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Research Article

Biotechnological Advancements for Environmental Conservation in East Africa

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Abstract

The environment serves as a critical lifeline for both humanity and diverse biotic organisms, necessitating the imperative of Environmental conservation to safeguard the natural world from the deleterious impacts of human activities. This paper explores the intersection of environmental sustainability and biotechnological advancements in East Africa. In the face of global environmental challenges, the study accentuates the importance of transitioning to eco-friendly industrial processes, with biotechnological tools emerging as sustainable alternatives to traditional methods. The research delves into the multifaceted applications of biotechnology, showcasing its potential to revolutionize the preservation and rehabilitation of contaminated environments, particularly in soil and water. Groundbreaking techniques such as in vitro culture and cryopreservation are highlighted for their efficacy in collecting and conserving genetic resources, particularly for species that pose challenges when conserved as seeds. Plant biotechnology emerges as a singular solution capable of addressing agricultural and food security concerns while simultaneously mitigating environmental issues in East Africa. A pivotal aspect of the examination is the emphasis on multidisciplinary infrastructure, recognizing the need for collaborative efforts to maximize the impact of biotechnological interventions. The paper explores diverse applications, including the role of plant biotechnology in enhancing agriculture, the contributions of bioremediation in ecosystem restoration, the transformative impact of genetic engineering on agriculture, and the potential of synthetic biology in providing renewable energy solutions. The results underscore the critical role played by biotechnology in promoting environmental conservation, fostering sustainable development, and addressing the unique challenges faced by East Africa. The findings contribute to the growing body of knowledge on the nexus between biotechnological innovations and environmental sustainability, providing insights that can inform policies, strategies, and collaborative initiatives aimed at achieving a harmonious balance between human activities and the natural world in the East African context.

Keywords

Environmental Sustainability, Biotechnological Development, Conservation, Biodiversity

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1. Introduction

East Africa, often called Eastern Africa, is an area in sub-Saharan Africa that includes the easternmost part of the African continent (Figure 1). Burundi, Comoros, Djibouti, Ethiopia, Kenya, Rwanda, Seychelles, Somalia, South Sudan, Sudan, Tanzania, and Uganda are the thirteen states that make up the east African area, according to the African Development Bank [1]. Approximately 342 million people, or one-third of the continent's total population, were predicted to live in the region in 2016 [2]. The repercussions of pollution have come to light more frequently during the past century, and governments and businesses have been impacted by popular pressure. It is no longer necessary to avoid environmental pollution. The need for less or non-polluting industrial processes to take the place of conventional ones is growing [3]. The process of ensuring that present environmental activities are carried out with the goal of maintaining the environment as pure as naturally feasible based on idealistic behaviors is known as environmental sustainability. The processes of bioscientific interests known as "biotechnological tools" use the chemistry of living things through cell manipulation to create new and creative ways to produce traditional goods in a more efficient and environmentally friendly way while preserving the natural beauty of the surrounding area. In place of traditional chemical product synthesis, biotechnology is currently the trend in industrial processes worldwide [4].

Figure 1. *Map of the East African region and countries selected for the study (AFDB [1]).*

The process of bio-scientific interest leading to a fundamental reconfiguration of science and its function in society is known as biotechnological development [5]. Through the manipulation of cells, biotechnology leverages the chemistry of living things as instruments to create novel and alternative approaches that preserve the environment while generating traditional goods purely and efficiently [6]. Protecting the environment and public health from potential harm caused by modern biotechnology products requires a biosafety regulatory framework [7].

Plant biotechnology has made significant strides in recent years, particularly in the areas of molecular biology and in vitro culture. These developments have also given rise to effective instruments for managing and preserving plant diversity. Currently, pathogen-free material, elite plants, genetic diversity, and crop decorative and medicinal species that are endangered or unusual can be preserved for short, medium, and long periods through the employment of biotechnological techniques [8].

African nations must comprehend national sustainability trajectories and assess them for suitable action to alleviate some of the environmental issues. The environmental performance index (EPI), created by Yale and Columbia University scholars, is one tool for tracking each nation's progress toward environmental sustainability [9]. The EPI offers a means of measuring and numerically comparing a nation's environmental performance in a variety of distinct problem areas, including biodiversity preservation, air and water quality, and natural resource management. For instance, disparities in environmental performance between regions in China indicate a division in sustainability [11].

