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Abstract

Purpose: The aim of the study was to investigate the use of biotechnology in improving crop yields and sustainability in south Africa.

Methodology: The study adopted a desktop methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library

Findings: The use of biotechnology in South Africa to improve crop yields and sustainability has yielded significant positive outcomes. Biotech crops, including drought-tolerant varieties and genetically modified maize, have been widely adopted by smallholder farmers, particularly in drought-prone areas. These crops have contributed to enhanced food security and increased resilience in the face of climate variability. Furthermore, studies have demonstrated that the adoption of biotech crops is associated with higher yields and reduced production costs, making farming more profitable. Overall, biotechnology plays a pivotal role in South Africa's agriculture, fostering both increased productivity and sustainability.

Unique Contribution to Theory, Practice and Policy: Theory of Green Revolution, Theory of Technological Determinism, Theory of Innovation Diffusion may be used to anchor future studies on use of biotechnology in improving crop yields and sustainability in south Africa. Findings can prioritize the development of drought-resistant crop varieties using biotechnology. Public-private partnerships can accelerate technology adoption and promote sustainable agriculture practices.

Keywords: *Biotechnology, Improving Crop Yields Sustainability*

INTRODUCTION

Crop yields and sustainability in developed economies have seen significant advancements over the years. For instance, in the United States, the adoption of biotechnology techniques such as genetically modified (GM) crops has played a pivotal role in increasing crop yields. According to a study by (Smith, 2018), GM crops like Bt cotton and herbicide-resistant soybeans have contributed to a 22% increase in cotton yields and a 10% increase in soybean yields, resulting in substantial economic benefits for American farmers. Furthermore, precision agriculture technologies, such as GPS-guided equipment and data analytics, have been widely adopted in the USA, leading to more efficient use of resources and improved sustainability.

In Japan, another developed economy, advanced biotechnology techniques have been applied to enhance crop yields while addressing sustainability concerns. A study by (Takahashi, 2019) highlights the successful development of drought-tolerant rice varieties through genetic engineering. These drought-resistant rice strains have not only increased yields in water-scarce regions but have also reduced the environmental impact by minimizing water consumption. Additionally, Japan has been a leader in vertical farming technology, allowing year-round crop production in urban areas with minimal land use and reduced transportation costs, contributing to sustainability goals.

In developing economies like India, crop yields and sustainability are also crucial factors for food security and economic growth. For example, India has made significant progress in adopting biotechnology techniques, including Bt cotton, which has led to higher cotton yields and reduced pesticide use, a study by (Ghosh, 2017). Additionally, the government has launched initiatives like the "Pradhan Mantri Krishi Sinchai Yojana" (PMKSY) to improve irrigation practices and promote sustainable farming.

In Brazil, a major player in the agricultural sector among developing economies, the adoption of precision agriculture technologies and sustainable farming practices has been on the rise. A peer-reviewed article in the "Journal of Sustainable Agriculture" (Santos et al., 2018) discusses the positive impact of precision agriculture on soybean production in Brazil, leading to increased yields and reduced environmental impacts through optimized resource use and reduced pesticide application. In Brazil, a significant developing economy, sustainable agriculture practices and biotechnology have played a crucial role in increasing crop yields and ensuring food security. A study by (Brandão, 2020) demonstratedthe impact of precision agriculture technologies on Brazilian soybean production. These technologies have allowed farmers to optimize resource use, resulting in higher yields and reduced environmental impacts.

In Indonesia, a developing economy with a significant agricultural sector, research in the "Journal of Sustainable Agriculture" (Wahyuni, 2018) discusses the adoption of sustainable rice cultivation practices, including the System of Rice Intensification (SRI). SRI has led to increased rice yields with reduced water and chemical fertilizer use, enhancing both productivity and sustainability in rice production.

In Argentina, a prominent developing economy, biotechnology has been employed to enhance crop yields while considering sustainability. A study by (Penna, 2017) discusses the impact of genetically modified (GM) maize and soybean varieties on Argentine agriculture. GM crops have contributed to increased yields and reduced pesticide use, ultimately benefiting both farmers and the environment. Argentina's adoption of no-till farming practices has also been on the rise, conserving soil and reducing erosion.

In Thailand, another developing economy, sustainable agriculture practices have gained momentum. A peer-reviewed article in the "International Journal of Agriculture and Biology" (Singh, 2018) highlights Thailand's efforts to promote organic farming and integrated pest management. These practices have not only increased crop yields but have also reduced the ecological footprint of agriculture, contributing to long-term sustainability.

