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Review Article

Emerging Agricultural Biotechnologies for Sustainable Agriculture and Food Security

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Abstract

This essay examines the potential of cutting-edge agricultural biotechnologies to advance sustainable farming practices and solve issues related to world food security. There is a growing need for agricultural production that is socially just, commercially viable, and environmentally conscious as the world's population rises. Modifying genes, genetic manipulation, and synthetic biology are examples of agricultural advances in biotechnology that present promising ways for enhancing crop resistance to environmental shocks, increase crop output, and lessen agriculture's environmental impact. Through the utilization of these technologies, agricultural scientists and farmers can create crop types that possess superior qualities including resistance to disease, drought, and increased nutritional value. These biotechnology advancements could boost sustainable farming methods, guarantee food security, and boost agricultural output. To ensure their appropriate and equitable deployment, moral social, and regulatory issues are brought up by the agricultural biotechnologies' broad use. This essay examines the current status of developing agricultural biotechnologies, as well as their possible advantages and disadvantages. It also emphasizes the significance of taking a comprehensive strategy that takes into account the environmental, social, and ethical ramifications of implementing these technologies. The aims for environmentally friendly food production and supply can be greatly advanced by emerging agricultural biotechnologies, but maximizing the possible advantages while reducing their risks requires their appropriate and ethical deployment.

Keywords: Crop Productivity; Environmental Sustainability; Genome Editing and Emerging Agricultural Biotechnologies

Introduction

Agriculture's objective throughout thousands of decades has been to produce sufficient feed, fibre, food, and biofuels to meet society's requirements. Sustainable agriculture prioritizes maintaining environmental quality, lowering agricultural input use, mitigating environmental consequences, and safeguarding the economy in its efforts to meet these same fundamental societal needs [1]. Global population growth is expected to reach nine billion people in the next thirty years, posing a challenge to the agricultural sector's ability to meet the rising need for nourishment, protein, fiber, and biofuel. A reduction in the volume of arable land and water used for agriculture, along with the effects of climate change and related extreme weather events, will also have an impact on agricultural production in addition to the increase in population pressure. We won't be able to meet growing consumer demands without developing crops that can perform better than the current types, which will require more area to be turned into cultivated acres and more inputs [2]. When everyone has physical and financial access to enough wholesome food to suit their dietary requirements and preferences for a life of health and activity, food security is achieved [3].

With the use of genes that give tolerances or susceptibility to biotic and abiotic issues, biotechnology helps to promote sustainable agriculture by lowering reliance on agricultural chemicals, especially pesticides. The sustainable growth of meals and additionally the main product-related industries, as well as forestry, fisheries, and agriculture sectors, is already supported by biotechnology. It has the potential to significantly affect the world's food security, animal and human health, the environment, and humankind's standard of living [4]. Nevertheless, the benefits of contemporary biotechnology are accompanied by several drawbacks and worries, just like with any complicated technology that affects a wide range of processes and advancements. The type and degree of both positive and negative effects will rely on the technique selected, the location and way the technique is applied, the product's final use, relevant laws, and regulations, such as the evaluation and management of risks skills, and, lastly, the necessity, importance, aspirations, and capacities of specific nations [5].

The importance of sustainable agriculture

It is common for sustainable agriculture to include both conventional and organic farming methods. The long-term outcomes of a spatially integrated approach to animal and plant production techniques include [6]:

- The ability to provide enough food, fuel, fiber, and other necessities for a rapidly growing population.
- preservation of biodiversity and growth in the availability of natural resources.
- Maintaining the agricultural systems' economic sustainability.
- Utilize non-renewable resources and farm resources as efficiently as possible, incorporating naturally processes and controls as needed.
- Improve the standard of living for agriculturalists and the community at large.

Challenges in achieving food security

A description of food insecurity is the state in which all individuals lack the physical and financial means to always obtain enough wholesome food that satisfies their dietary requirements and tastes while also leading active and healthy lives [7]. Food insecurity can result in significant productivity losses, a decline in cognitive function, and a decrease in job performance. They are all potential roadblocks to the expansion and improvement of the national economy. In recent years, India has achieved significant advancements in health-related factors. Critical health indices have steadily decreased throughout the years, including the child's mortality rate, child mortality ratio, prevalence of disease, morbidity, and deaths. India has seen improvements in life expectancy and a nearly halving of neonatal mortality over the past 50 years [8]. There has been remarkable economic growth, with notable contributions from the agricultural sector. India is the world's second-largest farmer. Farmed products and related industries, such as logging, forestry, and fishing, used 60% of the labour force and contributed 18.6% of the GDP in 2005 [9]. Nonetheless, it appears that malnourishment and persistent hunger are widespread issues. At 211 million, India presently has the highest rate of undernourishment worldwide. From 172.4 million in 1990–1992 to 237.7 million in 2005–07—a nearly 38% increase—there were more undernourished people overall [10].

