AGRICULTURAL AUTOMATION, CLIMATE CHANGE-ACTION AND FOOD SECURITY: GLOBAL ISSUES & LOCAL PERSPECTIVES

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AGRICULTURAL AUTOMATION, CLIMATE CHANGE-ACTION AND FOOD SECURITY (GLOBAL ISSUES & LOCAL PERSPECTIVES)

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TABLE OF CONTENTS

Preface

Editorial Note

Table of Contents

Acknowledgement

Dedication

Part one: AGRICULTURAL AUTOMATION Chapter One

Chapter One

Organic and Mineral Soil Amendments as Enablers of Climate-Smart Agricultural Automation: Implications for Soil Water Management and Food Security

*Paul Omaye Joseph[1,4], Enya Anari Akpa[2,4], King Ndeari Dedan[3,4],

Chapter Two

Climate Change–Driven Shifts in Plant Pathogen Epidemiology

IVOKE, Michael Anaelechi

Chapter Three

Bridging the Post-Harvest Loss Gap: Modernizing Middle-Mile Logistics to Eliminate Food Loss

Uzoma Uloma Onyewuchi (Ph.D)

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Chapter Four

Transforming Agriculture with Smart Technologies: Benefits,Challenges and Implementation Pathways

[1]Igbojionu, Donatus Okwudiri,[2]Igbojionu, Juliet Nnennaya and [3]Anyika, Felicia

Part two: THE CONCEPT OF CLIMATE CHANGE-ACTION

Chapter Five

Impact of Climate Change on Growth in Nigeria.

Tanimu Joseph[1] & Rebecca Yusuf Auta[2]

Chapter Six

Assessment of Conveyance Efficiency and Its Effect on Agricultural Activities in the Falalia Sector of Middle Rima Valley Irrigation Scheme, Goronyo, Nigeria.

***Sadiq Salihu Kumu[1]; Ibrahim Bala[1]; Umar Ibrahim Chonoko[2]; Fiddausi Salihu Kumu[3]**

Chapter Seven

Digital Veterinary Extension and Statistical Modelling for Climate-Resilient Livestock Disease Surveillance in Nigeria

[1]Chidinma Theresa Nwosu[1], Aren Fatandi Peter[2,] Silas Yibarga Gani[3] & Baridanu Hope Mbube[4]

Chapter Eight

Review of Environmental Degradations in Nigeria From 1960 To 2026: Threats, Policy Frameworks, and Strategic Responses

[1,3]Salami, K. D. [2]Iroko, O.A., [4]Pius, Emmanuel Ekomki and [3]Soba, T. M.

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Part three: THE CONCEPT OF FOOD SECURITY

Chapter Nine

Musa Paradisiaca (Plantain) Production In A Climate Change Agriculture

Omu, Paul B.

Chapter Ten

Building Climate Resilience in Nigeria's Food Systems: Integrating Adaptation Strategies for Sustainable Food Security:

Dr. Ijeoma Rose Ezebuike

Chapter Eleven

Snake Gourd as a Neglected and Underutilized Crop for Food Security and Climate Resilience in Southeast Nigeria
Dr. Ogechukwu Anulika Umeh

Chapter Twelve

Climate-Smart Livestock Production: Adaptation, Mitigation and Sustainable Strategies for Resilient Livestock systems

Amaechi, C.I. and Adeyemi, E.A

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous Agricultural Automation, Climate Change-Action and Food Security issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which Agricultural Automation, Climate Change-Action and Food Security issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue Agricultural Automation, Climate Change-Action and Food Security necessary in policy making process that will stimulate increase in food production and environmental sustainability. Agricultural Automation, Climate Change-Action and Food Security**:** *Global Issues & Local Perspectives* is organized in three parts. Part One deals with The Concept of Agricultural Automation, Part Two is concerned with The Concept of Climate Change-Action and Part Three deals with the Concept of Food Security

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SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

Chapter Two

Building Climate Resilience in Nigeria's Food Systems: Integrating Adaptation Strategies for Sustainable Food Security:

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Table of Content

1. Introduction
2. Climate Change and Food System Vulnerability in Nigeria
3. Concept of Climate Resilient Food Systems
4. Adaptation Approaches for Climate Resilient Food Systems
5. Strengthening Resilience across the Food Supply Chain
6. Institutional and Financial Support
7. Integrated Frame work for Sustainable Food Security
8. Challenges
9. Conclusion

1 Introduction

Climate change poses a serious threat to food security in Nigeria because it affects agricultural production, food availability, household income and access to nutritious food. Rising temperatures, irregular rainfall, flooding, drought and increasing pest and disease outbreaks can reduce crop yields, damage livestock and disrupt farming activities. These effects can reduce the quantity and quality of food produced, weaken farmers' livelihoods and increase the vulnerability of households that depend on agriculture. Climate-related shocks can also interact with poverty, insecurity and economic pressures, making it more difficult for many Nigerians to obtain sufficient and nutritious food. Consequently, building climate resilience is essential for protecting agricultural productivity and achieving sustainable food security in the country.

