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Review Article

The Role of Biotechnology in Shaping the Future of Agriculture Sector

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Abstract

Biotechnology serves as an elementary factor in the advancement of modern agriculture, providing a range of pioneering solutions that have the potential to convert crop productivity, improve nutritional quality, and endorse environmental sustainability. This detailed review explores the diverse functions of biotechnology in shaping the future of agriculture. The applications of biotechnology in agriculture are extensive and significant, addressing aspects from crop enhancement to pest and disease control, soil health, and sustainable agricultural practices. However, the widespread implementation of biotechnology in agriculture also raises important societal, economic, and ethical issues. In terms of food safety, environmental sustainability, and socio-economic fairness, it is crucial to establish stringent regulatory frameworks and effective risk assessment protocols to responsibly implement biotechnological advancements. Building trust and gaining support for agricultural biotechnology requires addressing public perceptions and encouraging dialogue among stakeholders. Education, transparency, and active engagement with stakeholders are vital for effectively navigating the intricate landscape of biotechnology governance and creating a supportive environment for innovation. This review aims to enlighten policymakers, researchers, and stakeholders about the transformative capabilities of biotechnology in tackling urgent global issues like food security, climate change, and environmental sustainability. By seizing the opportunities presented by biotechnology, we can pave the way for a more resilient, fair, and sustainable agricultural future.

Keywords: Biotechnology; Advancements; Food; Agriculture; Environment; Production

Introduction

The history of agricultural food production, which dates back about 10,000 years, is dotted with advances in biology and technology. In the 1960s, when the Green Revolution was still relatively new, worldwide study; in many regions of the world, investments in agricultural modification of the cereal grains maize, rice, and wheat produced new high-yielding varieties that were widely cultivated and increased food security [1,2]. Since the end of World War II, one of the most remarkable accomplishments has been the extraordinary rise in research-driven agricultural productivity, which has nourished millions and acted as the foundation for economic change in numerous impoverished nations, particularly those on the Indian subcontinent [3]. This "Green Revolution" has averted the grim forecasts of death and famine in Asia [4]. Instead, food production has surpassed population growth, primarily due to significantly higher yields and an expanded area of irrigated land. The per capita accessibility of food increased, and prices decreased. Food biotechnology is the process of enhancing food to make it safer, healthier, and tastier by using living organisms or their byproducts. In order to improve the quality and amount of food accessible to the world's population, this field modifies plants, animals, and microbes using techniques including genetic engineering, fermentation, and molecular biology [5]. The agriculture sector business will continue to undergo significant change as a result of biotechnology as we head towards a more technologically advanced future.

Food biotechnology has the potential to help millions of people globally, from enhancing food safety and quality to developing creative solutions to global food concerns [6]. In order to feed a growing population-which is expected to reach over 10 billion people by 2050-and lessen the adverse effects of food production on the environment, the future of food production depends on major advancements in microbiology, bioprocessing, enzyme technology, and artificial intelligence [7]. In the rapidly changing world of contemporary agriculture, biotechnology has emerged as a crucial driver of innovation and advancement. With its wide range of tools and methods, biotechnology provides a comprehensive strategy for tackling the complex issues facing global food production. By effectively combining genetics, molecular biology, and bioinformatics, biotechnology has transformed traditional farming practices, marking the beginning of a new age characterized by efficiency, sustainability, and resilience. Fundamentally, biotechnology embodies the integration of various scientific fields focused on leveraging the natural capabilities of living organisms to boost agricultural productivity, reduce environmental harm, and enhance global food security [8]. By deciphering the genetic codes of plants and animals, biotechnologists have achieved remarkable understanding of the molecular processes that influence growth, development, and adaptation, setting the stage for precise interventions that improve agricultural results [9]. This review entails the information about the role of biotechnology in revolutionizing the agriculture sector.

What is biotechnology?