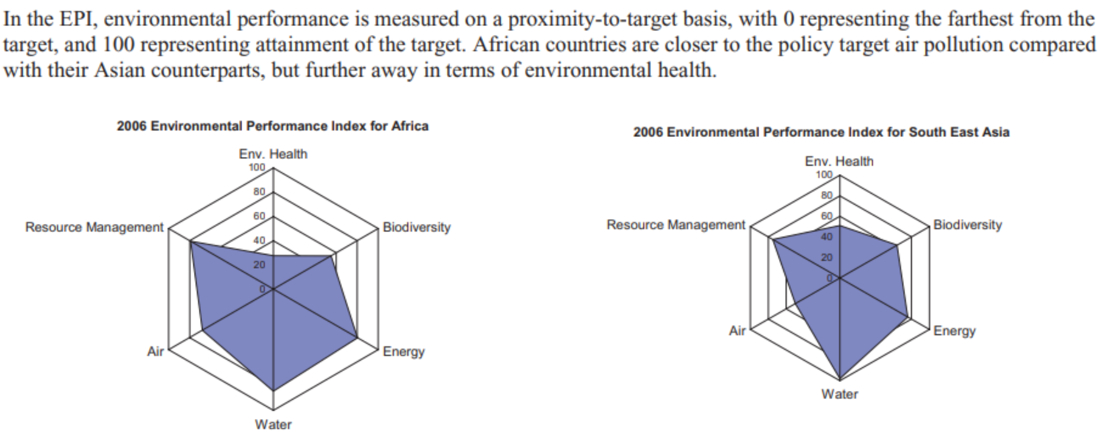

Figure 2. *Comparison of 2006 EPI for sub-Saharan African and South East Asia Source: [9].*

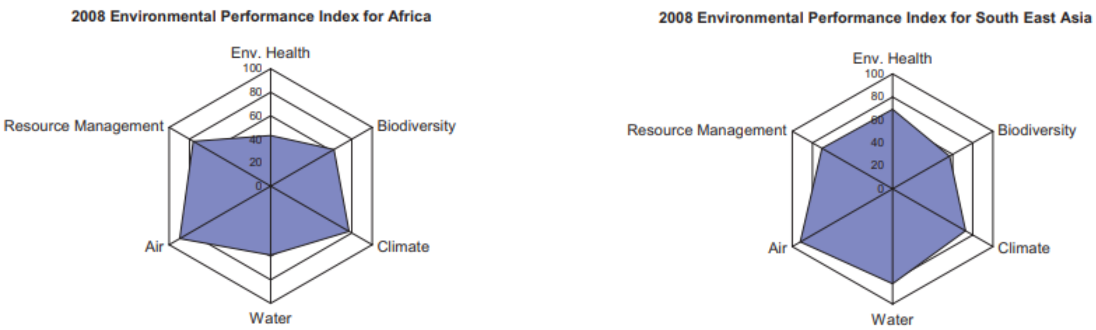

Figure 3. *Comparison of 2008 EPI for sub-Saharan African and South East Asia Source: [10].*

Though this is primarily because of low levels of industrialization, the EPI for 2006 and 2008 shows that Africa has good to median aggregate scores on biodiversity, access to water, air quality, and environmental degradation. On the other hand, as can be shown in (Figures 2 and 3), African nations fare extremely poorly on environmental health metrics. Sewage issues and indoor air pollution pose serious health risks. Indoor air pollution is primarily produced by cooking and heating with solid fuels on open flames or stoves without chimneys. Because of their low levels of industrialization, Africa's environmental metrics are comparable to those of Asia [11].

The aim of this study is multifaceted, seeking to comprehensively explore the intersection of environmental sustainability and biotechnological development, with a specific focus on their combined role in conservation efforts.

Biotechnological Landscape in East Africa

Many developing nations, especially those in Africa, have limited resources for agricultural biotechnology research and innovation. These include inadequately equipped laboratories, a lack of public money, salary disincentives, and a lack of governmental and regulatory support. Only 5.5% of South Africa's current R&D expenditures, which amount to over 0.9% of GDP, are allocated to agricultural research, despite the country's efforts to raise this percentage [12].