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Nigeria's food system is particularly vulnerable because much agricultural production depends on rainfall, while many farmers have limited access to irrigation, improved seeds, agricultural finance, extension services and reliable climate information. Changes in rainfall patterns make it difficult for farmers to determine appropriate planting and harvesting periods, while prolonged dry conditions can reduce soil moisture and water availability. Flooding can destroy crops, livestock, farmland and rural infrastructure, thereby disrupting agricultural activities and the movement of food from production areas to markets. Schmitt-Olabisi,, Liverpool-Tasie., Onyeneke., Choko., Osuntade., Sanou., Singa., & Chiemela, (2020) highlight the importance of climate change adaptation in Nigeria's agricultural sector, supporting the need for measures that strengthen farmers' capacity to respond to climate-related risks.

Climate change also affects other stages of the food system beyond agricultural production. High temperatures can accelerate food spoilage, while flooding, inadequate storage facilities, poor rural roads and inefficient transportation can increase post-harvest losses. These problems reduce the quantity of food reaching consumers and may contribute to higher food prices. When food supplies decline and prices increase, low-income households may struggle to afford balanced and nutritious diets. Therefore, addressing climate change requires a broader approach that considers agricultural production, processing, storage, transportation, distribution and market access. Strengthening these interconnected components can help reduce food losses, protect livelihoods and improve the reliability of food supplies.

Climate adaptation is therefore important for enabling farmers, households and food-system institutions to anticipate, withstand and recover from climate-related shocks. Relevant adaptation strategies include crop diversification, mixed farming, climate-resilient crop varieties, agroforestry, irrigation, soil and water conservation and integrated pest management. These practices can help reduce production risks, conserve natural resources and improve the capacity of agricultural systems to cope with changing climatic conditions. However, their effectiveness depends on farmers' access to finance, appropriate technologies, technical knowledge, extension services and supportive agricultural policies. Schmitt-Olabisi *et al*. (2020) provide a relevant basis for emphasizing adaptation within Nigeria's agricultural sector, particularly the need to strengthen responses to climate-related challenges.

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Building climate resilience also requires coordinated support from government agencies, research institutions, extension services, financial institutions, farmer organizations, non-governmental organizations and private businesses. Government policies and investments can improve irrigation, rural roads, storage facilities and access to agricultural inputs, while research institutions can develop technologies suited to local environmental conditions. Extension services can help farmers understand and adopt appropriate adaptation practices, and financial institutions can provide affordable credit for investments in resilient production and post-harvest technologies. Collaboration among these stakeholders can strengthen the entire food system, reduce climate-related disruptions and improve the ability of farmers and consumers to cope with changing conditions.

Problem Statement

Despite Nigeria's agricultural potential, climate change increasingly threatens food security through irregular rainfall, flooding, drought, extreme temperatures, and pest and disease outbreaks. These challenges reduce agricultural productivity, increase post-harvest losses, disrupt food distribution, and raise food prices. The situation is worsened by inadequate irrigation, poor storage facilities, limited access to finance, weak extension services, and insufficient climate information. Although adaptation practices are available, financial, infrastructural, and institutional constraints limit their effective implementation. Consequently, an integrated approach to building climate resilience across agricultural production, processing, storage, transportation, and marketing is necessary to improve food availability, accessibility, affordability, and stability in Nigeria.

Against this background, this chapter examines building climate resilience in Nigeria's food systems by integrating adaptation approaches for sustainable food security. It focuses on major climate risks, adaptation practices, and resilience across the food supply chain, institutional support and the challenges and opportunities for strengthening food security under changing climatic conditions.

