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Agricultural Biotechnology For Sustainable National Development: A Review

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ABSTRACT

The work shows us a great benefit or reward, such as the benefit from agriculture, where crops like maize and cowpea were improved by BT maize and PBR Cowpea to improve yield and chemical to bring more input, and also the tools like genetic modification/tissue culture and molecular markers to tackle drought and pests, thereby strengthening farmers' income. Biotechnology offers more efficient resource utilization and support due to climate change, so that farmers will benefit a lot from their produce. This work tries to look at the application of crops, to cross-bride selective breeding, which changes from traditional ways to modern methods of cross-breeding common crops into modern crop varieties. The climate change application also promotes a more resilient food system. This research work shows that with red biotechnology; it's helps in the area of medicine and healthcare, which includes developing drugs, vaccines, and regenerative medicines. Some crops cannot withstand the environment stressor so the agricultural Biotechnology help to improve crop productivity and yield. Also, it brings consistent and higher yields. It also helps in reducing food wastage. As a result of agricultural biotechnology, farmers produce more healthy food, and food security is greater in the Nation.

Key words: Seasonal Variations, Water Quality, Environmental Dynamics, Aquatic Ecosystem, Temperature.

INTRODUCTION

Modern Agricultural Biotechnology, which involves genetic engineering, started in the late 20th century. The first genetically modified plant was produced in 1983, and the first genetically modified crop approved for sale was the Flavr Savr tomato in 1994.

Agricultural Biotechnology (or Agribiotech) involves using scientific techniques – such as genetic engineering, molecular markers, and tissue culture – to modify living organisms (plants, animals & microorganisms) to improve agricultural productivity. It enhances crop resistance to pests & diseases, increases yields & improves nutrition.

Agricultural Biotechnology is a climate-smart solution enhancing national food security and resilience, with Nigeria leveraging it. Technologies like BT Maize and PBR Cowpea improve yields and reduce chemical inputs; key tools include genetic modification, tissue culture, and molecular markers to tackle drought and pests, strengthening farmers' income.

KEY AREAS OF FOCUS FOR NATIONAL DEVELOPMENT

- Crop Improvement: Developing high-yield, drought-tolerant (e.g., TELA Maize) and insect-resistant crops.
- Commercialized Crops: Nigeria has approved key biotechnology crops, including *Bacillus thuringiensis* (BT) cotton (2018) and PBR Cowpea (2019) to combat pests and decrease reliance on chemical pesticides.
- Climate Resilience: The development of TELA Maize (drought-tolerant and insect-

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resistant) helps farmers manage climate challenges.

- Regulatory framework: The National Biosafety Management Agency oversees the application of the technologies, ensuring safety, while organizations like OFAB Nigeria create awareness and public understanding.
- Future Innovations: Research is ongoing for nitrogen-use efficient, water-efficient, and salt-tolerant (NEWEST) rice, as well as tomatoes. These advancements are crucial for shifting from subsistence to sustainable, high-yield agriculture, strengthening national food self-reliance. Biotechnology in agriculture enhances crop productivity, sustainability, and food security through tools like genetic engineering (CRISPR), tissue culture, and molecular diagnostics. It enables the development of pest-resistant, disease-resistant, and drought-tolerant crops, reducing reliance on chemical pesticides and fertilizers. Key applications include Genetically Modified (GM) crops, bio-fertilizers, improved livestock breeding, and bio-fortification to boost food nutritional value.

KEY ROLES & APPLICATIONS

- Crop Improvements & Yield: Engineering crops for desirable traits, including increased yield, faster growth, improved nutritional value (e.g., golden rice), and better flavor.
- Pest & Disease Resistance: Develop GM Crops (like BT cotton/maize) that resist pests and viruses, reducing chemical pesticide use.
- Abiotic stress Tolerance: Enhancing crops to survive environmental pressures, salinity, and waterlogging.
- Sustainable Farming Practices: Utilizing biofertilizer (e.g., nitrogen-fixing microbes) and biopesticides to enhance soil health and minimize environmental impacts.
- Tissue Culture & Propagation: Accelerating the production of high-quality, disease-free plants, particularly for horticulture and forestry.
- Livestock Improvement: Using biotechnology for animal breeding, vaccine development, and improving nutrition to boost livestock productivity.

BENEFITS AND FUTURE OUTLOOK

Biotechnology offers more efficient resource utilization and supports climate change adaptation, promoting a more resilient food system. However, challenges regarding regulatory frameworks, environmental impact, and public perception are also actively managed in its application. Cross-breeding, selective breeding, and mutation breading are examples of traditional ways to make these changes. These breeding methods often involve mixing all of the genes from two different sources. They are used to create common crops like modern corn varieties and seedless watermelon.