Biotechnology is any technological application that uses biological systems, live creatures, or their derivatives to create or alter goods or processes for a particular purpose. It also includes the utilization of living systems and organisms to produce or create useful products. It frequently crosses over into the domains of bioengineering and biomedical engineering, depending on the instruments and uses. In order to improve food qualities like taste, aroma, shelf life, texture, and nutritional content, this research identified a few uses for biotechnology in fermentation of food [10]. When opposed to the substantial time and cost requirements of conventional approaches, biotechnological advancements have led to the widespread availability of inexpensive, quick identification methods. Both conventional and more advanced techniques are used in lower-middle income economies to keep an eye on the microbiological quality of foods and their compliance with global standards [11].

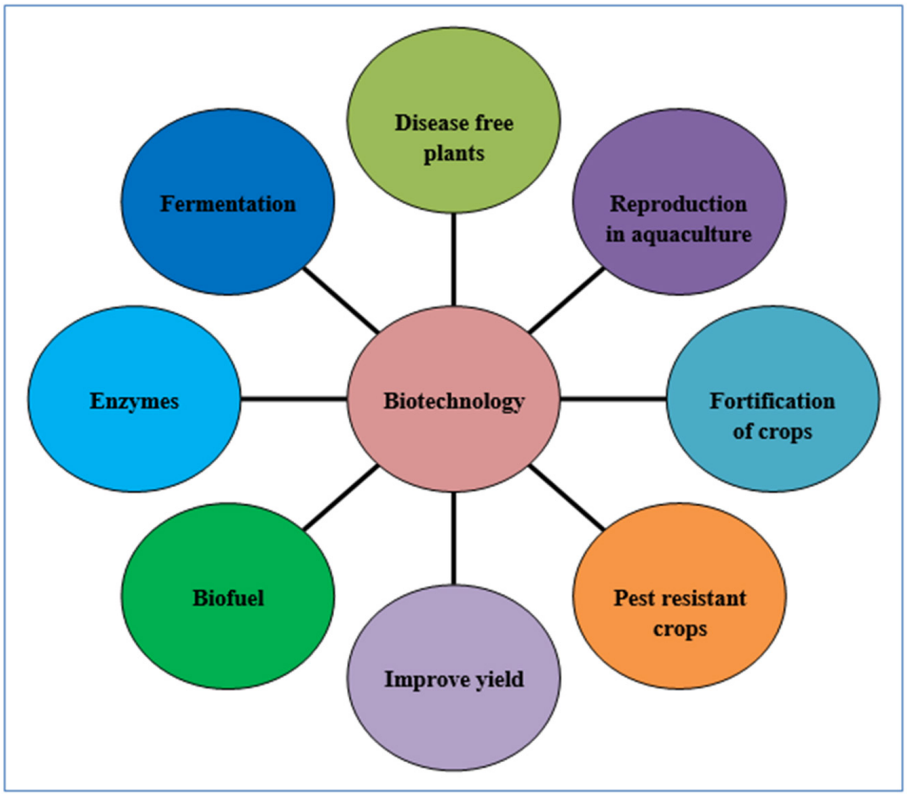

Figure 1: Benefits of biotechnology.

Using food biotechnology could potentially result in healthier food for both humans and animals. Foods with improved nutritional qualities are soon to be available on store shelves. By supplying more beneficial chemicals, such as higher quantities of vitamins and antioxidants and lower levels of bad fats, food biotechnology may help fight chronic diseases [12]. Natural products have been utilized for centuries. The processing of these products to derive significant benefits has been a focal point throughout various

scientific eras. Biotechnology, an advanced yet established field, involves the development or modification of products for specific applications using living organisms and/or their derivatives. This field encompasses all genera of organisms, ranging from simpler forms such as viruses and bacteria to more complex ones like plants and animals. Consequently, biotechnology has emerged as a crucial aspect of contemporary industry, agriculture, and medicine. Modern biotechnology offers a variety of techniques that scientists employ to identify and manipulate the genetic makeup of species for the purpose of agricultural product development or processing [13,14]. Biotechnology provides considerable environmental advantages by facilitating sustainable pest control, preserving soil health, managing nutrients effectively, and enhancing climate resilience in agricultural practices. Nevertheless, it is crucial to implement biotechnological advancements responsibly, considering potential risks and uncertainties, while adopting a precautionary strategy to protect environmental integrity and conserve biodiversity [15]. The benefits of biotechnology are summarized in Figure 1.