2 Climate Change and Food System Vulnerability in Nigeria

Nigeria's food system is increasingly vulnerable to climate change because agricultural production depends heavily on climate sensitive resources such as rainfall, soil and water. Major risks include

drought, flooding, irregular rainfall, extreme heat, pest and disease outbreaks, and water scarcity. Omokaro (2026) notes that rising temperatures, rainfall variability, flooding, drought, soil degradation and pest outbreaks are increasingly threatening agricultural productivity and food security in Nigeria.

Drought

Drought reduces soil moisture and water available for crops and livestock. Long term dry periods can cause crop failure, reduce pasture and increase livestock losses. It can also reduce the amount of food reaching markets, thereby increasing food prices and reducing household access to food.

Flooding

Flooding can destroy crops, livestock, farmland, roads, storage facilities and processing infrastructure. It may also cause soil erosion and disturb farming activities. Damaged roads can prevent farmers from moving produce to markets, resulting in food shortages and higher transportation and market costs.

Irregular Rainfall

Changes in the timing, duration and intensity of rainfall make it difficult for farmers to plan planting and harvesting. Excessive rainfall can cause flooding and crop damage, while insufficient rainfall can reduce yields. These disturbances can extend from production to food processing, storage and marketing.

Extreme Heat

High temperatures can reduce crop productivity, increase livestock heat stress and raise water requirements. Extreme heat can also increase the deterioration of harvested crops where adequate storage and cooling facilities are unavailable. As a result, heat affects both the quantity and quality of food available to consumers.

Pests and Diseases

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Changing climatic conditions can favour the spread and intensity of agricultural pests and diseases. Crop damage reduces yields and increases production costs. Pest outbreaks can also reduce the quality and market value of agricultural products. Biological crop protection and other ecological approaches have been identified as potential adaptation approaches for improving food security.

Water Scarcity

Water scarcity affects crop production, livestock, fisheries, processing and household consumption. Farmers who depend mainly on rainfall are especially vulnerable when rainfall becomes unreliable. Competition for limited water resources can further increase pressure on agricultural communities.

Effects across the Food System

The effects of these climate risks extend beyond agricultural production. Production may decline because of crop failure, livestock losses and pest outbreaks. Processing and storage can be affected by heat, flooding and inadequate water. Transportation may be halted by damaged roads and flooding. Markets may experience reduced supplies, increased transportation costs and higher food prices. Finally, consumers may face reduced food availability, lower purchasing power and poorer dietary quality. Thus, climate change should be addressed as a threat to the entire food system, not only to agricultural production. Recent evidence also shows that climate shocks can connect with insecurity and natural resource conflicts to further weaken food security in Nigeria.

3 Concept of Climate Resilient Food Systems

A climate resilient food system is a food system that can prepare for, withstand, recover from, and adapt to climate related shocks while continuing to provide sufficient, safe and nutritious food. Ngongolo, Sigala, & Mrimi, (2026) explain that climate resilient food systems require adaptation measures that strengthen agricultural production, food supply chains and livelihoods while addressing climate risks and institutional challenges.

Climate Adaptation

Climate adaptation refers to adjustments in agricultural practices, technologies, institutions and livelihoods in response to actual or expected climate changes. In food systems, adaptation may

include drought tolerant crops, improved water management, agroforestry, better pest management, climate information and improved farming practices. These measures help farmers and other food system actors reduce climate related losses.

Food System Resilience

Food system resilience is the capacity of the food system to withstand climate shocks and other disturbances, recover from them and continue to provide food and livelihoods. It covers not only agricultural production but also processing, storage, transportation, marketing and consumption. A resilient system can therefore maintain food supplies even when climate related disruptions occur.

Sustainable Food Security

Sustainable food security means ensuring that all people have reliable access to sufficient, safe and nutritious food, both now and in the future, without undermining the environmental, economic and social resources needed to produce food. It therefore requires food systems that are productive, economically accessible, environmentally responsible and capable of meeting future food needs.

Relationship among the Three Concepts

The three concepts are closely connected. Climate adaptation provides the actions, food system resilience provides the capacity to withstand and recover from shocks, while sustainable food security represents the desired outcome. Thus, effective climate adaptation strengthens the resilience of food production and supply chains, which helps maintain food availability, access, utilization and stability. Together, they provide an approach for Nigeria to maintain food security despite increasing climate risks. Nigeria's current policy direction also emphasizes linking climate action with food system transformation to achieve more resilient and sustainable food security.