Plant biotechnology deployment in Africa necessitates a multidisciplinary infrastructure that incorporates institutional frameworks, policies, regulations, and scientific know-how [13]. Only a few countries in Africa are producing transgenic material, and it is still difficult to "commercialize" the goods so that farmers and producers can purchase them. Many African institutions simply lack the resources or know-how to perform basic tissue culture procedures and create transgenic material, which contributes to the lack of adoption of biotechnology [14]. Furthermore, there are not enough laws and regulations governing biosafety, education, and long-term environmental evaluations to control the use of plant biotechnology for industrial and agricultural purposes once it leaves the laboratory. These factors apply to many other nations where transgenic crops are developed and farmed, not just those in Africa. Therefore, even if plant science has the potential to make a substantial contribution to achieving the MDGs, strengthening Africa's biotechnology infrastructure is imperative [15].

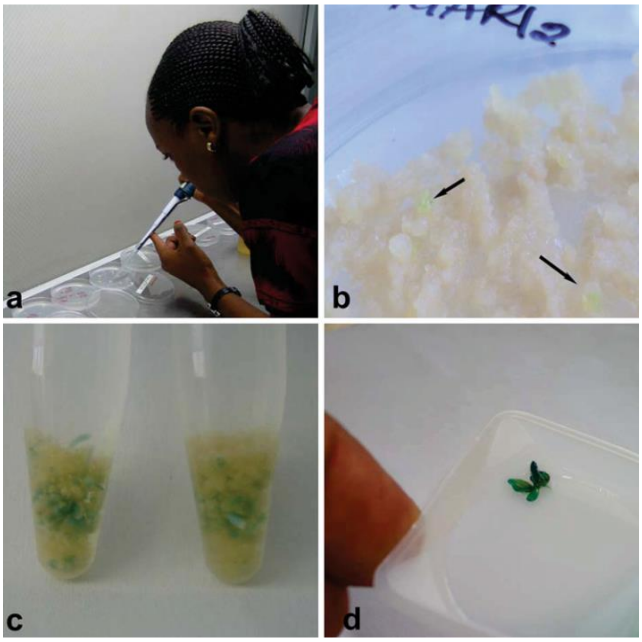

Figure 4. *Agrobacterium inoculation of FEC from cultivar TMS60444 (a), regenerating embryos (indicated by arrows) on hygromycin selection media (b), GUS assay using TMS60444 FEC (c) and regenerating embryo (d) transformed with pCAMBIA plasmid containing GUS reporter gene at MARI, Tanzania. Transformed material produces a blue precipitate.*

Transferring plant biotechnology to East Africa especially a case study in Tanzania: an illustrative case Examining a supplementary grant from the Bill & Melinda Gates Foundation's BioCassava Plus program, a Knowledge and Technology Transfer Partnership (KTTP) was formed involving ETH Zurich, the University of Bath, and MARI in Dar es Salaam, Tanzania. To facilitate this collaboration, new facilities were constructed at MARI with financial support from the Rockefeller Foundation. Unfortunately, local scientists initially lacked the necessary expertise for successful transformation experiments. Subsequently, with official approval for contained research and an initial training phase for MARI staff, the KTTP was initiated. Collaborating with European researchers, MARI scientists have successfully generated in vitro embryos of elite and locally preferred cultivars in Tanzania, including Kibandameno, TME7, Mahando, Katakya, Sagalatu, Mzungu, and Milundikachini. The early stages of the transformation process have been effectively executed, demonstrated by the production of transgenic FEC from cultivar TMS60444 and the regeneration of embryos on antibiotic selection media (Figure 4a, b). Employing a pCAMBIA binary vector with the GUS reporter gene (accession number AF234297.1) enables easy progress evaluation, as transformed materials develop a blue precipitate in a GUS assay. (refer to [16] for details; Figure 4c, d). Drawing on the ongoing initiative to establish a sustainable cassava transformation platform, we share our experiences and emphasize essential criteria for a successful KTTP in Africa.

