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Artificial Intelligence, Bioinformatics, and Genomics research in food production in Africa: A review

Adetunmbi Tella
Department of Animal production and health, Federal University Oye-Ekiti, Ekiti state, Nigeria.
Email: adetunmbi.tella@fuoye.edu.ng

Corresponding Author: Adetunmbi Tella

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Abstract

Artificial intelligence (AI), bioinformatics, and genomics are increasingly recognized as transformative tools for addressing food production challenges in Africa. This review critically examines how these technologies have been applied to mitigate constraints such as climate variability, soil degradation, low productivity, and population pressure. Using a structured qualitative review of peer-reviewed literature, institutional reports, and selected country case studies (Kenya, Nigeria, and South Africa), the paper synthesizes evidence on technological effectiveness, adoption barriers, and contextual feasibility. The findings reveal uneven levels of technology readiness and adoption across countries, driven by disparities in infrastructure, regulatory frameworks, human capacity, and investment. While AI applications show relatively higher short-term scalability, genomics and bioinformatics face greater institutional and policy constraints despite their long-term potential. The study contributes a comparative and context-specific assessment that informs policymakers, researchers, and practitioners on strategic pathways for deploying data-driven agricultural innovations to enhance food security and sustainable development in Africa.

Nomenclature and units

k	Kurtosis
γ	Skewness
τ_{MED}	Mean Excess Delay
τ_{RDS}	Root Mean Squared Delay Spread
μ	Mean

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1.0 Introduction

Agriculture remains a foundational pillar of African economies, contributing significantly to employment, income generation, and rural livelihoods. However, the sector is increasingly shaped by structural constraints that limit productivity and efficiency, including land degradation, demographic pressures, and fragmented market systems (FAO, 2023; IPCC, 2023). These constraints highlight the need for approaches that go beyond incremental improvements toward more data-driven and system-oriented agricultural practices.

Recent advances in artificial intelligence (AI), bioinformatics, and genomics offer distinct but complementary capabilities for transforming agricultural systems. AI enhances decision-making through predictive modelling and real-time analytics, enabling more precise farm management and resource allocation (Russell & Norvig, 2020; Lee et al., 2021). In parallel, bioinformatics and genomics provide molecular-level insights that support crop and livestock improvement, particularly through the identification of traits linked to productivity, resilience, and disease resistance (Mount, 2019; Kumar et al., 2022; Ouma et al., 2024). Together, these technologies shift agriculture from experience-based practices to evidence-based optimization.

At the same time, agricultural systems are becoming more integrated, extending beyond production to include value chains involving processing, storage, and distribution. This transition has increased reliance on digital technologies such as remote sensing, Internet of Things (IoT) devices, and big data platforms (Fan et al., 2021). Within this evolving landscape, AI-driven systems can support end-to-end optimization, from input management to market forecasting, thereby improving both efficiency and competitiveness (Zhang et al., 2023).

Despite growing adoption across parts of the continent, existing literature largely treats AI, bioinformatics, and genomics as separate domains. This fragmented perspective limits understanding of how their combined application can address complex agricultural challenges. To bridge this gap, this review provides a comparative and integrative analysis of these technologies within African contexts. Using case studies from Kenya, Nigeria, and South Africa, the study evaluates their practical applications, scalability, and implementation constraints, with the aim of informing policy and guiding future research on technology-enabled agricultural transformation.

2. Background of Food Production in Africa

2.1 Structural Characteristics of the Sector

Africa's agricultural sector is predominantly smallholder-based, with farmers cultivating approximately 80% of the continent's farmland (AGRA, 2022). The sector contributes about 23% to GDP and employs over 60% of the labour force, underscoring its socio-economic importance (FAO, 2023). Staple crops such as maize, cassava, sorghum, millet, and rice form the backbone of food systems across the region.

However, production systems are characterized by low input use, limited mechanization, and weak integration into formal markets. As a result, output growth has not kept pace with rising demand, leading to persistent reliance on food imports, which exceed $50 billion annually (AfDB, 2023). This imbalance reflects deeper inefficiencies in production, distribution, and market access rather than simply insufficient cultivation.

Efforts to modernize the sector driven by institutions such as AfDB and AGRA—have focused on improved seed systems, mechanization, and extension services. While these initiatives have delivered localized gains, their broader impact remains constrained by systemic limitations that affect scalability and sustainability.