4 Adaptation Approaches for Climate Resilient Food Systems

Climate change poses serious threats to agricultural production and food security in Nigeria through drought, flooding, irregular rainfall, extreme temperatures, water scarcity, pests and diseases. Therefore, adaptation measures are needed to reduce climate related losses and strengthen the ability of food systems to continue producing and supplying food. Akinkuolie,

Ogunbode & Adekiya. (2025) reported that climate induced floods and droughts are increasingly threatening food security in Nigeria and emphasized the importance of adaptation, investment, improved infrastructure and stakeholder participation in building resilient food systems.

Crop Diversification

Crop diversification involves growing different crops on the same farm or across different farming seasons instead of depending on one crop. It reduces the risk of complete crop failure because different crops respond differently to drought, excessive rainfall, pests and diseases. Farmers can combine cereals, legumes, vegetables, root crops and other crops that are suitable for their local environment. Crop diversification can also improve household nutrition and provide additional sources of income. It therefore contributes to food availability, income stability and resilience to climate shocks.

Mixed Farming

Mixed farming involves combining crop production with livestock production. The two activities can support each other because crop residues can be used as livestock feed, while animal manure can be returned to the soil to improve fertility. Mixed farming also provides farmers with different sources of food and income. When climate conditions negatively affect crop production, livestock may provide an alternative source of food and income. Similarly, when livestock production is affected, crops may still provide some returns. This makes mixed farming an important approach for reducing climate related production risks.

Climate Resilient Crop Varieties

The use of climate-resilient crop varieties can help farmers cope with changing climatic conditions. These varieties may be tolerant to drought, flooding, heat, pests or diseases and may also mature earlier than conventional varieties. Early-maturing crops are useful where rainfall seasons become shorter or less predictable. Drought-tolerant varieties can reduce yield losses during periods of limited rainfall, while flood-tolerant varieties can help protect production in flood-prone areas. Tofa, Kamara, Babaji, Akinseye., & Bebeley, (2021) found that drought-tolerant maize varieties could reduce the negative effects of climate change on maize yields in Nigeria's savanna zones, although combined tolerance to drought and heat remains important. Improving farmers' access to

suitable seeds through research institutions, extension services and agricultural programmes is therefore essential for strengthening food-system resilience.

Soil and Water Conservation

Soil and water conservation practices help protect agricultural resources from climate related damage. Practices such as mulching, cover cropping, minimum tillage, contour farming, terracing and the application of organic manure can reduce erosion, improve soil structure and increase water retention. These practices are important because heavy rainfall can wash away fertile topsoil, while long lasting dry periods can reduce soil moisture. Maintaining healthy soils allows crops to withstand climate stress better and can improve productivity over time. Conservation practices also contribute to sustainable management of agricultural land.

Irrigation and Water Management

Irrigation can reduce farmers' dependence on unreliable rainfall and allow food production to continue during dry periods. Efficient irrigation methods, water harvesting, storage facilities and improved watershed management can help farmers use available water more effectively. However, irrigation must be properly managed to prevent excessive water extraction, soil degradation and conflicts over water resources. Farmers should therefore be supported with appropriate irrigation technologies, technical knowledge and access to reliable water sources. Improved water management is especially important in areas experiencing frequent drought and irregular rainfall.

Agroforestry

Agroforestry involves the integration of trees with crops and livestock. Trees can provide shade, reduce wind damage, control erosion and improve soil fertility. They can also provide fruits, fodder, fuelwood and other products that diversify farmers' sources of food and income. The presence of trees can improve the farm environment by helping to regulate temperature and conserve soil moisture. Agroforestry therefore provides both environmental and economic benefits and can contribute to the long term resilience of agricultural communities.

Integrated Pest Management

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Integrated pest management involves using different methods to control agricultural pests while reducing unnecessary dependence on chemical pesticides. These methods may include resistant crop varieties, crop rotation, biological control, field sanitation, regular pest monitoring and the careful use of pesticides. Climate change can increase pest and disease risks by changing temperature and moisture conditions. Integrated pest management can therefore reduce crop losses while protecting soil, water and beneficial organisms. Farmers also need improved extension support to identify pest outbreaks early and apply appropriate control measures.

Climate Information and Early Warning

Climate information and early warning systems enable farmers and other food system actors to prepare for climate related hazards. Information on expected rainfall, drought, flooding, temperature and other climate conditions can guide decisions about planting dates, crop selection, irrigation, harvesting and livestock management. Early warnings can also help communities protect crops, animals, farm equipment and stored food before extreme events occur. Information should be communicated through extension officers, radio, mobile phones, farmer organisations and other accessible channels. Akinkuolie *et al.,* (2025) identified increased stakeholder engagement and the use of digital technologies as important opportunities for strengthening Nigeria's capacity to respond to climate induced food insecurity.