Biotechnology is generally a good, high-impact career, especially for those passionate about research, medicine, and innovation. It offers strong growth potential and diverse roles, though it can have limited job stability and lower sterling salaries compared to software or engineering. Biotechnology is divided into four main types of biotechnology, which are classified by colour – are red (medical), green (agriculture), white (industrial), and blue (marine). These fields utilize biological systems, organisms, or derivatives to develop products, improve sustainability, and advance human health. Red Biotechnology (medical) focuses on healthcare, including developing drugs, vaccines, and regenerative medicine.

KEY BENEFITS OF AGRICULTURAL BIOTECHNOLOGY

- Improved Crop Productivity and Yield: Biotechnology enables the development of crops that can withstand environmental stressors, such as drought, salinity, and heat. This resilience leads to more consistent and higher yields in crops such as GM crops, having increased production from low to high.
- Reduced Environmental Impact and Pesticide Usage: Genetically modified crops such

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as Bt Cotton and Corn, are engineered to resist pesticides. This decreases chemical runoff into waterways and lowers environmental contamination.

- Enhanced Nutritional Quality: Biotechnology is used to improve the nutritional value of staple crops, such as creating rice with high iron and vitamin A content (Golden rice) to address nutrient deficiencies.
- Weed Management: Herbicide-tolerant crops allow farmers to manage weed more efficiently without harming the crop, often facilitating no-till farming practices, which reduce soil erosion and carbon emissions.
- Reduced food wastage and post-harvest losses: Crops can be engineered for improved shelf life and resistance to spoilage, reducing waste and increasing the efficiency of food distribution.
- Alternative Energy Sources: Biotechnology supports the production of biofuels from agricultural products, such as corn and sugarcane, providing renewable energy sources.

APPLICATIONS IN AGRICULTURE

- Genetic Modification (GM)
- Developing, for example, pest-resistant crops such as Bt Cotton.
- Tissue culture: Rapidly producing large numbers of genetically identical plants.
- Biofertilizers & Biopesticides: using microorganisms to promote plant growth and protect them from pathogens
- The application of biotechnology in agriculture has resulted in benefits to farmers, producers, and consumers. Biotechnology has helped to make both insect pest control and weed management safer and easier while safeguarding crops against disease.

Other benefits of Biotechnology:

- Genetically modified crops increase sustainable food production
- Seawater bioprocesses to produce fuel and chemicals
- Zero-waste bio-processing
- Carbon dioxide as a raw material
- Regenerative medicine to create new organs.

THE CHALLENGES OF AGRICULTURAL BIOTECHNOLOGY:

Agricultural biotechnology faces significant challenges, including high R&D Costs, inadequate infrastructure, limited funding, and weak regulatory frameworks, particularly in developing nations. Key bottlenecks include public opposition to GM foods, ethical concerns about biosafety risks, and a lack of technical expertise hindering the widespread adoption of genetically modified crops.

Key Challenges of Agricultural Biotechnology:

Financial and Technical Limitations: R&D in biotechnology is expensive, and many developing countries suffer from a lack of research funding, modern laboratory infrastructure, and skilled personnel.

Regulatory and Policy Issues: There is often a lack of clear national policies, biosafety regulations, and intellectual property (IP) frameworks to govern the development and commercialization of biotech products.

Public and Social Opposition: Significant skepticism exists among consumers, environmental groups, and some farmers regarding the safety of genetically modified organisms (GMOs), which can lead to high resistance against their adoption.

Environmental Concerns: Risks regarding biodiversity loss, non-target species safety, and the long-term ecological impact of gene flow from transgenic crops are major contentious issues.

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- Ethical and socio-economic concerns: concerns are often raised about dependency on multinational corporations for seeds, the potential marginalization of small-scale farmers, and ethical objections to altering the genome of living organisms.
- Inconsistent leadership: poor political commitment and inadequate leadership in science and technology under the formulation of cohesive strategies for agricultural biotechnology.

CONSUMER ACCEPTANCE TRANSFER OF TECHNOLOGY AND GLOBALIZATION

Biotechnology is becoming more and more of a commercial reality; its impact on consumers as well as producers is well recognized. GM is relatively good to Nigerian Consumers. In general, the public is not well informed about these businesses. In the past, surveys have shown that these is significantly more support among those who said that they had heard about GM than those who heard little about it. The national biotechnology is stepping up for more effort to implement public awareness programmes on biotechnology during (2005-2010). The programmes include educating farmers in a nationwide public forum as well as in village town halls and in marketplaces, and also in schools' premises, and preparing and distributing farm tools and chemicals about biotechnology and to understand biotechnology.

In the case of globalization, there are two issues that need to be addressed, such as the transfer of technology and the threat of globalization. The majority of biotechnology and research is done in the private sector, and the relevant information and data are not available, and most of the relevant technologies and materials are not in the public domain. In that case, a developing nation like Nigeria views technology transfer as a critical agenda since the nation is still far behind in expertise, infrastructure, and financial support.

Developed nations must facilitate technology transfer to developing counterparts in order to face challenges that came up with globalization. The challenges for a country like Nigeria to acquire expertise and capability in biotechnology as it moves forward in the era of globalization.

