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Biotechnology's Contribution to Achieving Sustainable Agriculture and Enhancing Food Security

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Abstract
Global population growth will make it difficult for agricultural output to maintain without depleting vital environmental resources. To address the global food crisis, a proactive and comprehensive strategy will be needed. Modern biotechnology-enhanced crops that have been genetically modified (GM) constitute a significant collection of techniques that may contribute to food security and sustainable agriculture. In a recent symposium organized in conjunction with the 15th IUPAC Global Conference in New Delhi, India, some cutting-edge biotechnology methods were discussed. This presents the latest agricultural biotechnology technologies discussed at the symposium, highlighting unique research and emerging developments in the field. This conversation focuses on how biotechnology for agricultural use fits into the framework of enhanced food security and sustainable agriculture, and how it might be utilized to encourage the ongoing creation and acceptance of advantageous genetically modified crops.

Keywords: Sustainable agriculture, genetically modified crops, food security, and semiochemicals

1. Introduction

Agriculture has long sought to meet societal demands by producing adequate food, fiber, feed, and biofuel (Schulte *et al.,* 2019). Sustainable agriculture aims to achieve these same fundamental social needs with a focus on maintaining economic viability, cutting back on agricultural inputs, and lowering environmental effects. It will be difficult for the agricultural industry to keep up with the rising need for food, feed, fiber, and biofuel as the world populace is expected to reach 10 billion people over the next 30 years. Aside from increased population pressure, factors such as climate change, associated extreme weather, and restrictions on the amount of water and arable land that can be used for agriculture will have an impact on agricultural production (Gołaś *et al.,* 2020). To meet rising societal demands, more land must be converted into agricultural acres of land, and more inputs must be required. This can only be done if crops that can exceed current types are developed.

Achieving food security requires a comprehensive strategy of these obstacles without leaving a bigger environmental legacy. "Everyone always has physical and financial access to sufficient, wholesome food that satisfies their appetites and meets their nutritional needs for an active and healthy lifestyle. O'Hara and Toussaint (2021) cite the World Food Program as saying this. Despite the complexity and dependence on several The capacity of In order to enhance crop yield and output without endangering the foundation of environmental resources, the agricultural sector will be crucial given the socioeconomic, infrastructural, and political problems at play. Biotechnology in agriculture has a significant deal of potential to support food security and can be improved through sustainable agriculture, however, agricultural biotechnology's function and prospective benefits for food security and sustainability are still being realized (Tricarico *et al.,*2020). Biotechnology is defined by in addition to the The CBD, or Convention on Biological Diversity, "any technological device that uses living organisms, biological systems, or derivatives thereof to make or modify products or processes for particular uses."According to this inclusive suggesting, biotechnology has been utilized in farming for a very long time to selectively breed for desirable traits, improve genetic material, and increase crop genetics. Agricultural biotechnology also encompasses more recent genetic and molecular techniques, such as cell culture, embryo rescue, twin haploids, and marker-assisted development, which adds context and refines this concept (Thomson *et al.,* 2022). Compared to conventional breeding, the use of these biotechnology techniques has sped up and improved the efficiency of picking desired features and helped expedite the creation of pure genetic lines. Transgenic crops, often known as genetically modified (GM) crops, are produced using genetic and molecular technologies and are at the core of the study of contemporary agricultural biotechnology.

Munaweera *et al.,* 2022 was to draw attention to the negative impacts of climate change on plants, especially crop yield, and to argue that biotechnology is a useful tool for raising agricultural production and preparing for climate change. The article discusses the many negative effects of climate change on plants and crops in a detailed manner. It asserts that the creation of agricultural varieties resistant to environmental stress and contribute to sustainable agricultural productivity was made possible by biotechnology's cutting-edge techniques. The success or widespread application of the aforementioned biotechnology approaches in enhancing agricultural production is not supported by the text with any examples or evidence that are precise enough to justify them. Delgado *et al.,*2019 suggested the SPAE initiative (Sustainable Precision Agriculture and Environment) upcoming breakthrough in precision agriculture. The WebGIS framework is presented in the study as an organizing principle to link small intelligent farms to a local and global perspective on agriculture. The authors also stress the significance of AI, robots, drones, and the big data, automation, and Internet of Things (IoT) in creating a worldwide "Digital Twin" that may support conservation and management that is site-specific methods. They contend that policymakers and the agricultural sector can improve incomes and ensure the sustainability of agricultural systems around the world by utilizing cutting-edge technologies and a data-driven strategy.