Integrated Application of Adaptation Approaches

The adaptation approaches discussed above should not be implemented in isolation. Their effectiveness can increase when they are combined according to local environmental and socioeconomic conditions. For example, crop diversification can be combined with mixed farming, agroforestry and soil conservation. Irrigation can support the use of climate resilient varieties, while climate information can help farmers decide when and how to apply these practices. Integrated adaptation can therefore reduce production risks, protect natural resources, stabilize food supply and improve farmers' livelihoods.

Overall, climate adaptation should extend beyond agricultural production to the wider food system. Resilience requires actions that protect production, processing, storage, transportation and markets from climate related disruptions. Such an integrated approach can help Nigeria maintain food

availability and access while improving the capacity of farmers, communities and food system institutions to cope with future climate shocks.

5 Strengthening Resilience across the Food Supply Chain

Building climate resilient food systems requires attention beyond agricultural production. Food can be produced successfully but still fail to improve food security if substantial quantities are lost during harvesting, storage, processing, transportation or marketing. Khan, Siddiqui, Siddique, & Ali (2024) emphasize that reducing post-harvest losses is an important strategy for improving food availability and reducing food insecurity, particularly in developing countries like Nigeria.

Post-Harvest Loss Reduction

Post-harvest losses occur when food is damaged, spoiled or wasted between harvesting and consumption. In Nigeria, losses can result from poor handling, pests, inadequate packaging, unsuitable storage conditions and weak transportation systems. Reducing these losses means that more of the food already produced reaches consumers. Improved harvesting methods, better packaging, drying, cooling, preservation and farmer training can reduce losses and increase the effective supply of food without necessarily expanding cultivated land.

Food Storage

Adequate storage is essential for protecting food from moisture, pests, mold, excessive heat and physical damage. Farmers and food traders need access to improved warehouses, silos, sealed or air tight storage, cold rooms and other appropriate storage facilities. Better storage also allows farmers to keep produce for longer periods instead of selling immediately after harvest when prices may be low. This can reduce seasonal shortages and contribute to greater stability in food availability and prices.

Processing

Food processing can increase the shelf life and value of agricultural products. Crops such as cassava, maize, rice, fruits and vegetables can be processed into products that are easier to store, transport and market. Processing can therefore reduce waste, create employment and provide income opportunities. Small-scale processing facilities located close to production areas can also reduce the distance that highly perishable products travel before being preserved or transformed.

Transportation

Efficient transportation is necessary to move food from farms to processors, storage facilities, markets and consumers. Poor rural roads, high transportation costs, inadequate vehicles and the absence of refrigeration facilities can increase food losses, particularly for fruits, vegetables, meat and other perishable products. Strengthening rural roads, transport infrastructure, refrigerated transportation and affordable logistics services can help maintain food quality and reduce losses along the supply chain. Evidence from Nigeria shows that long distance movement through poor road networks and inadequate refrigeration systems are important supply chain problems.

Market Access

Farmers need reliable access to markets where they can sell their produce at fair prices. Limited market access can force farmers to sell quickly, sometimes at low prices, resulting in reduced income and discouraging further production. Strengthening farmer cooperatives, market information systems, aggregation centres, digital marketing platforms and linkages between farmers and processors can improve market access. Better market connections also help match food supply with consumer demand and reduce unnecessary movement and losses.

Food Price Stability

Climate shocks and supply chain setbacks can reduce food availability and increase food prices. Flooding, drought, poor transportation, storage losses and high processing costs can all contribute to price increases. Strengthening storage and transportation systems, reducing post-harvest losses and improving market coordination can help moderate sudden changes in food supply and prices. Food price stability is very important for poor households because rising food prices reduce their ability to purchase sufficient and nutritious food. Recent evidence also shows that food insecurity

SAEREM BOOK CHAPTERS First Published 2026 ISBN 978-978-60709-7-6

in Nigeria is influenced by economic conditions, population growth and other pressures affecting food availability and access.