2.2 Key Constraints to Agricultural Productivity

2.2.1 Environmental and Resource Constraints

Agricultural productivity in Africa is strongly influenced by environmental variability, particularly in rain-fed systems where output depends heavily on seasonal conditions. Increasing unpredictability in rainfall and temperature patterns complicates farm planning and reduces yield stability (IPCC, 2023). Projections suggest that without adaptive measures, key staples such as maize could experience significant yield declines in the coming decades (Thornton et al., 2022).

In addition, declining soil quality continues to undermine production capacity. Unsustainable land-use practices including continuous cropping, overgrazing, and improper fertilizer application have led to nutrient depletion and erosion. Estimates indicate that a substantial proportion of agricultural land is already degraded, reducing its capacity to sustain high yields (Lal et al., 2023). While soil restoration techniques such as agroforestry and crop rotation are effective, their adoption remains uneven due to knowledge and resource constraints.

2.2.2 Infrastructure and Market Limitations

Beyond production, inefficiencies in post-harvest handling and distribution significantly affect food availability. Limited access to storage facilities, poor rural road networks, and weak market linkages contribute to high post-harvest losses, estimated at nearly 30% of total production (FAO, 2023). These losses reduce farmer income and limit the overall efficiency of food systems.

Market access is further constrained by inadequate transport systems and fragmented supply chains, which often force farmers to sell produce under unfavourable conditions. While digital platforms such as M-Farm and iCow have begun to improve price transparency and market connectivity, their reach is still limited relative to the scale of need.

2.2.3 Institutional and Financial Barriers

The adoption of improved agricultural practices is also hindered by limited access to finance, extension services, and technical knowledge. Many smallholder farmers are unable to invest in productivity-enhancing inputs due to credit constraints and high costs. In addition, weak institutional frameworks and inconsistent policy environments reduce incentives for long-term investment in agricultural innovation.

2.3 Transition toward Technology-Enabled Agriculture

Addressing these constraints requires a shift from traditional practices toward more integrated and technology-enabled systems. Digital tools, data analytics, and biotechnology are increasingly positioned as enablers of this transition. However, their effectiveness depends not only on technical performance but also on the broader context of infrastructure, policy support, and human capacity.

This background underscores the importance of examining how emerging technologies particularly AI, bioinformatics, and genomics can be deployed in a complementary manner to overcome structural limitations and improve agricultural outcomes across diverse African settings.

3. Methodology

This review adopts a qualitative, integrative approach to analyze secondary data derived from academic journals, institutional reports, and policy briefs. Sources were selected based on three main criteria: (i) publication within the last five years to ensure relevance, (ii) African focus or context-specific applicability, and (iii) contribution to either AI, bioinformatics, or genomics in agriculture. Over 70 sources were initially considered, with 45 retained based on their methodological rigor and African relevance.

This study adopts a qualitative integrative review approach to synthesize existing knowledge on the application of artificial intelligence, bioinformatics, and genomics in African food production systems. The review design was chosen to allow for the integration of multidisciplinary evidence spanning agriculture, computer science, genomics, and development studies.

Search Strategy

Relevant literature was identified through systematic searches of major academic databases, including Scopus, Web of Science, Google Scholar, PubMed, and IEEE Xplore. Additional sources were obtained from reports published by international and regional organizations such as the Food and Agriculture Organization (FAO), African Development Bank (AfDB), CGIAR, and national agricultural research institutes.

Search terms included combinations of keywords such as “artificial intelligence,” “machine learning,” “bioinformatics,” “genomics,” “precision agriculture,” “food production,” and “Africa.” Boolean operators were applied to refine the search and ensure relevance.

The selected literature was analyzed thematically and organized around key agricultural challenges, including climate change, soil degradation, low productivity, and population growth. Country-level case studies from Kenya, Nigeria, and South Africa were used to illustrate variations in technological readiness, effectiveness, and adoption constraints. Comparative analysis was applied to identify cross-cutting patterns, strengths, and limitations across technologies and regions.

Case studies from Kenya, Nigeria, and South Africa were chosen for their representativeness and diversity in applying AI, genomics, and bioinformatics respectively. Each country has demonstrated measurable progress in these domains, enabling comparative insights into success factors and limitations. Applications were categorized under four key agricultural challenges climate change, soil degradation, infrastructure deficits, and population growth allowing for thematic mapping of how each technology addresses specific issues.

To enhance analytical depth, this review also includes comparative evaluation frameworks for technology cost, scalability, yield impact, and implementation feasibility.

Visual data (e.g., tables and figures) will be integrated in future drafts to improve clarity and reader engagement.