Agriculture biotechnology

The necessity for experimental data and good scientific judgment to weigh the advantages and risks to society has been brought to light by recent developments in agricultural biotechnology. To take part in this evaluation, nutrition scientists and other animal biologists must have a fair grasp of the problems. Producers have benefited from the majority of crop plant alterations to date. Crops have been modified to improve yields, increase shelf life, guard against stresses, and reduce the use of pesticides and herbicides. Consumers stand to gain from the development of food crops with higher nutritional content, medicinal qualities, improved flavor, and aesthetic appeal in addition to the environmental advantages of less pesticide and herbicide use [16]. New Plant Breeding Techniques (NPBTs) represent a collection of agricultural biotechnology tools utilized in the food and agriculture sectors for the genetic enhancement of plant varieties and animal populations, as well as for the characterization and preservation of genetic resources, diagnosis of plant and animal diseases, among other applications [17,18]. These techniques provide a range of scientifically-based strategies to address global food insecurity and the effects of climate change, both of which are escalating at a concerning rate. Nearly ten years ago, it was projected that global food production would need to be doubled by 2050 to satisfy the demands of the ever-increasing human population. Furthermore, the COVID-19 pandemic and geopolitical tensions have posed significant threats to food security on a global scale. Farmers can implement a comprehensive array of tools, including biotech crops that are resilient to climate change and can better endure various stresses such as drought, heat, and flooding [19,20]. As of now, 44 countries have approved 385 genetic modification events (either stacked or singular traits) for food use, encompassing 24 plant species. The agricultural biotechnology sector is intrinsically linked to the therapeutic biotechnology sector, as both share common traits such as lengthy timelines for product commercialization. Nevertheless, the unique challenges, goals, and opportunities inherent in agricultural biotechnology foster a distinct landscape for innovation and entrepreneurship. Innovation refers to the introduction of new processes or methodologies. Biotechnology entrepreneurship encompasses the full range of activities required to create, develop, and eventually market a biotechnology product. Both sectors offer fresh business prospects that, similar to the advancement of agricultural biotechnology traits, motivate entrepreneurs to pursue the creation of disruptive enterprises rather than simply disruptive technologies within established business models. In this chapter, the authors underscore the unique aspects of entrepreneurship in the biotechnology field in contrast to other industries and highlight the vital importance of biotechnology entrepreneurs in the agricultural sector [21].

Increase in genetically modified crops

There is still worry that these advantages may come at the expense of the environment or put consumers at greater risk. The majority of American consumers are unaware of how widespread genetically modified foods have become. Although there appears to have been a rise in consumer understanding of biotechnology in the past ten years, the majority of consumers are still perplexed by the science. In Europe, concerns about the effect on food supply safety are significantly higher than in the United States. To guarantee a secure food supply and reduce environmental risk, a genetically modified crop must undergo regulatory review by up to four federal regulatory agencies before it can be put into commerce [22]. The creation of genetically modified, stress-resistant crops is a top research goal since the world's population is growing and there is a greater chance that main food crops will yield less as a result of climate change. The identification of the genes influencing significant agronomic features related to food production and quality has increased due to the convergence of low-cost genome sequencing, enhanced computational power, and high-throughput molecular phenotyping methods [23]. The impact of Genetically Modified (GM) crops on food security remains a contentious issue in public discourse. GM crops have the potential to enhance food production and increase food availability. Additionally, they may affect food quality and nutrient content. Furthermore, the cultivation of GM crops could affect farmers' incomes, thereby influencing their economic access to food. While GM crops alone cannot resolve the issue of hunger, they can play a vital role in a comprehensive food security strategy [24].