Strengthening the Whole Food Supply Chain

Resilience therefore requires a coordinated approach from farm to consumer. Reducing post-harvest losses increases the quantity of food available; improved storage protects food quality; processing extends shelf life and adds value; efficient transportation connects producers with consumers; better market access improves farmers' incomes; and stable prices improve consumers' ability to obtain food. Addressing these components together gives climate resilience a broader food system perspective rather than limiting adaptation to agricultural production alone. The 2024 systematic review of food losses in Nigeria similarly concludes that food loss is a multifaceted problem requiring integrated solutions across the food system.

6. Institutional and Financial Support

Building climate resilient food systems requires strong institutional and financial support. Farmers may be willing to adopt climate resilient practices, but limited finance, weak infrastructure, inadequate extension services and insufficient technical knowledge can prevent effective adoption. Gabriel, Olajuwon, Klauser, Michael, & Renn (2023) found that improved agricultural financing, extension services and capacity building are important for strengthening climate smart agriculture and improving farmers' resilience in Nigeria.

Government

Government has the primary responsibility for creating policies and an enabling environment for climate resilient food systems. It should provide adequate agricultural funding, improve rural roads and irrigation infrastructure, support access to improved inputs and strengthen climate adaptation programmes. Government policies should also promote sustainable farming, food storage, processing and market development. Stable and consistent agricultural policies are important because frequent changes in programmes can discourage long term investment.

Research Institutions

Research institutions should develop and promote technologies that respond to local climate conditions. These include drought and flood tolerant crop varieties, improved livestock breeds, water saving technologies, soil management practices and better post-harvest technologies. Research institutions should work closely with farmers, extension personnel and private sector organisations so that innovations are practical, affordable and accessible.

Extension Services

Extension services provide the link between research institutions and farmers. Extension officers should train farmers on climate resilient farming, soil and water management, pest control, improved varieties, post-harvest handling and climate information. Extension services should also provide regular advisory support rather than only visiting farmers occasionally. Nigeria's 2023 National Agricultural Extension Policy emphasizes stronger collaboration among government, private sector actors, NGOs and farmer based organizations in delivering extension services.

NGOs

Non-governmental organizations can support climate resilient food systems through funding, training, demonstration farms, provision of inputs and community development programmes. NGOs can also reach vulnerable farmers who may have limited access to government programmes. Their activities should, however, be coordinated with government policies and local institutions to avoid duplication and ensure that successful projects can continue after external funding ends.

Farmer Organizations

Farmer organizations and cooperatives can improve farmers' access to finance, inputs, information and markets. Through collective action, farmers can purchase inputs in larger quantities, access training, negotiate better prices and obtain credit more easily. Farmer organizations can also strengthen farmers' bargaining power and provide a platform for sharing climate information and adaptation experiences.

Financial Institutions

Banks, microfinance institutions and other financial institutions are important for providing the capital required to adopt climate resilient technologies. Affordable agricultural loans, insurance,

savings schemes and climate related financing can help farmers invest in irrigation, improved seeds, machinery, storage and processing equipment. Access to credit is particularly important because climate resilient technologies often require initial investment. Evidence from Nigeria shows that access to credit and cooperatives can significantly support the adoption of climate smart agricultural practices.

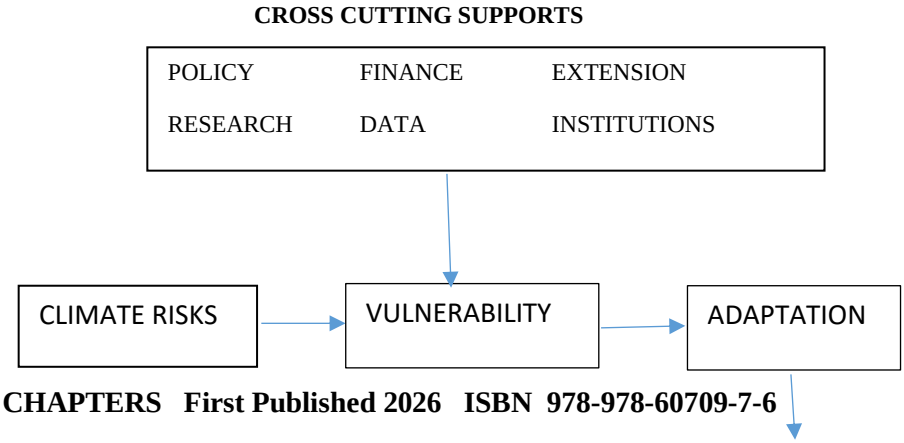
Private Sector

The private sector can provide agricultural inputs, machinery, processing facilities, storage, transportation, digital services and market opportunities. Private companies can also invest in climate smart technologies and establish partnerships with government, research institutions and farmer organizations. Their participation can improve efficiency across the food supply chain and create stronger links between farmers and consumers.