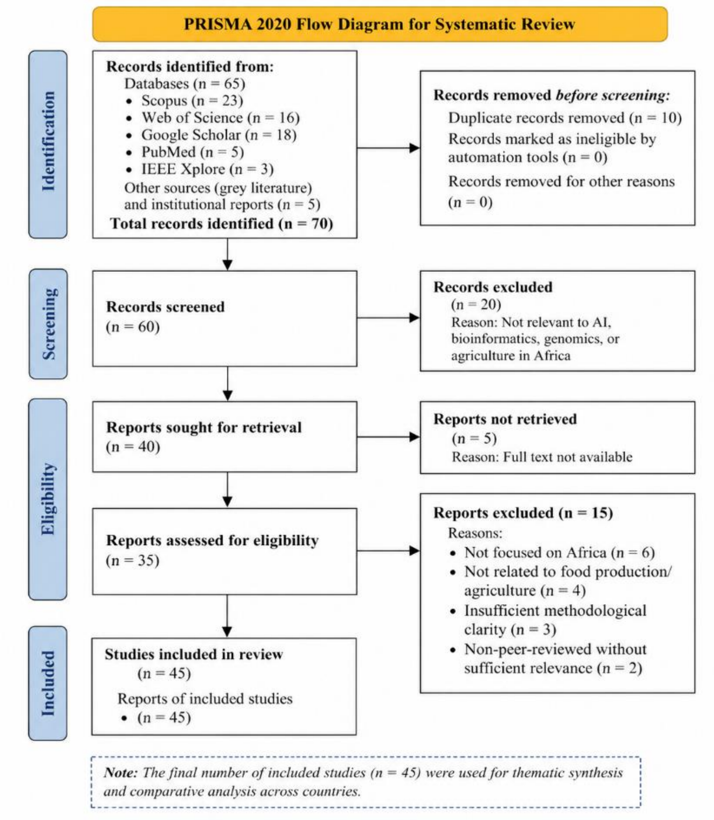

Fig. 2 Prisma Flow Diagram

Data Extraction and Synthesis

Data were extracted using a standardized template capturing study location, technology type, application area, reported outcomes, limitations.

A thematic synthesis approach was applied to identify recurring patterns, comparative insights, cross-cutting challenges.

Reproducibility Protocol

To ensure replicability all databases, keywords, and criteria are explicitly stated, Screening process is clearly defined and selection decisions are based on documented criteria, this enables future researchers to reproduce or update the review.

4. Results (Thematic Findings)

The reviewed literature reveals that the impact of AI, bioinformatics, and genomics in African agriculture cannot be adequately explained by technological capability alone. Rather, effectiveness is mediated by a combination of institutional readiness, infrastructural capacity, and user-level accessibility. This challenges the dominant assumption in existing studies that technological superiority directly translates into agricultural transformation.

AI-based tools demonstrate relatively faster uptake due to their compatibility with mobile platforms and existing digital ecosystems. However, this apparent success is conditional rather than universal. In low-connectivity environments, AI systems often fail to deliver actionable insights due to poor data quality and limited user interpretability. This suggests that AI effectiveness is not an inherent property of the technology but a function of the surrounding data infrastructure and human capacity.

In contrast, genomics and bioinformatics exhibit slower adoption rates but offer deeper, long-term transformative potential. Their impact is constrained by high entry costs, regulatory complexity, and dependence on specialized expertise. This creates a paradox in which technologies with the highest potential impact remain the least accessible within the contexts that need them most.

4.2 The Technology–Context Misalignment Problem

A critical pattern emerging from the analysis is the misalignment between technological design and local agricultural realities. Most AI and genomics solutions are developed in data-rich environments and later transferred to African contexts with minimal adaptation.

For example: AI models trained on non-African datasets often produce unreliable predictions under local conditions. Genomic solutions assume regulatory stability and laboratory infrastructure that are absent in many countries. This misalignment leads to what can be conceptualized as a “contextual performance gap”, where technologies perform well in controlled environments but underperform in real-world African farming systems.

4.3 Comparative Functional Roles of Technologies

Rather than viewing AI, bioinformatics, and genomics as competing tools, the findings indicate that they occupy distinct but complementary functional layers within agricultural systems:

- AI → Operational Layer (real-time decision support, farm-level optimization)
- Bioinformatics → Analytical Layer (data interpretation, genetic analysis)
- Genomics → Foundational Layer (trait development, biological innovation)

This layered perspective reveals that isolated deployment limits overall effectiveness. Maximum impact occurs when these technologies are integrated across layers, enabling feedback loops between field-level data, analytical processing, and genetic improvement.