Singh *et al.,* 2022 was to look into how post-harvest zones of fruit degradation in apple storage can be found and predicted using deep learning models, specifically A few examples of Among the convolutional neural networks (CNNs) are Mask R-CNN, DeepLab, and U-Net. In particular, it looks at the use of deep learning models in the management and post-harvest physiology of fruits and vegetables. While minimizing its effects on biodiversity and natural ecosystems, the application of AI to precision farming can help to ensure food security. There are restrictions to take into account, even though deep learning models have shown effectiveness in several fields, including object recognition and image processing. Adenle *et al.*, 2019 make the case that low-tech methods, albeit having lower yields, might be more effective at enhancing food security and fostering sustainable farming. International Agricultural Research Consultative Group (CGIAR) and other pertinent sources are examined. The importance of evidence-based policies that encourage a blend of low- and high-tech approaches, suited to particular situations was emphasized. A thorough examination of the possible economic, social, and environmental effects of using low-tech solutions on a bigger scale may also be missing from the research.

Chaudhary, and Kumar, 2022 discussed how the EU Green Deal and Sustainable Development Goals (SDGs) relate to achieving both food security and sustainable growth in agriculture, taking into account the threats posed by the recent military strife in and the COVID-19 pandemic. It states that the biotechnology industry, in specific plant biotechnology, agricultural, and AI systems, can significantly contribute to achieving food security by increasing crop output, minimizing environmental impact, and better resource management. Although the biotechnology and AI systems have enormous promise to enhance food security, some other problems and restrictions need to be considered. The aim of Martinho *et al.,* 2023 connections between artificial intelligence (AI) and food security, as well as how these factors affect Agriculture 4.0's perspective on agricultural planning. The researchers looked at numerous Agriculture 4.0 technologies and practices, including big data, the IoT, drones and sensors, and machine learning approaches. The results show how important it was for sustainable enterprises and a reliable food supply to incorporate new technology into Era 4.0 along with Climate-Smart Agriculture practices.

Cheng 2023 utilized a neural network to examine the ecological agriculture development plan in the context of the environmental economy. It suggests a brand-new approach that combines ecological agriculture with artificial neural networks, known as EA-ANN (Ecological Agriculture-Artificial Neural Network). Artificial neural network integration, such as the suggested EA-ANN technique, boosts agricultural productivity, increases forecast accuracy, and optimizes energy utilization. The recommended method's or the analysis's shortcomings aren't specifically mentioned. Sayed ***et al.***, 2022 investigated Wheat was grown on small, medium, and large-scale farms. They examined the various farming practices using K-means clustering and made suggestions for each cluster on how to increase yield through mechanization. The study's findings showed that smallholding farmers needed mechanization, which could be accomplished by using rental services. Its single-minded concentration on wheat crop farming operations poses a restriction, perhaps limiting the applicability of the findings to other crops or geographical areas.

Liu 2021 employed the Internet of Things (IoT) and machine learning to enhance the management efficiency of sustainable agricultural development. In broad agricultural base regions, IoT and machine learning technologies, combined with the specified architecture and intelligent sensor network equipment, help to improve efficiency, reliability, and data completeness. The suggested platform and network architecture's ability to scale may not have undergone thorough testing, which limits its applicability to bigger agricultural enterprises. Yadav ***et al.***, 2023 utilized an analysis using machine learning to look at customers' present semantic inclination for utilizing technology at various levels of operation in agriculture. Their uses machine learning to examine consumers' semantic propensities for adopting technology in agriculture. Using data mining techniques, the researchers extract user comments and conversations concerning agritech from Twitter. By offering insights into how information seekers make decisions and the influence of direct communication channels like Twitter on agricultural technology adoption choices. The analysis's choice of machine learning models and approaches could have its drawbacks, such as overfitting, model interpretability issues, or performance restrictions.