FUTURE STRATEGIES

There are two strategies have been adopted:
On the part of government, the problems include lack of adequate implementation of government policy on bio-safety and genetically modified products. These challenges also include lack of effective leadership, poor funding of agricultural biotechnology research and the slow rate of adoption and implementation of agricultural biotechnology, which can be attributed to lack of knowledge and high costs of the available ones. The capacity of biotechnology to be a useful tool in dealing with major problems such as the environment, hunger, and population growth must be in consideration. The design, development, and adoption of agricultural biotechnologies in Nigeria remain low due to several socio-economic, ethical, and health factors.

The Way forward for biotechnology:

It centers on converging advanced technologies like synthetic biology, artificial intelligence, and genomics to drive innovation. This shift is vital for building sustainable economies, achieving food security, and developing localized, personalized healthcare solutions globally.

Healthcare and Medicine:

- Personalized Medicine: Advancements in genetic profiting allow for treatments explicitly tailored to individual DNA, revolutionizing disease prevention and pharmaceutical development

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- Local Manufacturing: For regions like Nigeria with high disease burdens (e.g malaria), the way forward requires transitioning from heavy drug importation to domestic vaccine and therapeutic manufacturing through academic-industry partnerships.
- Agriculture & food security – climate-resilient crops: utilizing genome editing and molecular breeding to develop seeds that withstand extreme weather, resist pests, and increase yields.
- Private – Sector Integration: Implementing policies that ease regulatory pathway for agricultural biotech and encourage farmers to adopt high-tech bio-inoculants to prevent post-harvest losses.
- Sustainability & Environment – Bioremediation: Employing engineered microorganisms and biosensors to clean up industrial wastewater and track environmental pollution.
- Metagenomics: Tapping into uncultivable environmental microbes using a blend of metagenomics and nanotechnology to discover new industrial enzymes.
- Policy and Global Integration–Supportive Regulations: Modernizing legal frameworks to enable the safe application of new genomic techniques.
- Global Alignment: Ensuring that strategic growth remains aligned with sustainable development goals as outlined by the European Commission.
- Global & Nigeria Strategies: The Nigerian Commission can revive the Biotech & Sustainable Development for foundational perspectives on advancing the industry.
- Bio-manufacturing Innovations: Access the ResearchGate publication on the way forward for Bio-manufacturing and Biotechnology in Nigeria to learn about emerging Industrial trends.
- Agricultural & General Advancements: One of the ways is the insights into overcoming supply chain hurdles and empowers farmers.
- Advanced Bio-manufacturing: The industry is heavily focused on scaling synthetic biology, improving bioprocesses, sustainability, and shifting away from chemical synthesis.
- Global Impact: Researchers emphasize solving global footprints using genetically modified crops and bio-fuels.

CONCLUSION

In conclusion, biotechnology is a powerful tool with wide-reaching benefits; however, challenges such as ethical concerns, safety issues, and unequal access still need to be addressed. Consuming food containing ingredients derived from GM Crops is no riskier than consuming the same foods containing ingredients from crop plants.

Multidisciplinary Nature: Biotechnology relies on a blend of genetics, molecular biology, biochemistry, and engineering to manipulate living organisms for human benefit.

Widespread impact: It revolutionizes fields such as healthcare (e.g vaccine development, gene therapy), agriculture (e.g genetically modified crops for food security), and environmental management (e.g. waste treatment)

Historical Evolution: the field has evolved from ancient biotechnology (like brewing and selective breeding) to classical applications (antibiotics) and modern genetic engineering.

RECOMMENDATION

There shall be a good, active advancement of its bio-economy to tackle food insecurity and improve public health through genetically modified crops and vaccine, research and to build a resilient sector, the country must bridge the gap between policy and practice by boosting Laboratory Infrastructure, expanding biotechnology education, and effectively combating public misinformation.

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These are ways to make sure that biotechnology grows in the country such as the following:

a. Scale Agricultural Innovations: Adopt and expand the cultivation of approved, climate-smart biotech crops like TELA Maize and PBR Cowpea, which are specifically designed to resist pests, improve yields, and withstand severe drought.
b. Expand Educational Curricula: Introduce biotechnology education into secondary school curricula and form dedicated "Biotechnology Clubs" to inspire the next generation of scientist at a tender age.
c. Invest in Bio-manufacturing: Government and Private sectors should invest in essential bio-manufacturing infrastructure (e.g., good manufacturing practices facilities to independently produce vaccines, bio-fertilizers, and medical therapeutics.
d. Strengthen Regulation and outreach: support the science-driven regulations managed by the National Biosafety Management Agency. There is an urgent need to counter public misinformation about Genetically Modified Organisms (GMOS) through Community engagement and transparency.
e. For professionals, academics, and stakeholders looking to stay connected with the latest findings and policies.
f. Academic Research: Explore cutting-edge scientific publications through the Biotechnology society of Nigeria.
g. Industrial & Sustainable Development: Review how biotechnology acts as a catalyst for economic diversification in research like the RSIS International Journal.

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