Population Growth

Africa's population is expected to double by 2050 (UN, 2022), placing enormous pressure on the continent's agricultural systems to meet the growing demand for food. With a rapidly expanding population, there is a pressing need to increase food production in order to avoid widespread hunger and malnutrition. However, many African farmers, particularly smallholder farmers, face significant challenges in meeting this demand due to limited access to agricultural inputs such as quality seeds, fertilizers, and modern farming equipment.

The high cost of inputs, coupled with limited access to financial services, prevents many farmers from adopting more productive agricultural practices. Without access to credit or financing, farmers are unable to invest in the tools and technologies that could improve their productivity. Moreover, many farmers lack the necessary knowledge and training to implement modern farming techniques, which limits their ability to increase yields and improve food security.

In response to this challenge, recent developments in agricultural finance have sought to address the financial gap. Digital lending platforms and mobile banking services, such as *M-Shwari* in Kenya, have made it easier for smallholder farmers to access credit and financial services. Organizations like the *One Acre Fund* provide small loans and training to farmers, enabling them to purchase inputs such as seeds and fertilizers and adopt modern farming practices (Rutten & Mwangi, 2012). These initiatives have shown promise in improving farm productivity and income. However, the increasing demand for food production in Africa requires more than just access to credit. Governments and international organizations must invest in the education and training of farmers, ensuring that they have the skills and knowledge to implement sustainable agricultural practices. Additionally, investments in agricultural research and innovation are essential for developing high-yield, climate-resilient crop varieties that can withstand the challenges posed by climate change and soil degradation.

The Need to Incorporate AI, Bioinformatics, and Genomics

Addressing these challenges requires integrating AI, bioinformatics, and genomics into agricultural practices. These technologies enhance precision farming, identify genetic traits for resilient crops, and enable predictive pest and disease management. They also optimize resource allocation and bridge knowledge gaps through AI-driven training platforms, making them indispensable for sustainable agriculture.

Prospects and Limitations of the Approaches

Artificial Intelligence (AI) holds immense potential for revolutionizing agriculture. Tools like AI-powered drones enable real-time monitoring of crop health, while machine learning models optimize the use of fertilizers and water, reducing waste (Zhang et al., 2023). These advancements offer farmers a powerful way to increase efficiency and productivity. However, there are notable limitations to AI adoption, particularly the high implementation costs and the limited digital literacy among farmers. These barriers hinder the widespread application of AI technologies, especially in rural areas where the infrastructure and skills needed to leverage such innovations are lacking.

Bioinformatics also provides invaluable insights into crop genetics, contributing significantly to agricultural development. By identifying genetic markers for pest resistance, bioinformatics enhances crop breeding programs and helps improve overall agricultural resilience. Additionally, bioinformatics supports collaborative research across regions, enabling countries to share knowledge and resources. Despite these benefits, bioinformatics faces limitations due to the lack of adequate infrastructure and reliance on high-speed internet, which restricts its accessibility in many African countries. This digital divide is a major hurdle in fully capitalizing on the potential of bioinformatics in the agricultural sector.

Genomics research, particularly through tools like CRISPR, facilitates the development of resilient crop varieties. Genomic editing technologies enable the creation of drought-resistant crops, while sequencing technologies advance our understanding of genetic traits (Huang et al., 2021). These innovations can revolutionize crop breeding and improve food security. However, the adoption of genomics in agriculture is impeded by ethical concerns surrounding genetically modified organisms (GMOs) and regulatory hurdles. These issues raise debates about safety, environmental impact, and consumer acceptance, limiting the widespread use of genomics in crop development.

Several African countries exemplify the successful application of these technologies in agriculture. South Africa, with a population of 60 million (Stats SA, 2023), has leveraged AI tools to improve maize yields by 15%. In Nigeria, home to 220 million people (UN, 2023), bioinformatics has been used in cassava research to enhance disease resistance. Similarly, Kenya, with a population of 55 million (KNBS, 2023), has employed genomics to develop drought-tolerant maize varieties, significantly reducing crop losses. These examples highlight the promising impact of AI, bioinformatics, and genomics in enhancing agricultural productivity and resilience across the continent.

Bioinformatics in Food Production

The thematic organization of results reveals that AI, bioinformatics, and genomics contribute differently to addressing Africa's agricultural challenges, with varying levels of effectiveness and maturity.