Integrated Institutional Support

The different institutions should work together rather than operate independently. Government provides policies and public infrastructure; research institutions provide knowledge and technologies; extension services provide technical support; NGOs strengthen community programmes; farmer organizations facilitate collective action; financial institutions provide capital; and the private sector provides investment, technologies and markets. Coordinated action across these institutions can improve finance, infrastructure, extension, technology adoption and capacity building, thereby strengthening the resilience of Nigeria's food system

7. Integrated Frame work for Sustainable Food Security



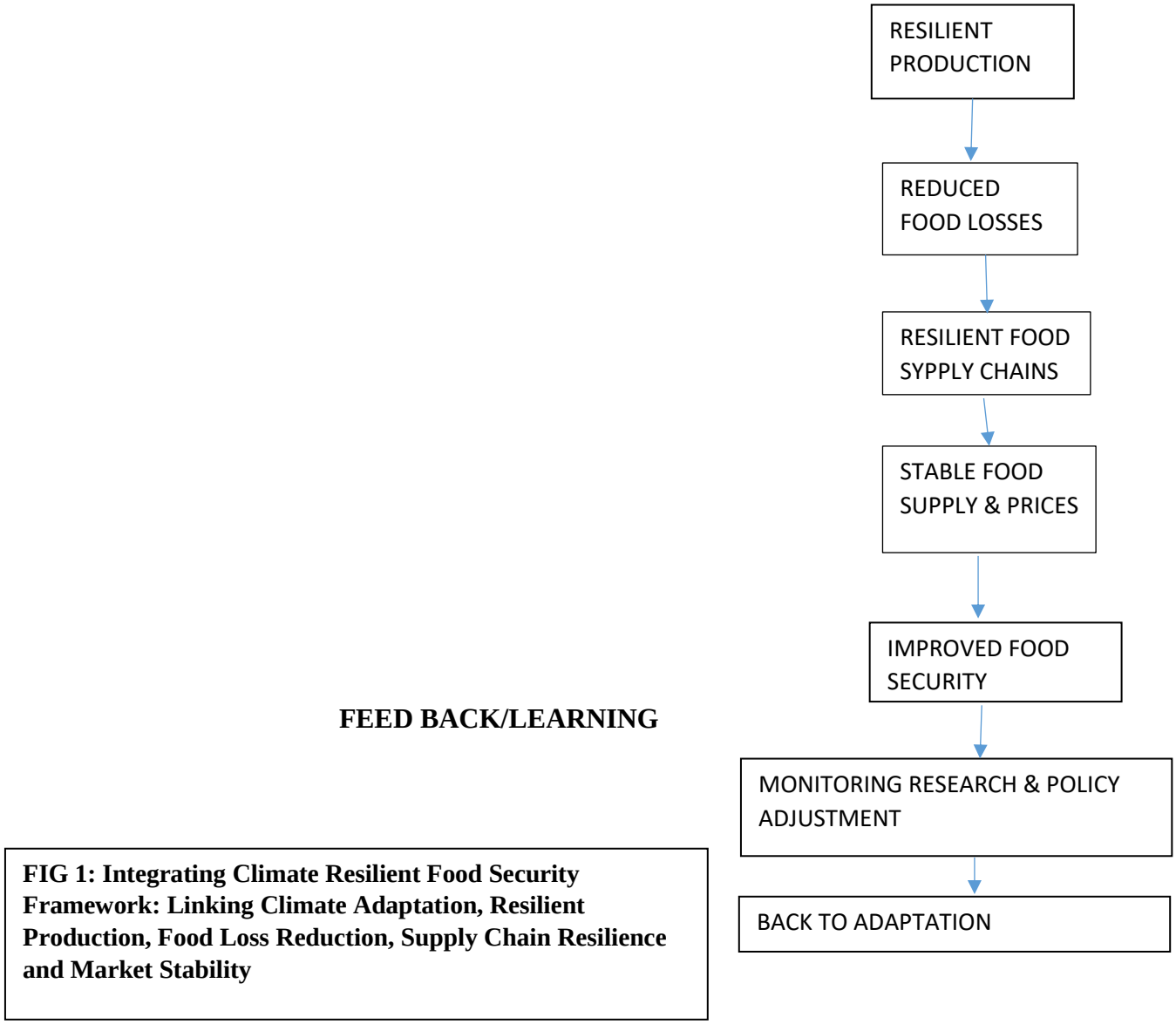


FIG 1: Integrating Climate Resilient Food Security Framework: Linking Climate Adaptation, Resilient Production, Food Loss Reduction, Supply Chain Resilience and Market Stability