Causes of India's current food insecurity

There are many causes of India's current food insecurity such as.

In rural and tribal areas

This is mostly because there hasn't been an increase in agricultural productivity because there aren't enough markets and resources available to achieve agricultural stability. India is currently experiencing an agrarian crisis due to several factors, the most notable of which is the significant reduction in government development spending in the 1990s, especially in rural areas [11]. In rural areas, there are less career and educational options, which has made the issues worse. Food security is impacted by agricultural productivity, which in turn affects food availability due to climate change. In addition to rice and wheat, rain-fed crops are mostly impacted by climate change [12].

In urban population

The main factor that causes malnutrition in urban areas and must be addressed is the significant percentage of the workforce that works informally, which leads to an unplanned development of slums that lack basic hygienic and medical amenities. The percentage of migration from rural to urban areas has been steadily rising; between 1971 and 200, it went between 16.5% to 21.1% of all migration [13]. These rural migrants make up a sizable portion of the population known as the "informal sector." These metropolitan regions' rural origin pockets have given rise to a variety of slum settlements with poor housing, poor access to water and sanitation, and higher rates of food insecurity [14].

In children and mothers

Due to issues related to inequalities in gender, poverty, overcrowding, and lack of education, the children face food insecurity. Poverty is a big cause as it reduces the amount of sustenance available to children. Children that are malnourished may result from overcrowding, which is associated with competition for food, particularly in rural areas where food access is scarce. Another area of worry is that moms may not have enough understanding about nutrition, breastfeeding, and parenting [15]. Due to being fed last and viewed as less important than males, female children are more disadvantaged and suffer more because of gender inequality [16].

Unmonitored nutrition programmes

Even though the nation has several programs established with the primary goal of boosting nutrition, these are not being carried out effectively. For example, the Mid Day Meal Scheme (MDMS) has not yet been implemented in several states. The supply of food is greatly impacted by the inadequate implementation of nutritional programs that have been shown to be successful in states with high rates of poverty, such as Bihar and Orissa [17].

Lack of intersectoral coordination

A contributing factor to this problem is an absence of cogent food and nutritional policies and cross-functional collaboration across the government's several ministries, including those of agriculture, finance, women and child health, and health and family welfare.

Role of biotechnologies in agriculture

The discipline of farming science, also known as agricultural biotechnology, or agrotechnology, works with live species like animals, plants, and microorganisms to transform them using scientific tools and techniques like genetic manipulation, propagation of tissues, molecular markers, vaccinations, and molecular diagnostics. Biotechnology with an emphasis on agriculture is known as agricultural biotechnology. Ever since the earliest methods of farming appeared thousands of years ago, traditional biotechnology has been utilized, in the broadest sense, to enhance plants, animals, and microorganisms. Transforming plant traits has become much more precise, quicker, and possible from a larger number of potential sources because of modern biotechnology. Giving researchers access to new techniques in biotechnology for agriculture and related sectors is its main goal.