Climate Change and Weather Variability

AI-based climate prediction models and decision-support systems have demonstrated moderate to high effectiveness, particularly in countries with stronger digital infrastructure such as Kenya and South Africa. Reported yield improvements range from **10–30%** in pilot studies involving precision irrigation and early warning systems. However, adoption remains limited in regions with low internet penetration and weak extension services.

Soil Degradation and Crop Productivity

Genomics-driven crop improvement programs have enabled the development of stress-tolerant and disease-resistant varieties. While these innovations show high long-term potential, their impact is constrained by high research costs, lengthy regulatory approval processes, and limited local breeding capacity, particularly in West African contexts.

Genetic Analysis and Crop Improvement

Bioinformatics tools enable the analysis of genetic sequences to identify desirable traits in crops. This facilitates marker-assisted selection and genome editing for improved yield, disease resistance, and climate adaptability. By leveraging bioinformatics, scientists can rapidly analyze large-scale genomic datasets, uncovering genes responsible for drought tolerance, pest resistance, and nutritional enhancement. Additionally, bioinformatics enhances plant breeding programs through genome-wide association studies (GWAS) and quantitative trait locus (QTL) mapping, accelerating the development of high-yield, climate-resilient crop varieties.

Livestock Breeding and Health Management

Bioinformatics aids in the selection of superior livestock breeds by analyzing genomic data. It also helps in disease surveillance and management by identifying genetic markers associated with resistance to common livestock diseases. By integrating next-generation sequencing (NGS) and comparative genomics, researchers can optimize breeding strategies, ensuring sustainable and productive livestock populations. Additionally, bioinformatics tools facilitate the identification of microbial populations in animal gut microbiomes, leading to improved livestock nutrition and overall health.

Pathogen Identification and Control

Bioinformatics techniques help in the identification of plant and animal pathogens through genomic sequencing. Early detection and characterization of pathogens allow for timely interventions, reducing crop and livestock losses. Metagenomic sequencing and bioinformatics pipelines enable researchers to track emerging diseases and develop targeted interventions, such as disease-resistant crop strains and vaccines for livestock.

Genomics Research in Food Production

Genomic Selection in Crops

Genomic selection accelerates breeding programs by identifying genes associated with desirable agronomic traits. This approach enhances crop resilience, nutritional value, and productivity. By utilizing whole-genome sequencing and CRISPR-based gene editing, scientists can introduce precise genetic modifications to enhance crop performance. Genome sequencing also helps in understanding the genetic basis of plant-microbe interactions, allowing for the development of bioengineered crops with enhanced resistance to pests and environmental stress.

Livestock Genomics

Advances in livestock genomics have led to the development of breeds with enhanced growth rates, feed efficiency, and disease resistance. Genomic selection tools enable more precise breeding strategies, reducing production costs and improving food security. The use of single nucleotide polymorphism (SNP) arrays and whole-genome sequencing facilitates the identification of favorable genetic variants, allowing for the selection of livestock breeds that are better adapted to local environmental conditions.

Biodiversity Conservation

Genomics research supports the conservation of indigenous crop varieties and livestock breeds. By preserving genetic diversity, African agriculture can maintain resilience against climate change and emerging diseases. Ex situ and in situ conservation programs, supported by genomic databases and biobanks, help safeguard valuable genetic resources for future breeding and food security initiatives. Additionally, genome-editing technologies such as CRISPR offer the potential to enhance genetic diversity by reintroducing lost traits into breeding populations.

Challenges and Opportunities

Infrastructure and Technological Barriers

Limited access to high-performance computing facilities and bioinformatics tools hampers research and implementation of AI-driven agricultural solutions.

Data Availability and Management

The lack of comprehensive agricultural datasets poses a challenge for developing accurate AI models and bioinformatics analyses. Efforts to establish open-access data repositories are crucial for progress.

Policy and Funding Constraints

Insufficient funding for agricultural research and lack of supportive policies hinder the adoption of AI, bioinformatics, and genomics in food production. Government and private sector investments are needed to drive innovation.

5. Comparative Analysis

Applications and Comparative Effectiveness of AI, Bioinformatics, and Genomics in African Agriculture

This section synthesizes how AI, bioinformatics, and genomics are applied in African agriculture, drawing comparisons on deployment costs, adoption rates, and impact on productivity across selected case studies from Kenya, Nigeria, and South Africa.