2. Common Bean Genetically Modified for Virus Resistance

A significant development in agricultural biotechnology is the common bean that has been genetically modified to be viral resistant. The genetic makeup of the common bean plant has been effectively altered through the use of genetic engineering techniques to give resistance against harmful viral infections. The modification entails inserting particular genes into the genome of the common bean, enabling it to generate proteins that recognize and kill viral infections. These proteins, which are frequently taken from other plant species or microbes, prevent infection and reduce production losses by thwarting the viruses' ability to replicate and propagate within the bean plant. Both farmers and consumers can gain greatly from the virus-resistant common bean. As bean plants are shielded against viral infections that can wipe off entire harvests, farmers can see greater crop output. For farming communities that depend on bean cultivation, this results in increased food security and financial stability. This genetic change benefits consumers as well since it assures a more continuous and reliable supply of common beans, minimizing price swings and potential shortages. The modified beans also support farming methods that are environmentally friendly by lowering the demand for chemical pesticides. Common beans that have been genetically modified to resist viruses are a big step toward addressing issues with food security and advancing sustainable agriculture. **Figure 1** depicts the bean golden mosaic virus (BGMV)

Figure 1: *Image of BGMV*

3. Genetic Engineering for Disease Resistance and Antifungal Plant Defensins: Mechanisms of Action

Around the world, fungi and oomycete infections pose a danger to food safety and agricultural output, resulting in crop yield losses of 10% to 15%. These infections continue to be a problem despite the creation of resistant cultivars and chemical fungicides. As a result, there is an urgent need for safe and efficient antifungal medications with original, fungi-specific mechanisms of action. The generation of cationic antimicrobial peptides like plant defense is one of the many defense systems that plants have evolved. Plant defensins are tiny peptides that have a conserved primary structure and strong antifungal properties. They might have an interaction with the fungal cell membrane, which would make the cell more permeable and eventually kill it. By causing ion imbalances or by selectively targeting particular components in the fungus cell wall or the plasma membrane, Defensins can also impair critical cellular functions.

Two plant defensing MsDef1 and MtDef4, have been the subject of research in the Centre. Both defend and permeabilize the Fusarium graminearum fungus's plasma membrane, although they do so in various ways. MtDef4 is absorbed phosphatidic acid, a molecule that interacts with fungal cells, and is a crucial component of the cell, while MsDef1 interacts with a particular sphingolipid in the fungal cell wall. Through genetic engineering, plant defensins have shown promise in producing crops that are resistant to disease. Plants that overexpress defensins are more resistant to oomycete and fungal diseases. However, difficulties still exist in developing robust and long-lasting resistance without jeopardizing critical agronomic features and crop yields. By decreasing the need for chemical fungicides and increasing yields, this method can support environmental sustainability and food security. **Figure 2** depicts the disease resistance genetic engineering. **Table 1** depicts the disease resistance genetic engineering.