In China, one of the world's largest developing economies, biotechnology has been extensively utilized to enhance crop yields. A study by (Qaim, 2020) highlights the adoption of genetically modified (GM) cotton and rice varieties in China. GM cotton has significantly increased yields while reducing the need for chemical pesticides, contributing to higher income for farmers. GM rice varieties, such as insect-resistant Bt rice, have also played a role in improving yields and reducing post-harvest losses.

In South Africa, a developing economy with a well-established agricultural sector, precision agriculture technologies have been implemented to optimize crop production. A study by (Bekker, 2019) discusses the benefits of precision agriculture in maize cultivation. These technologies, including satellite imagery and soil testing, have led to increased maize yields and resource use efficiency.

In sub-Saharan African economies like Kenya, crop yields and sustainability are critical for addressing food security challenges (Mugo, 2016) highlighted the adoption of drought-resistant maize varieties through biotechnology, which has contributed to higher yields in regions prone to erratic rainfall. Additionally, sustainable agricultural practices such as conservation farming and agroforestry have gained traction in countries like Kenya, promoting soil health and biodiversity while improving crop yields.

Nigeria, another sub-Saharan economy, has been exploring the use of precision agriculture and soil health management to enhance crop productivity. A study by (Iwuagwu, 2019) discussed the positive impact of precision agriculture techniques on crop yields in Nigeria, emphasizing the importance of sustainable practices in achieving food security. In Nigeria, another sub-Saharan economy, the promotion of improved crop varieties has been crucial for enhancing crop yields. A study by (Adesina, 2019) highlights the adoption of improved cassava varieties through agricultural extension services. These varieties are disease-resistant and have led to significant yield increases in cassava, a staple crop in Nigeria.

In Ethiopia, a prominent sub-Saharan African economy, sustainable agricultural practices are essential for food security (Teklewold, 2020) discussed the adoption of conservation agriculture (CA) techniques in maize cultivation. CA practices, such as minimal soil disturbance and mulching, have led to increased maize yields while conserving soil and water resources, which are crucial for agriculture in the region.

In Kenya, sustainable agriculture practices and innovations are critical for addressing food security challenges. A study by (Marenya, 2018) discussed the impact of sustainable intensification practices, such as agroforestry and intercropping, on maize production. These practices have contributed to increased maize yields, reduced soil erosion, and improved soil fertility, enhancing overall agricultural sustainability.

In Ghana, another sub-Saharan African economy, the adoption of improved seed varieties has been instrumental in improving crop yields. A study by (Etwire, 2019) examined the impact of improved maize varieties on productivity. These varieties have demonstrated higher yields and resilience to environmental stressors, contributing to food security and economic well-being.

Biotechnology techniques encompass a diverse array of scientific approaches that manipulate living organisms at the molecular level. These techniques have profound implications for agriculture, particularly in enhancing crop yields and sustainability. One notable application is the development of genetically modified (GM) crops. Through genetic engineering, scientists can introduce specific genes into crops to confer desirable traits, such as resistance to pests or tolerance to drought. These GM crops can significantly increase yields by reducing crop losses due to pests and environmental stressors, contributing to food security and sustainability (Qaim, 2016).

Another biotechnological approach is precision breeding, which involves the use of marker-assisted selection and genome editing techniques like CRISPR-Cas9. These methods enable breeders to precisely modify or select for specific traits without introducing foreign genes. Precision breeding accelerates the development of crop varieties with improved yields, nutritional content, and disease resistance while maintaining genetic diversity, which is crucial for long-term sustainability (Kanchiswamy,2015). Additionally, biotechnology can enhance sustainable agriculture by optimizing resource utilization. For instance, biotech-derived crops can be engineered to require fewer inputs like water and fertilizers, reducing the environmental impact of agriculture and promoting long-term sustainability (Gosal, 2016).

Problem Statement

Biotechnology is the application of biological processes and organisms to improve human activities, such as agriculture, medicine, and industry. In South Africa, biotechnology has been used to enhance crop yields and sustainability by introducing genetically modified (GM) crops that are resistant to pests, diseases, drought, and herbicides (Chetty, 2018). However, the adoption and impact of biotechnology in South Africa is still limited by several factors, such as biosafety regulations, public perception, intellectual property rights, and socio-economic issues. Therefore, there is a need for more research on the potential benefits and risks of biotechnology for South African agriculture, as well as the development of appropriate policies and strategies to promote its responsible and sustainable use. (Chetty, Mabhaudhi, Modi, & Mafongoya, 2018). The potential role of neglected and underutilized crop species as future crops under water scarce conditions in Sub-Saharan Africa. International Journal of Environmental Research and Public Health, 15(6), 1185.)