Technology	Country	Main Application Area	Estimated Yield Impact	Cost Barrier (High/Med/Low)	Notes on Scalability
Artificial Intelligence	Kenya	Crop monitoring, pest control	10–15% improvement	Medium	High in mobile-access areas
Genomics	Nigeria	Cassava and maize breeding	20–30% improvement	High	Medium (due to regulatory barriers)
Bioinformatics	South Africa	Livestock disease surveillance	Improved herd health	Medium	High in research institutes

AI applications such as mobile-based advisory platforms (e.g., iCow) have gained traction in Kenya due to mobile penetration and demand for weather-adaptive farming. In contrast, genomics research in Nigeria focuses on drought-resistant and disease-tolerant crop varieties, especially cassava and maize. These efforts are supported by local institutes like IITA. South Africa has implemented advanced bioinformatics pipelines to manage livestock diseases, reducing losses from foot-and-mouth disease and avian flu.

However, adoption is uneven across the continent. AI adoption tends to be limited by digital literacy, while genomics and bioinformatics face infrastructure and regulatory challenges. A key finding is that countries with stronger R&D institutions and supportive policies tend to report better outcomes in technology uptake and agricultural transformation.

Case Studies from Africa

Africa's agricultural sector has long been the backbone of the continent's economy, contributing to employment, food security, and economic stability. However, the region's agriculture faces numerous challenges, including climate change, pest outbreaks, and the lack of access to advanced technologies. Fortunately, the rise of modern technologies such as Artificial Intelligence (AI), genomics, and bioinformatics offers hope for overcoming these hurdles. The successful application of these technologies in various African countries showcases their potential to revolutionize agriculture. Below, we explore case studies from Kenya, Nigeria, and South Africa, demonstrating the effective use of AI, genomics, and bioinformatics in agriculture and livestock management.

AI Applications in Kenya's Agriculture Sector

Kenya is one of Africa's leaders in agritech innovation, leveraging technology to address the challenges faced by its agricultural sector. Kenyan agritech companies have successfully integrated AI-driven mobile applications to enhance productivity, improve market access, and mitigate the impact of climate change on farming. One such application is *iCow*, a mobile-based platform that uses AI and data analytics to provide farmers with advice on optimal farming practices, including crop rotation, pest control, and fertilization schedules. Additionally, *iCow* helps farmers access financial services, find markets for their produce, and obtain real-time weather forecasts, all of which are essential for improving yield and managing risks effectively (Rutten & Mwangi, 2012).

AI-powered weather forecasting applications in Kenya, such as *FarmDrive*, utilize data from satellites and local sensors to provide real-time updates on weather patterns. This is particularly important in Kenya, where farming is heavily dependent on weather conditions. By receiving accurate weather predictions, farmers can make informed decisions about planting, irrigation, and harvesting schedules, thus reducing crop failure rates caused by unexpected weather events. Moreover, these AI tools enable farmers to access important market information, such as the best times to sell crops based on prevailing weather conditions, which improves profitability.

Another notable AI application in Kenya's agricultural sector is the use of AI for pest detection. AI-powered image recognition tools like *Taimba* allow farmers to capture images of pest-affected crops using their smartphones. These images are analyzed by AI algorithms that can quickly detect pest infestations and recommend appropriate treatments. This is particularly important in Kenya, where pests such as locusts and aphids can devastate crops and lead to significant losses if not managed swiftly. With AI's ability to detect pests early, farmers can take timely action to mitigate damage and reduce pesticide use, leading to more sustainable farming practices.

Furthermore, Kenyan agritech companies have developed AI systems that facilitate market access for farmers. By using AI to analyze demand patterns and supply chains, platforms like *M-Farm* help farmers connect directly with buyers, eliminating middlemen and ensuring they receive fair prices for their produce. These platforms also allow farmers to engage in group buying, gaining access to affordable inputs such as seeds, fertilizers, and tools. The integration of AI in Kenya's agriculture sector not only improves the efficiency and profitability of farming but also strengthens the broader agricultural ecosystem by providing smallholder farmers with the tools they need to thrive in a competitive market.

Genomics Research in Nigeria's Crop Improvement Programs

Genomics research has become an essential tool for improving the productivity and resilience of staple crops in Nigeria. Research institutions and agricultural scientists have used genomic techniques to enhance the disease resistance, drought tolerance, and nutritional content of important crops such as cassava, maize, and rice. These crops are vital to the food security of Nigeria's growing population, and improving their yield and resilience is crucial for reducing hunger and poverty.