2. Bioremediation in Ecosystems

The primary benefit of bioremediation is its ability to lower remediation costs in comparison to traditional methods like dredging, which involves physically removing contaminated sediment layers, capping, which involves covering the contaminated sediment surface with clean material and isolating the sediments, and incineration, which is a waste treatment technique that involves burning organic materials found in waste materials. On-site bioremediation lowers the possibility of worker exposure during cleanup operations or, in the event of a transportation accident, wider exposure. Other benefits of bioremediation include lower costs, permanent waste elimination, long-term liability elimination, and compatibility with chemical or physical treatment technologies. In addition, the procedure is non-invasive, meaning that the ecology remains unaltered [17]. However, because several environmental factors affect how bioremediation proceeds, it is difficult to predict how quickly a bioremediation exercise will be completed. As a result, scientists are still trying to come up with guidelines for estimating how quickly a pollutant will degrade in different environmental components [18].

The following are the most crucial factors in bioremediation: (1) Nutrients—nutrients are insufficient for the growth of microorganisms in contaminated locations and for cellular metabolism. Due to the high concentration of organic carbons in contaminated locations, which may be reduced during microbial metabolism. Therefore, adding extra nutrients to the contaminated site, such as potassium, phosphate, and nitrogen, might encourage the development and cellular metabolism of the bacteria, enhancing the bioremediation process. For bioremediation, the carbon-to-nitrogen (C: N) ratio needs to be 10:1, and the carbon-to-phosphorous ratio needs to be 30:1. However, contaminated soil with a significantly greater C: N (25:1) ratio saw microbial development for biodegradation. (2) The nature of pollutants include several forms, such as solid, semi-solid, liquid, and volatile substances; they can also be organic or inorganic, hazardous or non-toxic, heavy metals, polycyclic aromatic hydrocarbons, pesticides, chlorinated solvents, and more. (3) Soil Structure: The soil structure consists of a variety of textures with varying proportions of sand, silt, and clay. (4) The ideal pH range for the growth of microbes and the destruction of pollutants is between 5.5 and 8.0. A granular and well-structured soil can help effectively provide air, water, and nutrients to the microorganisms for in situ bioremediation. (5) Moisture content: Soil and other media's dielectric constants are mostly determined by water content [19].

3. Genetic Engineering for Enhanced Agriculture

A genetically modified organism (GMO) is the result of altering an organism's genetic composition to achieve particular goals (such as promoting the expression of desirable physiological features or the production of desired biological products). According to the FOA [20], a genetically modified organism (GMO) is defined as "an organism in which one or more genes (called transgenes) have been introduced into its genetic material from another organism-ism using recombinant DNA technology." Any living being that has a unique mix of genetic material acquired by the use of contemporary biotechnology is considered a "living modified organism," [21]. Furthermore, efforts have been made to create crops that can withstand a variety of climatic and environmental stresses, including frost, salt, drought, boron, and other environmental stressors [22].

In accordance with its 2003 resolution [i.e., EX.CL/Dec.26 (III)], the African Union formally decided in 2006 to adopt a single policy on modern biotechnology, acknowledging that biotechnology can help farmers boost productivity. This signified a clear support of biotechnology and genetically modified organisms (GMOs) and has so functioned as the official African position on issues concerning contemporary biotechnology. However, polarized policy perspectives across different nations and regions of the continent have ultimately caused acceptance and implementation to stagnate severely. A 20-year African Biosafety Strategy was created, and in 2003 the African Union Commission wrote the African Model Law on Biosafety, which was later updated in 2009 [23, 24].

The economic value of genetically modified products and services, such as GM seed sales and GM commodity imports, is known as the GMO market. As of 2018, the market was estimated to be worth USD 615.4 million in Africa, and it is expected to grow by roughly 5% to reach an estimated USD 871 million by 2025 [25]. Two genetically modified (GM) crops, Bt cotton that is resistant to pests and pod-borer resistant cowpea known as SAMPEA 20-T, were approved by Nigeria in 2019, marking a significant advancement in agricultural biotechnology [26].

4. Harnessing Synthetic Biology for Renewable Energy

Applications of synthetic biology have enormous potential to address global humanitarian concerns, such as zero hunger, sustainable development, greater access to ethically produced commodities and services, and health and well-being. With a variety of host species, synthetic biology has started to make it possible to produce biochemicals, pharmaceuticals, and even food and food ingredients both continuously and on-demand (or responsively). Innovations in synthetic biology have undoubtedly made a significant contribution to better industrial manufacturing of small molecules, as evidenced by other publications [28].