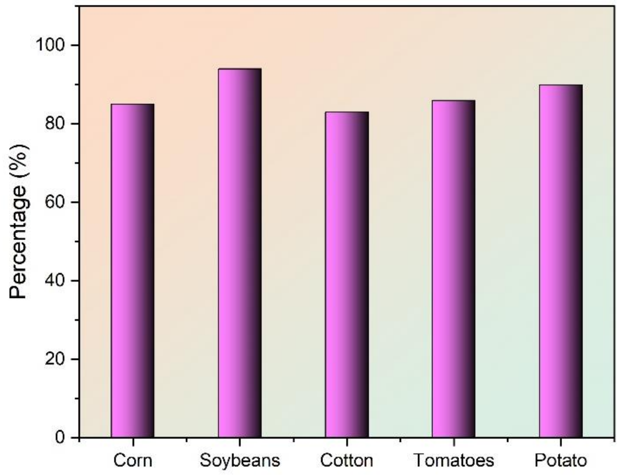

Figure 2: *Using Genetic Engineering to Create Resistance to Disease*

Table 1: Values of Genetic Engineering to Prevent Illness

Crop	Percentage (%)
Corn	85
Soybeans	94
Cotton	83
Tomatoes	86
Potato	90

4. GM Crops' new targets are semiochemicals

To create Small Lipophilic Molecules (SLMs) made from natural sources are used as insecticides, fungicides, and herbicides products and have frequently been used as a development technique. These SLMs can be created via Genetic Engineering (GE) methods or derived from natural sources. A new breed of pest-resistant crops could be produced by adding the SLM pesticide manufacturing requires certain genes to genetically modified plants. Through seedlings or other planting materials, these crops would have the ability to supply pesticides sustainably. Only GM methods can be used to create some SLMs, which might be unstable or have possible non target effects. SLMs, which function through complex signaling systems, can be used in GM pest-resistant crops in addition to directly harmful modes of action (MOA). For instance, the expression of (E)--farnesene, an aphid alarm pheromone that not only also enhances foraging while hurting aphid pests by aphid parasitoids, is now possible in wheat due to genetic engineering. Field tests are currently being conducted to gauge how well this strategy works.

It is also being investigated if GM pest-resistant crops could target other semiochemicals, such as defense-related is an oprenoid oxidation product. According to the "push-pull" approach, companion crops are used to produce semiochemicals that keep pests away from the primary source of food and draw them to trap crops. Where agriculturalists have little access to insecticides, this strategy has shown potential for safeguarding cereal crops. Defense elicitor-activated gene promoter sequences are used for achieving non-constitutive expression of related genes.

5. Engineering the tolerance for Biotic Stress in crop plants

Arcadia has acknowledged the importance of fertilizer, accessible water, and high-quality water in agriculture productivity and global food security. The potential agricultural production can be lost by more than 35% as a result of the limited water supply, the harmful impacts of salt, and water shortage stress. Additionally, because of numerous issues like leaching, runoff, soil obsession, and gaseous emissions, the effectiveness of nitrogen fertilizers has recently fallen lower than 50%. Arcadia has worked with business and humanitarian partners in development to solve these issues. They have seen encouraging outcomes in the laboratory for treatments that increase Nitrogen Usage Efficiencies (NUE), as well as technologies that increase resistance to salinity and water deficiency stress. Initial field testing that included both nitrogen and stress from water shortages has shown that these technologies work well.

Efficiency of nitrogen usage (NUE)

Efficiency of nitrogen usage (NUE) technology, created by Arcadia, increases plant yield while minimizing the negative environmental effects of nitrogen applications. Plants can control a gene for aminotransferase is expressed, specifically Hordeum vulgare produces the enzyme alanine aminotransferase (AlaAT) in transgenic plants using a Brassica napus stress-inducible promoter (btg26), to more effectively absorb and use nitrogen fertilizer. This innovation reduces nitrogen runoff into the water and the atmosphere while still enabling conventional crops to produce crops with excellent yields.

Salt tolerance technology

To increase the osmotic balance and sodium tolerance in plant tissues, Arcadia's salt tolerance technology includes overexpressing plants' vacuolar $Na+/H+$ antiproton(s) (NHXs), which encourage the sequestration of the sodium ions into vacuoles. Numerous crops, such as wheat, soybeans, rice, corn, and vegetables, have benefited from the use of this technology. It permits crops to develop and generate seeds in conditions of salt stress that would otherwise hurt output. To increase rice yields under chronic stress from salinity, Arcadia is also collaborating with BRRI on complementary salinity resistance genes for rice. This technology can increase agricultural productivity, lessen the requirement to increase agricultural activities' geographic reach and allow for the use of water sources with lesser quality.

Plants can better control senescence initiation and guard against yield losses in low water conditions by incorporating a transgenic construct that regulates the synthesis of isopentenyl transferase (IPT), the enzyme that limits the pace at which cytokines are produced, through the maturation-induced promoter. This device tries to protect yields and reduce yield loss brought on by protracted soil drying or ongoing irrigation deficits.