One of the most notable examples of genomics research in Nigeria is the application of gene editing and genomic selection techniques to improve cassava. Cassava is a staple food crop in Nigeria, serving as a primary source of calories for millions of people. However, cassava is vulnerable to several pests and diseases, including the cassava mosaic disease and cassava brown streak disease, which have caused significant losses in crop yield. Nigerian scientists have used genomics to identify and map the genes responsible for resistance to these diseases, allowing for the development of disease-resistant cassava varieties.

The International Institute of Tropical Agriculture (IITA), in collaboration with Nigerian research institutions, has developed genetically modified cassava varieties with increased resistance to viral diseases. These varieties are not only more resilient to disease but also produce higher yields. The success of these genomics-driven cassava improvement programs has the potential to boost food security in Nigeria, particularly in rural areas where cassava is a major food source. Furthermore, genomics research has led to the development of cassava varieties with enhanced nutritional content, such as higher levels of beta-carotene, which can help combat vitamin A deficiency in the population.

Maize, another staple crop in Nigeria, has also benefited from genomics research. Nigerian scientists have applied genomics tools to identify genes that confer resistance to maize diseases, including the maize streak virus and the fall armyworm. These pests and diseases have significantly impacted maize production in the country, leading to reduced yields and increased food insecurity. By using genomic selection, scientists can identify and propagate maize varieties that are naturally resistant to these threats, improving overall crop productivity.

While genomics research has shown great promise in improving crop productivity in Nigeria, challenges remain. One of the main obstacles to widespread adoption is the regulatory framework surrounding genetically modified crops. There is also resistance to genetically modified organisms (GMOs) in certain segments of the population, who express concerns over potential health and environmental risks. Nonetheless, the continued development and refinement of genomics technologies in Nigeria offer great potential for improving the resilience and productivity of its agricultural sector, helping to address food security challenges in the country.

Bioinformatics in Livestock Disease Management in South Africa

South Africa has become a regional leader in the application of bioinformatics in livestock disease management. The country's livestock sector, which includes cattle, sheep, and poultry, is a vital component of its agricultural economy. However, livestock diseases such as foot-and-mouth disease, tuberculosis, and avian influenza pose significant threats to both animal health and the economic stability of farmers. South African researchers and veterinarians have increasingly turned to bioinformatics tools to track, manage, and control these diseases, improving overall herd health and reducing economic losses (Bharadwaj et al. 2019).

Bioinformatics involves the use of computational tools and data analytics to analyze biological data, such as genomic sequences and disease outbreaks. In South Africa, bioinformatics has been used to analyze the genetic makeup of livestock pathogens, enabling scientists to better understand how diseases spread and evolve (Adjognon et al. 2017). By studying the genetic sequences of pathogens, bioinformaticians can track disease outbreaks in real time and identify the most effective treatments and vaccines. This approach has been particularly useful in managing the spread of diseases like foot-and-mouth disease, which can rapidly decimate herds if not controlled effectively.

For example, the *Foot-and-Mouth Disease Monitoring Program* in South Africa uses bioinformatics to analyze the genetic diversity of the virus and track its movement across regions. This allows authorities to predict where outbreaks are most likely to occur, enabling them to implement targeted vaccination campaigns and control measures. By identifying high-risk areas and potential sources of infection, South African farmers can take preventative measures to protect their livestock from outbreaks, reducing the need for mass culling and minimizing economic losses (Batista & Vincente, 2020).

In addition to tracking diseases, bioinformatics is also used in the development of vaccines and treatments for livestock diseases. Researchers in South Africa have utilized genomic data to develop more effective vaccines against diseases like avian influenza, which has had devastating effects on poultry production. By analyzing the genetic makeup of the virus, scientists can design vaccines that target specific viral strains, improving the efficacy and safety of vaccination programs.

The application of bioinformatics in livestock disease management has not only improved animal health in South Africa but also contributed to the country's economic stability. By reducing the spread of diseases and improving the effectiveness of vaccination programs, bioinformatics helps safeguard livestock production, which is a major source of income for many farmers. Additionally, it enhances the overall resilience of the agricultural sector, ensuring that South Africa's livestock industry remains competitive in both local and international markets.

Critical Assessment of Technological Integration in African Agriculture

While the transformative potential of AI, bioinformatics, and genomics in food production is clear, the extent of their impact remains constrained by several underlying issues. These include inadequate infrastructure, insufficient policy support, and limited technological literacy.