Table 1 lists eight Sustainable Development Goals that synthetic biology may help achieve. Synthetic biology could be most helpful in four areas: 1) reducing the use of harmful industrial chemicals by providing biologically based alternatives, (2) cleaning up environmental pollutants, (3) increasing crop productivity and soil health, and (4) replacing synthetic, non-renewable materials with those derived from biological sources. The aforementioned contributions align with Goals 6, 9, 14, and 15. Even though some of the hypothetical uses shown in Table 1 might appear absurd, they are supported by current developments in science. These include the synthesis of bioplastics from potato starch, wheat proteins, and bacterial storage compounds (polyhydroxyalkanoates, or PHAs) [27].

Table 1. *Synthetic biology's contribution to the United Nations 2030 Sustainable Development Goals.*

UN Sustainable Development Goals	Example innovation/Scenarios	Changes need in scientific biology practice.
Clean water and sanitation	A water filter made of wheat proteins and potato starch incorporates bacterial monooxygenases to remove benzene from contaminated wells after an oil spill	Scale-up lab experiments to ensure real-world application; collaborate with non-governmental organizations to identify key toxins
Decent work and economic growth	A startup in Kenya uses synthetic biology to produce a high-value compound from an over-harvested plant in the alga Chlamydomonas reinhardrii	Collaborate with small-scale farmers and industries to provide education and training; target industrial funding to support start-ups in non-Western countries
Industrial Innovation	Dyes produced from silica diatom frustules exploit structural colour to replace Azo dyes used in the textile Industry Gene synthesis companies automatically apply designated benefit-sharing charges for the use of certain genetic materials	Reduce risk; identify key industrial chemicals and dyes that could be replaced by synthetic counterparts

UN Sustainable Development Goals	Example innovation/Scenarios	Changes need in scientific biology practice.
Reduced Inequalities	Products made using synthetic biology are found in everyday life	Promote access to resources (for example, gene synthesis, vectors, and lab equipment) needed for synthetic biology in non-Western countries; engage with policy-makers to develop new policies on the use of organisms and genetic sequences in synthetic biology applications
Sustainable cities and communities	Industrial chasses use biosynthetic pathways for waste valorization as a source of energy instead of glucose and nitrogen	Raise public education and awareness of the social benefits of synthetic biology
Responsible Production and Consumption	Paper-based biosensors based on glutamate sensors from Bacillus subtilus detect algal neurotoxins in fish and shellfish to prevent human deaths	Reduce the use of plastics and antibiotics: switch to using waste and light for industrial production of recombinant proteins
Life below Water	Bacteria and plants are engineered to remove poly-aromatic hydrocarbons and polychlorinated biphenyls from polluted land.	Develop new tools to allow the safe use of bioengineered organisms in the environment to clean up toxins, restore degraded landscapes, and improve agricultural productivity
Life on Land	Changes needed in synthetic biology practice	

The table presents example innovations or scenarios that meet each goal along with potential changes needed within synthetic biology to make these visions a reality.

5. Conservation of Endangered Species in East Africa

The Earth's life support system depends on biodiversity to offer natural resources including clean water and air, food, clothes, shelter, medicine, and aesthetic pleasure. Natural resources frequently offer a wide range of vital natural services. Hence, biodiversity, or the biological richness of ecosystems, is arguably the single most significant element affecting the integrity and stability of our environment and, consequently, the continuation of human civilization, including political stability and economic growth. To ensure that the human species survive on this planet for as long as possible, it is in the best interests of humanity to use these resources responsibly and sustainably. The creation and implementation of infrastructure, standards, and tools that might lead to the evolution of an interoperable framework presents one of the obstacles to the smooth, simple, and effective integration of various datasets. The creation of (1) standards and protocols, (2) collection and management tools, (3) geo-referencing and mapping tools, (4) data cleaning tools, (5) modeling tools, and (6) web services and computational frameworks are some of the initiatives working toward this goal. These standards, laws, and policies must be documented in the context of Eastern Africa by identifying the gaps and opportunities for additional policies, protocols, and standards necessary for the integration of biodiversity and non-biodiversity data. This is because of the breadth, depth, and heterogeneity of biodiversity information. Building an informatics infrastructure with exponential technological capabilities, processing power, storage capacity, and analytical capability is underway. After 1990, several international, regional, national, and thematic projects either directly or indirectly aided in the development of the informatics infrastructure. However, not all parts of the world are experiencing this development equally, with East Africa and Sub-Saharan Africa as a whole appearing to be falling behind [29].