Theoretical Review

Theory of Green Revolution

The Theory of Green Revolution, primarily associated with American agronomist Norman Borlaug, emphasizes the potential for increased agricultural productivity through the adoption of modern biotechnological practices and the development of high-yielding crop varieties. This theory highlights the role of advanced biotechnology techniques, such as genetic engineering, in enhancing crop yields and addressing food security challenges. In the context of South Africa, which faces the dual challenge of food security and sustainable agriculture, the Theory of Green Revolution underscores the relevance of biotechnology in improving crop yields and ensuring long-term sustainability (Borlaug, 1970).

Theory of Technological Determinism

The Theory of Technological Determinism posits that technological advancements drive social and economic change. In the context of biotechnology in South Africa, this theory suggests that the adoption of biotechnological innovations in agriculture, such as genetically modified crops, can transform the agricultural sector by increasing crop yields, reducing the need for chemical inputs, and enhancing sustainability. Originating from scholars like Thorstein Veblen and later developed by Marshall McLuhan, this theory is relevant as it highlights the transformative potential of biotechnology in South Africa's agriculture, which can lead to increased productivity and economic growth (McLuhan, 1964).

Theory of Innovation Diffusion

The Theory of Innovation Diffusion, developed by Everett Rogers, posits that the adoption of new technologies follows a predictable pattern, beginning with innovators and eventually reaching a broader population. In the context of biotechnology in South Africa, this theory suggests that the successful integration of biotechnological advancements into agriculture depends on how well these innovations are communicated and adopted by farmers and policymakers. Understanding the diffusion process is critical for ensuring that biotechnology's benefits, including improved crop yields and sustainability, are realized across the agricultural landscape in South Africa (Rogers, 1962).

Empirical Studies

Wadvalla (2022) examined the advances and challenges of biotechnology in developing drought and disease resistant crops in several African countries, including South Africa. The study used a qualitative approach to collect data from interviews with researchers, policymakers, and farmers. The study found that biotechnology has the potential to solve some of the food security problems in Africa, but there are also major obstacles such as lack of resources, regulatory barriers, and public acceptance. The study recommended more investment, collaboration, and communication to promote biotechnology adoption and innovation.

Dionglay (2021) analyzed the progress and impact of biotech crop adoption in Africa, focusing on six countries that planted biotech crops in 2019: South Africa, Sudan, Eswatini, Malawi, Nigeria, and Ethiopia. The study used a quantitative approach to collect data from official statistics, reports,

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and surveys. The study found that biotech crops contributed to food security and uplifted farmers' lives by increasing yields, reducing pest damage, lowering production costs, and enhancing income. The study recommended more support for biotech crop research, development, and dissemination in Africa.

Njoroge (2022) evaluated the effects of better seeds and biotechnology on crop productivity in Africa, using a meta-analysis of 52 studies from 2000 to 2020. The study used a quantitative approach to synthesize data from experimental trials, field observations, and surveys. The study found that better seeds and biotechnology increased crop productivity by an average of 21%, with higher effects for maize, cotton, and soybeans. The study also found that biotechnology had positive spillover effects on soil health, water use efficiency, and biodiversity. The study recommended more adoption of better seeds and biotechnology by smallholder farmers in Africa.

IUCN (2021) explored the benefits and practices of regenerative agriculture in Africa, using a case study of three businesses from Kenya, Uganda, and South Africa. The study used a mixed-methods approach to collect data from interviews, focus groups, and field measurements. The study found that regenerative agriculture improved crop yields for farmers by increasing soil nutrients and organic content, reducing soil erosion, improving water retention, and enhancing biodiversity. The study also found that regenerative agriculture reduced costs for farmers by decreasing the need for fertilizers and pesticides. The study recommended more scaling up of regenerative agriculture practices and policies in Africa.

Mabaya (2019) assessed the adoption and diffusion of drought-tolerant (DT) maize varieties in South Africa from 2007 to 2016. They found that DT maize varieties were widely adopted by smallholder farmers, especially in drought-prone areas, and contributed to improved food security and resilience.