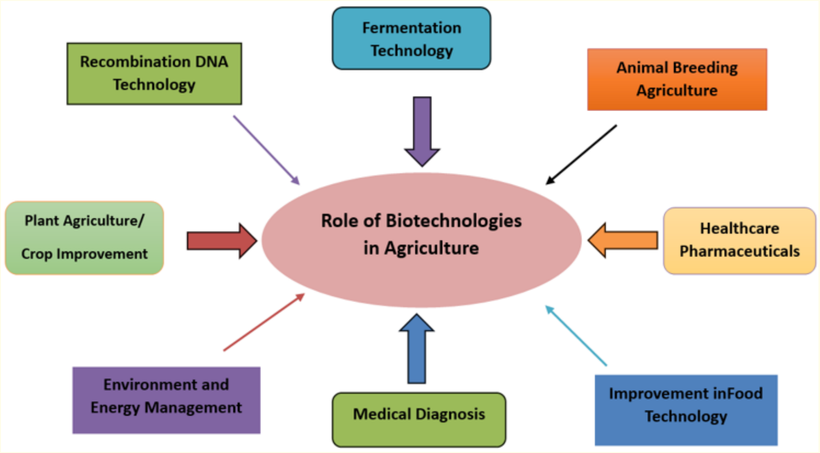

Figure 1

A plethora of employment prospects exists in the ever-evolving field of agricultural biotechnology. Aside from hiring people for development and research. Fisheries, poultry, dairy, floriculture, and horticulture are among the numerous agricultural biotechnology-related industries that the division services. Through connections to after harvesting, food processing, or genetically modified technologies, agriculturally orientated biotechnology can also enhance scholarly knowledge. Improvement of seed quality, development of disease-resistant cultivars, and productivity gains are the three primary objectives of biotechnology in agriculture. Boosting and maintaining yields, fortifying products against pests and illnesses, fortifying products against cold and drought, etc [18].

Career prospects in agricultural biotechnology

Global demand for agricultural biotechnology is rising. Occupation possibilities for a variety of fascinating vocations are brought about by this increase. Across the globe, public (government or sponsored) organizations and institutions, as well as commercial agricultural firms, employ people with a diverse range of talents and educational backgrounds. Gaining additional knowledge and experience will help you find a job with greater autonomy and a higher income as the industry grows.

Research and development, or R&D

The process of creating new products and seeing them through to market readiness is known as research and development. These two procedures are used in agricultural biotechnology to create novel goods that are sold commercially. Senior scientists who conduct fundamental scientific research at educational institutions, government labs, or businesses are known as research scientists. Often, the inspiration for a new product comes from the researchers themselves. Research scientists contribute specialized knowledge and in-depth understanding of a particular scientific topic. Usually, they oversee creating unique experiments and determining which inventions are patentable.

- **Scientist for Process Development:** Your objective is to raise your production unit's efficiency and put process controls in place to guarantee that goods are produced regularly and to a high standard.
- **Independent contractors**: Produce stores, agribusinesses, and agricultural companies provide employment opportunities for freelancers.
- **Management of agriculture:** Professionals in this field are usually employed in the dairy, agriculture, or animal production industries. In addition to working on machinery and overseeing human resources, they are also responsible for overseeing agricultural administration, designing plans and tactics for high yields, and managing associated operations.
- **Consultants in agriculture:** Agricultural consultants help their clients run their businesses or activities as profitably and efficiently as possible by offering guidance, solutions, and support.
- **Product Creation:** These experts are required by manufacturing organizations to oversee and comprehend the processes that result in the finished product. They are involved in the production of a wide range of goods, including food, beauty dyes, and medicines.

- **Agronomic biotechnologist:** Experts in the application of science, technology, research, and various other techniques to modify living things, including plants and animals, are known as agricultural biotechnologists. Even though some of them only work with crops, they are frequently referred to as agricultural biotechnologists. Among the tools and procedures that biotechnologists use include tissue culture, genetic engineering, genetic markers, molecular diagnostics, and vaccinations. Desirable features from a single plant are transferred to entirely new species through these methods. Thus, transgenic crops are characterized by the intended flavour, colour, pace of fruiting, timing of harvest, resistance to disease and livestock, etc.
- **Industries:** Jobs related to agricultural biotechnology can be found in both public and private (government-sponsored or founded) institutions and agencies.

Genetic engineering in crop improvement

The technique of manually introducing additional DNA into an organism is called genetic engineering, sometimes referred to as genetic alteration. The objective is to give the animal one or more additional features that aren't already there [19]. It takes recombinant DNA to create genetically altered, modified, or transgenic creatures. DNA from distinct organisms or regions within one genome that are rarely found in nature can combine to form recombinant DNA. Using genetic recombine techniques, genetic engineers have been able to modify the gene sequences of plants, animals, and other species to express features. As engineers and scientists collaborate to determine the locations and purposes of genes in the DNA sequences of diverse organisms, the applications for genetic engineering are growing. After classifying each gene, engineers work out how to change it to generate beneficial species like more meat-producing cows, microorganisms that manufacture fuel and plastic, and crops that are resistant to pests [20].