Combining technologies

Throughout their growing season, crop plants are frequently subjected to a variety of abiotic stressors. There are tactical and technical benefits to combining innovations that increase nitrogen use efficiency (NUE) with those that provide combined resilience to salinity and drought. In comparison to conventional rice, rice grown in fields using the "triple-stack" technology has demonstrated notable yield gains by combining salt tolerance, water efficiency, and NUE. Under different nitrogen supply rates, Arcadia's triple-stack rice exhibited production gains of 13-18%, 12-17% under water stress, and 15% under combined stress. Experiments conducted in greenhouses under salt stress showed up to 42% increases in yield. These findings show how these qualities could work together to enhance crop performance in a variety of stressful environments.

To create NERICA rice using NUE alone and layered technologies that are specifically made for dryland agriculture, Arcadia is collaborating with the Foundation for Agricultural Technology (AATF). Other significant food and feed crops, such soybeans and wheat, are the focus of Arcadia's efforts to create similar trait stacks. The objective is to feed an expanding global population while making the most of finite agricultural resources including land, fertilizer, and water. Enhanced global food security will result from this, together with improvements in productivity attributes, resistance to pests, and sustainable agriculture practices techniques. **Figure 3** depicts the crop improvement. Table 2 depicts the value of crop improvement

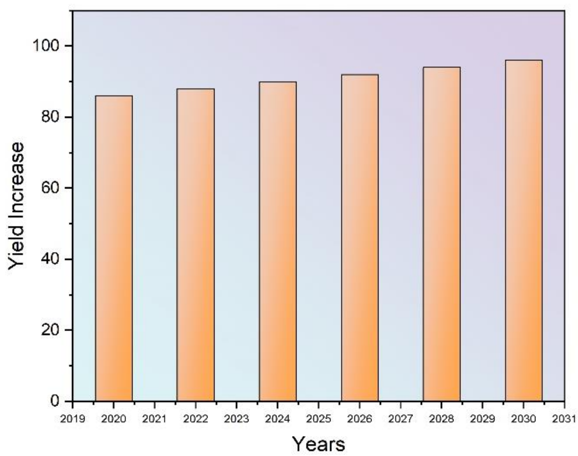

Figure 3: *Outcome of crop yield increases*

Table 2: Values of crop yield increases

Years	Yield Increase
2020	86
2022	88
2024	90

2026	92
2028	94
2030	96

6. Bananas using genetic modification (GM) Xanthomonas wilt (BXW) disease-resistant

globe produces over 150 million tons of bananas a year. Thirty percent of the global output of bananas is produced. Various difficulties with illnesses and pests affect banana production. Banana crops are seriously threatened by illnesses such as banana bunchy top virus, banana streak virus, Fusarium wilt, and black Sigatoka and banana Xanthomonas wilt (BXW), as well as pests like weevils and nematodes.

A plant protein called Hrap improves the hypersensitivity reaction (HR), which is a defense mechanism used by plants to fend off infections. It causes a greater, more hypersensitive kind of cell death by dissociating particular harpin protein variants. Increased resistance to virulent pathogens has been seen in tobacco and Arabidopsis when Hrap is overexpressed. Similar to this, over expressing the plant ferredoxin-like protein found in sweet peppers: Pflp gene in other plants has given rise to resistance against a variety of bacterial diseases. The triggering of defense responses through the generation during pathogen infection the illness is caused by a combination of HR activation and active oxygen species.

Where bananas are significant for food security and are a key income crop for small-scale farmers, the development of BXW-resistant cultivars is necessary. Increased resistance to BXW would greatly help fight the illness outbreak and protect the economic security of farmers in that mostly grow bananas as a key food crop.

7. Cassava that is virus-resistant

Cassava is a significant root and tuber crop that is a key factor in ensuring food security and eradicating poverty. Even though economic transformation strategy depends heavily on the cassava sub-sector, the industry is constrained by a shortage of high-quality seeds, pests and diseases, inefficient markets, a lack of supportive environments, and a general underperformance of market players. The diseases Mosaic (CMD) and Cassava Brown Streak (CBSD), which have reduced productivity by more than 85% and further jeopardized Millions of people's food security has always presented the biggest danger to increased cassava yields and production. To address this issue, the Virus Resistant Cassava, Plus project creates and distributes CBSD and CMD-resistant seeds.