Mafongoya (2021) evaluated the impact of biochar on soil quality and crop productivity in South Africa. They found that biochar improved soil properties such as pH, organic carbon, nitrogen, phosphorus, potassium, and water holding capacity. They also found that biochar increased crop yields of maize, soybean, sunflower, and sorghum.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low-cost advantage as compared to field research. The study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

FINDINGS

The results were analyzed into various research gap categories that is conceptual, contextual and methodological gaps

Conceptual Research Gaps: While the studies mentioned provide valuable insights into the adoption and impact of biotechnology and regenerative agriculture in African countries, several conceptual research gaps can be identified. Firstly, there is a need for research that delves deeper into the socio-cultural and ethical aspects of biotechnology adoption. While (Wadvalla, 2022) touched upon public acceptance as an obstacle, understanding the underlying factors and perceptions that shape public attitudes towards biotech crops could inform more targeted communication and engagement strategies. Furthermore, there is a conceptual gap in assessing the long-term ecological consequences of biotechnology adoption, including potential unintended effects on biodiversity and ecosystems, which could be explored in future research. Secondly, while the studies focus on specific countries and technologies, a conceptual gap exists in synthesizing the collective experiences and challenges across African nations to provide a more comprehensive overview of the continent's biotechnology landscape.

Contextual Research Gaps: In terms of contextual research gaps, there is a need for studies that investigate the role of governmental policies and regulations in shaping the adoption of biotechnology and regenerative agriculture in African countries. While some studies allude to regulatory barriers (Wadvalla, 2022), a more detailed analysis of policy frameworks, their enforcement, and their impact on technology dissemination is essential. Additionally, understanding the unique challenges faced by each African country in the adoption of biotech crops and regenerative practices, such as political stability, access to resources, and infrastructure development, could help tailor strategies to specific contexts. Furthermore, contextual research should explore the experiences and perceptions of smallholder farmers, as their perspectives are crucial in assessing the feasibility and sustainability of these agricultural approaches.

Geographical Research Gaps: Geographical research gaps are evident in the limited geographical representation of the studies. Most of the research focuses on South Africa or a small selection of countries, leaving a significant portion of the African continent unexplored. To provide a more comprehensive understanding of the impact of temperature on insect behavior, it is imperative to expand research efforts to encompass a wider range of African nations with diverse climates, ecosystems, and agricultural practices. Additionally, studies should consider the regional variations within countries to account for the heterogeneity in environmental conditions and socio-economic factors. A more extensive geographical coverage will contribute to a more nuanced understanding of the complexities involved in the relationship between temperature, insect behavior, and agriculture in Africa. (IUCN, 2021)

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The use of biotechnology holds significant promise in improving crop yields and promoting sustainability in South Africa's agricultural sector. This technology has the potential to address the unique challenges faced by the country, including droughts, pest pressures, and limited arable land. Biotechnological innovations, such as genetically modified (GM) crops engineered for drought tolerance, pest resistance, and increased nutritional content, offer South African farmers the tools to enhance agricultural productivity and food security.

Furthermore, biotechnology can contribute to sustainability by reducing the need for chemical pesticides and fertilizers, thus minimizing environmental impacts and conserving natural resources. The adoption of biotechnology can also lead to reduced greenhouse gas emissions associated with traditional farming practices. However, it is essential to consider ethical, social, and regulatory aspects alongside the potential benefits of biotechnology to ensure its responsible and equitable deployment in South African agriculture. In summary, the judicious integration of biotechnology into South Africa's farming practices has the potential to bolster crop yields, enhance sustainability, and address the pressing challenges of food security and environmental conservation.

Recommendation

Theory

Invest in research and development to harness the full potential of biotechnology in crop improvement. Encourage collaboration between universities, research institutions, and private companies to enhance scientific understanding and develop cutting-edge biotechnological tools tailored to South Africa's unique agricultural challenges. Foster a skilled workforce by providing training and educational programs in biotechnology for farmers, agronomists, and researchers. This will ensure the effective adoption and responsible use of biotechnological solutions in agriculture.

Practice

South Africa has successfully adopted GM crops like maize, soybeans, and cotton. Continue to embrace and expand the cultivation of GM crops, ensuring that regulatory processes are efficient and transparent. Encourage small-scale and subsistence farmers to adopt GM crops to improve yields and resilience. Prioritize the development of drought-resistant crop varieties using biotechnology. Given South Africa's susceptibility to drought, these crops can enhance food security and reduce the environmental impact of irrigation.

Policy

Simplify and expedite the regulatory processes for biotech crop approvals while ensuring rigorous safety assessments. Clear, science-based regulations will attract investment and innovation in the biotechnology sector. Implement strict biosafety measures to prevent unintended environmental and health consequences. Effective monitoring and enforcement of biosafety regulations are essential for building public trust and ensuring responsible biotech adoption. Foster collaborations between government agencies, private companies, and research institutions to leverage resources and expertise for the development and dissemination of biotech solutions. Public-private partnerships can accelerate technology adoption and promote sustainable agriculture practices.

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