotechnology assessment make it possible that the product likely shows potential plant characteristics to weeds (Beyleveld & Jianjun, 2017). In many cases, for the use of modern biotechnology, we will become much more familiar with the possible behavior of a genetically modified organism, which, if based on a single gene modification from the parents, would be a strange organism that we are not familiar with it in this environment. We are not. Therefore, it can be said that if there are problems with the use of modern biotechnology products, it is likely to be similar to the problems that we are familiar with and have experience as a result of using products traditionally produced in similar settings. We will analyze further in this regard.

National or regional biosafety systems

The approach that a country takes to ensure the safety of modern biotechnology products depends on existing regulatory structures. Five principles that deserve the attention of national policymakers are: 1. regulatory oversight should focus on the characteristics and risks of the biotechnology product-not the process-by which it is created. 2. for biotechnology products that need to be reviewed, the review process should be adjusted for efficiency and effectiveness while ensuring the protection of public health and environmental safety. 3. any additional regulatory requirements for new biotechnology products should be integrated into all regulatory systems governing the release of new products in the relevant sector.

Biosafety guidelines

There are benefits to incorporating biotechnology regulations into existing laws and organizational arrangements to prevent the creation of new regulatory infrastructure, especially for biotechnology. New guidelines, usually related to existing regulations, can be developed and implemented to cover laboratory methods, small-scale field experiments, and commercial publications. This often requires the establishment of a National Biosafety Committee to be supported by any biosafety committee in any research institute dealing with modern biotechnology (Savadye et al., 2020). Flexible instructions that can be easily modified in response to new techniques. Ensuring permanent access to current expertise is achieved through part-time cooperation on evaluation committees. Laws are always behind events, and in this area of knowledge, knowledge is expanding rapidly. Laws are designed to be interpreted precisely. Many countries have a law (in addition to the provisions of the common law) that can control new technology. The new law may duplicate existing regulations and, at worst, cause disputes between different regulatory bodies. The dangers of genetic manipulation are still speculative, and therefore guidelines seem more appropriate than rules that are generally designed to address a specific and defined problem (Kiran et al., 2017 & Nathan, 2017).

Conclusion

Human unsafe activities will result in an undesirable change in the environment. As a result, the whole of humanity must think about the deteriorating environmental conditions. The greater the human effort to control nature, the greater the pollution of the environment, and the future becomes more and more insecure. Environmental protection is the most important concern for the future of humanity. Biotechnology clearly holds promise as a solution to environmental problems. Environmental biotechnology has recently gained credibility due to the hard work of skilled and dedicated scientists. Biotechnology has played an important role in various fields by using environment-friendly techniques and products to eliminate environmental pollution. This research provides a review of previous research in the field of biotechnology. In addition, biotechnology application in various environmental fields was also investigated.

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