Biotechnology: A future need

Without a doubt, biotechnology discovery research will be at the heart of many advances that society will experience by 2050. However, the advancements made in biotechnology research today have a larger or smaller chance of serving as the foundation for future innovation, depending on how the future turns out. Furthermore, the absence of a broad open innovation culture between academics and industry raises the possibility of missing out on innovations that, in terms of trends, are likely to satisfy consumer or corporate demands [25]. The world's future depends on a wide range of developments, such as the shift to renewable energy [26] and decentralized storage, the global policy

approach to allow the use of new genomic technologies, patients adopting new treatments, society adopting preventive medicine or demanding transparency about food properties, dietary changes, the development of new high-tech materials, lifestyle changes, and advancements in robotics and artificial intelligence. By tracking these developments and extrapolating their long-term impact on our way of life, scientists may be inspired to take a translational step and open avenues of biotechnology discovery research that would serve as the foundation for future needs research and innovation [27,28]. Recent advancements in biotechnology have significantly improved agricultural output to satisfy global food demands. In addition to fulfilling essential human needs, agricultural biotechnology promotes the efficient use of natural resources, contributing to environmental sustainability. Scientific researchers are dedicated to addressing the growing need for healthy crop production, which could alleviate poverty and hunger, thereby enhancing human security, resilience, and sustainability [29]. The Sustainable Development Goals (SDGs) support the future creation of new, enhanced, and effective cultivars to address global food and energy challenges. Cutting-edge technologies in agronomy offer genetic and molecular insights that bolster agricultural productivity in the face of biotic and abiotic pressures [30]. Through scientific farming practices, numerous Genetically Modified (GM) crops can be cultivated sustainably in various environmental conditions. The adoption of these crops can reduce labor demands and protect farmers from carcinogenic and other harmful chemicals [31]. The potential applications of agriculture are given in Figure 2.

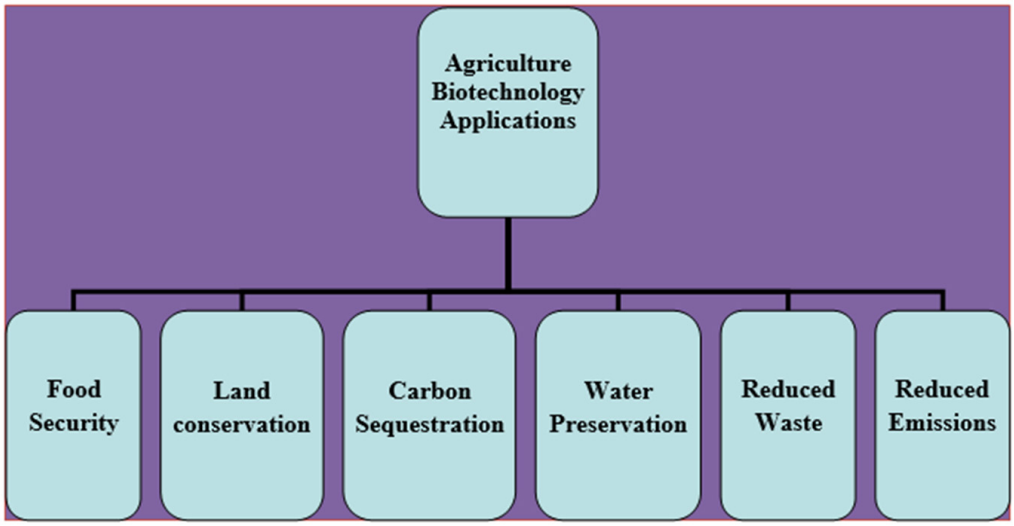

Figure 2: The potential applications of agriculture.

Conclusion

The sector of food biotechnology is undergoing rapid advancement, distinguished by a wide range of applications and innovations across food processing, engineering, packaging, nutrition, and preservation. This dynamic transformation includes the implementation of gene editing technologies, synthetic biology, and nanotechnology. Food biotechnology promises to facilitate the development of functional foods, biodegradable packaging options, and alternative protein sources, while also improving food production efficiency, reducing food waste, and enhancing the sensory qualities of food products. As we look to the future, the potential of food biotechnology is extensive, with the capacity to revolutionize global food production and consumption. It is essential in addressing challenges related to global food security and sustainability by creating crops that are more resilient to environmental stressors and lessening the need for pesticides and fertilizers. This review summarizes the multifaceted impacts of food biotechnology, which is poised to transform food systems towards a more pliant, sustainable, and resourceful future.

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