Root Challenges:

- **AI**: Despite high potential, AI is constrained by data sparsity, especially in rural regions, and unreliable electricity/internet. Many farmers are unaware of AI-based tools or lack the capacity to interpret predictive outputs. Moreover, there is a shortage of locally trained AI professionals in agricultural applications.
- **Bioinformatics**: The main limitation is infrastructural—high-performance computing (HPC) clusters and trained personnel are scarce. Additionally, national bioinformatics networks are often weak or non-existent, making cross-country research difficult.

- **Genomics**: Ethical and regulatory concerns over GMOs restrict experimentation and commercialization. The absence of unified biosafety legislation across the continent hinders innovation. For instance, genetically modified cassava in Nigeria faces societal resistance despite promising results.

Feasibility of Future Prospects

Prospects such as CRISPR gene editing, AI-based autonomous farming robots, and blockchain for data transparency have high potential but remain aspirational. CRISPR could revolutionize drought and pest tolerance in crops, but ethical and legal barriers remain unresolved. AI automation may be feasible in South Africa or Egypt but is currently out of reach for smallholder farmers across sub-Saharan Africa.

Opportunities for Transformation

- **Collaborative Platforms**: Cross-border genomic data sharing and AI model co-development could reduce costs and improve knowledge dissemination.
- **Public-Private Partnerships (PPPs)**: These could enhance infrastructural investment, as seen in Kenya's digital agriculture platforms funded by donor agencies and fintech firms.
- **Open-Source Tools**: Deploying lightweight bioinformatics and AI tools through open-source platforms could facilitate use in low-resource settings.

While the reviewed technologies demonstrate significant promise, their adoption across Africa remains uneven. A comparative assessment shows that **AI technologies exhibit higher short-term readiness,** largely due to their reliance on existing mobile and digital platforms. In contrast, **genomics and bioinformatics require deeper institutional investment,** including laboratories, skilled personnel, and regulatory harmonization.

Country-level comparison reveals that Kenya's relative success with AI applications is driven by mobile connectivity and private-sector involvement, whereas South Africa's leadership in bioinformatics reflects long-term investment in research institutions. Nigeria's progress in genomics highlights growing potential but is constrained by policy uncertainty and funding gaps.

These findings suggest that technological effectiveness alone does not determine impact. Instead, adoption is shaped by governance structures, capacity development, and alignment with local farming systems. Without targeted policy support and infrastructure development, advanced technologies risk deepening existing inequalities within African agriculture.

6. Critical Insight

Despite widespread recognition of AI, bioinformatics, and genomics as transformative technologies, this review reveals that their impact in Africa is not primarily limited by technical capability, but by systemic constraints. Unlike in developed regions where technological performance drives adoption, African contexts demonstrate that **institutional readiness, policy alignment, and infrastructural capacity are the dominant determinants of success**.

Furthermore, the analysis shows a clear **technology maturity gap**: AI applications exhibit higher short-term scalability due to compatibility with mobile platforms, whereas genomics and bioinformatics require long-term investment in research infrastructure and regulatory frameworks. This creates a structural imbalance in innovation diffusion across the continent.

Importantly, this study advances existing literature by demonstrating that **integrated deployment of these technologies rather than isolated implementation offers the greatest potential for sustainable agricultural transformation**. However, such integration remains largely absent in current practice.

7. Conclusion

This review highlights the vast potential of integrating artificial intelligence, bioinformatics, and genomics in transforming Africa's food systems. Case studies demonstrate notable success in yield improvements, disease management, and resilience building. However, systemic challenges such as infrastructural deficits, high deployment costs, and fragmented policy environments continue to limit scalability.

The findings suggest that to move from pilot projects to continent-wide adoption, African nations must address root infrastructural and regulatory barriers. Investments in education, research collaboration, and digital infrastructure will be pivotal.

Recommendations

1. **Develop National Digital Agriculture Strategies**
   Governments should craft context-specific policies that encourage investment in AI and genomics

infrastructure while ensuring alignment with national development plans.

2. **Invest in Agricultural Bioinformatics Hubs**
   Support for regional data centers and training institutions will close the skills gap and facilitate data-driven research in crop and livestock improvement.
3. **Establish Harmonized GMO and Gene Editing Policies**
   Unified regulations will reduce uncertainty, encourage innovation, and facilitate cross-border trade of improved crops.
4. **Support Open-Access Genomic and Agricultural Databases**
   These can foster collaborative innovation and reduce redundancy in research across the continent.
5. **Promote Farmer-Facing AI Platforms**
   Mobile-based AI tools should be subsidized or integrated into extension services to promote uptake and support decision-making among smallholder farmers.

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Declaration of conflict of interest

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