The goal of biotechnology's significant contribution to plant conservation is to enhance and supplement existing techniques rather than to completely replace them (Figure 5). Plant conservation biotechnology includes the management, characterisation, and application (sustainable use) of plant genetic resources in addition to their conservation. Specifically, plant material can be easily evaluated, used, and exchanged safely through the use of tissue culture technology for in vitro conservation, which is the preservation of plant germplasm in culture collections. Plant germplasm is preserved in culture collections for medium-term durations (slow growth), which are accomplished by slowing growth, or short-term periods (standard tissue culture), depending on the length of storage. Liquid nitrogen (LN) cryopreservation of plant material is referred to as long-term storage [31].

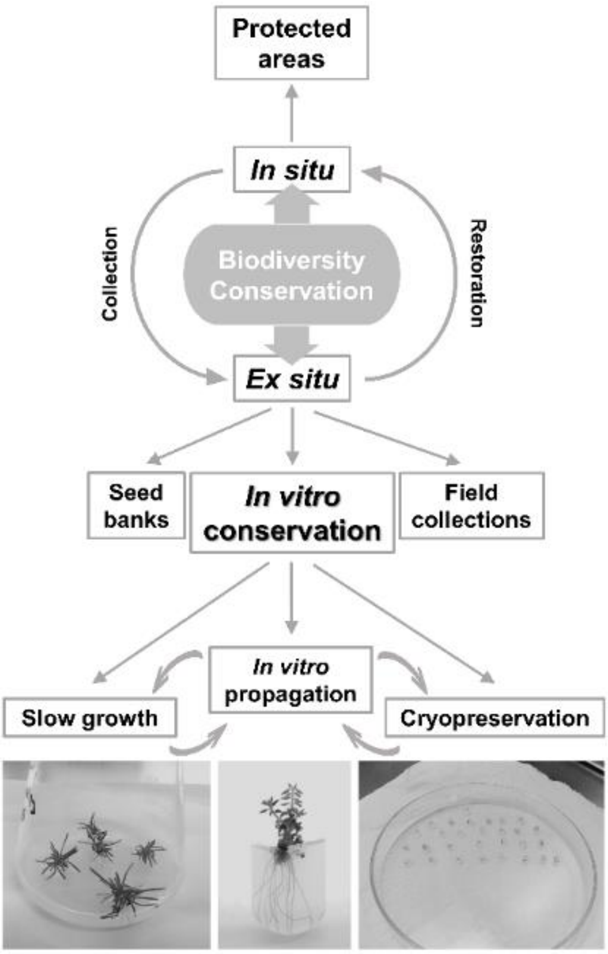

Figure 5. *Schematic representation of different conservation strategies with focus on biotechnological-based techniques [30].*

6. Conclusion

The adoption of biotechnological tools holds promise for sustainable industrial processes, particularly in agriculture and environmental conservation. The case study in Tanzania demonstrates the collaborative efforts required to bridge knowledge gaps and build necessary infrastructure. While East Africa faces resource constraints in agricultural biotechnology research, efforts must be directed toward strengthening the region's capabilities. The application of bioremediation emerges as a cost-effective and non-invasive solution for environmental cleanup. Genetic engineering, including the controversial field of genetically modified organisms (GMOs), presents both economic opportunities and policy challenges in the African context. Synthetic biology's potential for renewable energy and its alignment with Sustainable Development Goals are highlighted. The importance of biodiversity conservation is emphasized, with a call for standardized protocols and tools in East Africa. Overall, the paper advocates for a holistic approach to address environmental concerns, promote sustainable practices, and harness the potential of biotechnological innovations for the benefit of East Africa and beyond.

Conflicts of Interest

The authors declare no conflict of interest.

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