Genetic engineering benefits human society greatly in additional to enabling GMO crops and plants to flourish in a range of environments. It is a contemporary tool that plant breeders can employ to expedite the breeding program, not a replacement for traditional plant breeding. Genetically modified (GM) crops with unique genes and favourable traits, such as increased yields, resistance to herbicides, insects, and diseases, drought, salinity, and others, were produced by transgenic technology [21].

GMO development and crop improvement

agricultural improvement is the ongoing process of utilizing genetic diversity to enhance beneficial features in agricultural plants. Before the end of the 1800s, changes in the genetic composition of crops mostly happened because of laborious field phenotypic selection, with little understanding of the fundamental principles of reproduction or the relationship between genotype and phenotype. But since the development for contemporary plant breeding and the field of genetics, breeders have employed a variety of scientific techniques to expand the genetic variation that is accessible and to exert more control over the relationship between intentional genetic modifications and the phenotypic traits that result. The revolution described in the first instance mentioned was made possible by variations induced by compounds or radiation, which has given rise to at least 3240 improved varieties from all our major crops worldwide. Meanwhile, more recent methods such as gene editing and genetic modification (GM) have greatly increased the ability to manage the breeding process and produce genetic variation.

With the advancement of genetic technology, plant breeders were able to select for desirable features by using their knowledge of a plant's genes. Known as classical plant breeding, this method of genetic manipulation involves creating crosses and choosing new, superior genotype combinations to alter the genetic makeup of plants. The practice of traditional plant breeding has persisted for hundreds of years and is still widely employed today. Although useful, breeding plants is a limited tool. Initially, only two plants that are capable of sexual reproduction can engage in breeding [22].

Applying genetic engineering to enhance crop yield

Particularly cost-effective and early application of genetically engineered crops (GE) has been to establish pesticide and insecticide tolerance in field crops. To stabilize the production in the face of changing environmental conditions, there is currently a lot of interest in introducing stress tolerance in crop varieties. Furthermore, several transgenic cultivars with increased nutritional contents have been made available because the increased nutritional value of crops has attracted attention as a means of addressing malnutrition in developing nations and satisfying naturalists' dietary preferences. Additionally, some progress has been made in the development of crops with chemical constituents of significance to industry and the use of plants as carriers of pharmaceutical medicines [23]. Compressed environments with high impedance which significantly lower yields of crops, high temperatures, and nutrient and water stress are just a few of the challenging conditions that must be overcome for agriculture to become sustainable and to produce enough food to feed the world's growing population. The knowledge of the molecular, cellular, and epigenetic mechanisms that coordinate plant responses to abiotic stress has advanced recently. This knowledge will provide the foundation for the engineering of better crop plants with more efficiently designed root systems and optimized metabolisms to improve rock penetration, water, and nutrient uptake, and use efficiency. We cover these developments in this review, along with how the knowledge they produce may be applied to incorporate successful crop engineering techniques using genome editing or gene transfer technology [24].

There are currently some progresses made in genetic engineering to create cultivars that are resistant to abiotic stress. A complicated system is required to handle the frequent occurrence of multiple stresses in crops. Possibilities to create transgenic crops with good yield retention under stress are made possible by new technology. It is important to focus on studying abiotic-stress-tolerant crops in field settings, particularly at the reproductive stage [25]. Despite ordinary breeding, which allows genes for species that are related to be transferred solely, transgenic breeding allows genes to be transferred across taxonomic boundaries. In comparison to conventional breeding, it also provides new pathways for plant improvement in a shorter amount of time and the ability to incorporate new genes without experiencing incompatibility issues. Here are some examples of how genetic engineering is being used in plant breeding [26].

Precision agriculture techniques and technologies

Precision agricultural is a technology-driven agricultural method that aims to increase crop output by assisting farmers in making more informed decisions to increase farming efficiency. It also reduces resource waste. The first part of precision agriculture focuses on the methods employed, while the other half highlights the technologies included [27].