The concept is built on a paradigm of formal Cassava Seed Entrepreneurs (CSEs) producing cassava seeds CSEs are creative farmers who are motivated by higher revenues, have an entrepreneurial mentality, and are receptive to learning about formal cassava seed production. MEDA will instruct CSEs in agronomic and business management techniques. Following this, farmers will be connected to CSEs to acquire high-quality cassava stems and introduced to new and improved cassava varieties through demonstration farms, with a focus on women and young people. MEDA is collaborating with key seed actors to promote the creation of cassava seed protocols and regulations to sustainably improve the quality of cassava seeds. Additionally, MEDA offers women and young people, in particular, equitable job possibilities in the seed system by utilizing targeted, evidence-based initiatives for their involvement in seed distribution. **Figure 4** and table 3 depicts the historical overview, present understanding, and future outlook of the Cassava brown streak disease.

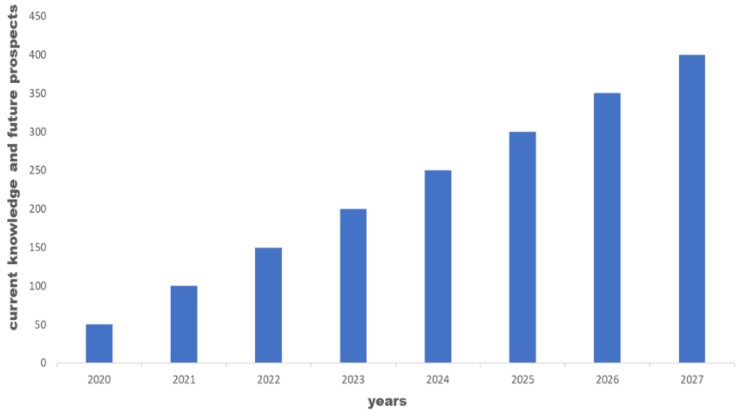

Figure 4: *Outcome of Cassava brown streak disease: historical overview, present understanding, and future possibilities*

Table 3: Cassava brown streak disease reduces yearly improvement

Years	current knowledge and prospects
2020	50
2021	100
2022	150
2023	200
2024	250
2025	300
2026	350
2027	400

8. Impacts of gm crops on the environment and socioeconomic system using life Cycle assessment (LCA)

A GM maize variety that is herbicide-tolerant (specifically tolerant to glyphosate), GM maize that also contains insect resistance and a GM maize type with varying degrees of herbicide resistance and tolerance to insects were all evaluated for their effects on the environment and socioeconomic factors. The outcomes indicated that GM goods had favorable benefits across a range of areas. The introduction of the herbicide-tolerant corn varieties' preference for no-till farming techniques, resulted in a 74% reduction in soil erosion and a reduction in land utilization of compared to non-GM maize, up to 28%. Reduced insecticide use was blamed for the improvement in ecotoxicity potential.

The manufacture of fertilizer is a substantial driver regarding the use of resources, energy, and greenhouse gas emissions, which is why the study also emphasized the significance of taking a life cycle view. In general, the GM characteristics improved production and sustainability from an environmental and socioeconomic standpoint. For the GM varieties of RR, RR&Bt, and SmartStax, respectively, the sustainability scores were 8%, 17%, and 18% higher than the non-GMO equivalent. This results show how agricultural biotechnology, when included in future food security and sustainability can be maximized by using a variety of farming approaches.

9. Conclusion

The promise of contemporary biotechnology-enhanced crops in alleviating the global food crisis and advancing sustainable agriculture was highlighted in the symposium held during the 15th IUPAC Global Conference of Pesticide Chemistry. The symposium's goal was to examine how biotechnology may be incorporated within the framework of improved food security and sustainable agriculture. GM crops, which have the potential to favorably transform the agricultural business, were one of many promising techniques highlighted by the research. The findings presented at the symposium showed how biotechnology may significantly improve food security by raising crop yields, enhancing pest and disease resistance, and improving nutrient content. Nevertheless, it is critical to recognize the drawbacks and potential dangers of GM crops, such as worries about biodiversity and unintended effects on ecosystems. Future research and development efforts should focus on biotechnological techniques that prioritize environmental sustainability and safety.

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