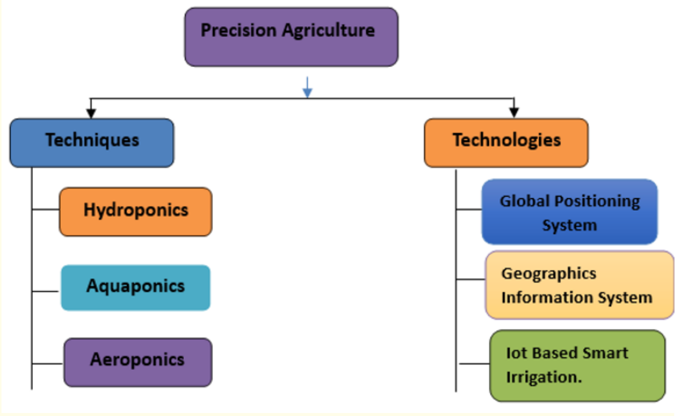

Figure 2

Technique of precision agriculture

Hydroponic

Plants are cultivated soullessly using hydroponics, a technique that involves growing plants in water that is rich in nutrients solutions. With this method, producers may maximize their use of water and nutrients, which boosts output and conserves resources. Hydroponic systems reduce waste and create perfect growing conditions by supplying nutrients straight to plant roots, which leads to quicker growth rates and larger yields. Furthermore, hydroponics is appropriate for a variety of crops and regions since it enables year-round production in controlled settings.

Aquaponics

Fish waste supplies plants with nutrients, and plants purify fish water in an eco-friendly system known as aquaponics, which blends aquaculture and hydroponics. The production of nutritious food results from this closed-loop ecosystem's reduction of water uses and removal of the need for synthetic fertilizers. Since they use waste materials from one aspect for the benefit of the other, aquaponic systems provide an equilibrium and self-sustaining ecosystem, which has considerable benefits when thinking of resource efficiency.

Aeroponics

With aeroponics techniques a high-tech farming technique, plants are cultivated without soil in an atmosphere of mist or air. A nutrient-rich solution is misted on plant roots that are suspended in mid-air on a regular basis. This method facilitates accurate regulation of environmental factors and nutrient supply, resulting in quick development and large harvests. Aeroponic systems are perfect for vertical farming and urban agriculture since they use less water and space than conventional farming

Technologies of precision agriculture

Global positioning system

It is necessary to map crops in order to identify areas that require irrigate or have varying amounts of moisture in the soil since technology can provide precise location data. A farmer can make comprehensive field mapping and set irrigation zones according to crop requirements and soil properties by combining The Global Positioning System with smart irrigation systems. In order to minimize water waste and maximize water utilization, this allows targeted irrigation, which guarantees water is only provided to places where it is needed.

Geographic information system

GIS technology combines information from GPS with other spatial data to build detailed maps and evaluate spatial correlations, including soil types, geography, and weather conditions. GIS gives farmers the ability to evaluate elements like soil texture, drainage patterns, and slope that affect soil moisture levels in smart irrigation systems. Farmers can create irrigation plans suited to particular field circumstances by superimposing these layers and evaluating the data, increasing crop yields and water efficiency.

Internet of things (IoT)

Technology is essential to smart irrigation systems because it allows for real-time irrigation parameter control and monitoring. IoT devices gather information on agricultural water requirements, weather, and soil moisture levels. Examples of these devices are automated irrigation controllers, weather stations, and sensors. Wireless transmission of this data to a controlled platform enables real-time analysis. This analysis allows the innovative irrigation system to precisely tailor irrigation schedules, volumes, and duration to the needs of individual crops. Smart irrigation systems make sure crops get an appropriate quantity of water at the right time, resulting in successful development and water savings, by continuously tracking the moisture content of soil and surrounding factors.

Conclusion

Finally, new developments in agricultural biotechnologies present hope for addressing the issues of food security and sustainable agriculture. Through the application of biotechnology, including genome editing, genetic engineering, and synthetic biology, scientists and agriculturalists can create crops that possess superior qualities including higher nutritional value, resistance to disease, and drought tolerance. These biotechnologies minimize environmental effects and reduce the demand for chemical inputs by enabling the production of resilient crop types that can flourish in a variety of environmental circumstances. Additionally, by raising crop yields, strengthening crop quality, and boosting agricultural productivity, biotechnology advancements offer the potential to address concerns about global food security. But it's imperative to make sure these technologies are deployed responsibly and ethically, taking social, ethical, and legal issues into account. We can ensure sufficient food for foreseeable futures by paving the road for a more resilient and environmentally friendly agricultural future through the ethical adoption of developing agricultural biotechnologies.

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