Explanation of the Integrated Framework for Sustainable Food Security

The Integrated Framework for Sustainable Food Security presents a systematic approach through which climate related risks can be addressed to improve the availability, accessibility, affordability and stability of food. The framework recognizes that food security cannot be achieved through increased agricultural production alone. Rather, it requires coordinated action across climate adaptation, agricultural production, post-harvest management, food supply chains, markets and

institutional support. This integrated approach is consistent with Mudzielwana (2025), who noted that climate smart food systems require the integration of adaptation measures, sustainable production, resilient value chains, appropriate technologies and supportive policies.

The framework begins with climate risks, including drought, flooding, excessive heat, pests, diseases and irregular rainfall. These risks can reduce agricultural productivity and disrupt food supply systems, particularly where farmers depend heavily on rain fed agriculture and have limited access to infrastructure and financial resources. The extent to which climate risks affect food security is influenced by the vulnerability of agricultural systems, which may arise from poor infrastructure, inadequate finance, limited technical knowledge and weak institutional support. In Nigeria, climate related floods and droughts have been identified as important threats to agricultural production and food security, making adaptation an important component of resilience building (Akinkuolie *et al.,* 2025).

The next stage of the framework is climate adaptation. Adaptation involves actions that enable farmers and food systems to anticipate, withstand and recover from climate related shocks. Such actions include the use of climate resilient crop varieties, irrigation, diversification, improved soil and water management, conservation agriculture and access to reliable climate information. These practices can help farmers maintain agricultural production even when climatic conditions become unfavorable. Mudzielwana (2025) similarly argues that climate smart agricultural practices, including drought resistant crops, improved water management and agro ecological approaches, are important for strengthening resilience and supporting sustainable food production.

Effective adaptation contributes to resilient agricultural production, which represents another important component of the framework. Resilient production means that farmers are better able to maintain or recover crop and livestock production following climate shocks. However, producing more food does not automatically guarantee food security. Food can still be lost after harvesting because of inadequate storage, poor processing, weak packaging, pest damage and inefficient transportation. Therefore, the framework extends beyond the farm to include post-harvest loss reduction. Improved harvesting practices, storage facilities, processing technologies, packaging and transportation can reduce the amount of food lost before it reaches consumers.

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The framework also emphasizes resilient food supply chains. Agricultural products must move efficiently from farms through processors, traders and markets to consumers. Reliable transportation, adequate storage facilities, processing infrastructure, market information and effective distribution systems are therefore necessary. Climate resilient value chains are particularly important in developing countries because climate shocks can affect not only production but also transportation, markets and food distribution. Chirombo and Pangapanga-Phiri (2025) emphasize the importance of adaptive practices, infrastructure, governance and policy integration in strengthening climate resilient agrifood value chains in Sub Saharan Africa.

When production, post-harvest management and supply chains function effectively, they contribute to a stable food supply and more stable food prices. Reduced production losses and improved distribution can minimize shortages and interruptions in food availability. Similarly, efficient markets can improve access to food by ensuring that agricultural products reach consumers at reasonable prices. Consequently, the framework connects agricultural resilience with the major dimensions of food security. Increased and reliable food availability, improved physical and economic access, affordability and stability ultimately contribute to better food security outcomes.

The framework is further supported by four important cross cutting factors: policy, finance, extension and research. Government policies provide the institutional direction and regulatory environment needed to promote climate resilient agriculture and sustainable food systems. Finance provides resources for farmers, schools, agricultural institutions and other actors to invest in improved technologies, infrastructure and adaptation measures. Extension services provide farmers with practical knowledge and technical assistance, while research generates improved technologies, climate information, production methods and evidence for decision making. These supporting factors operate across all stages rather than at only one point in the framework. Recent evidence from Nigeria also indicates that greater investment in climate adaptation, improved institutional coordination and technological development are important for strengthening food system resilience (Akinkuolie *et al.,* 2025).

Finally, the framework contains a monitoring, research and policy adjustment feedback process. This component ensures that the performance of adaptation strategies, agricultural production,

post-harvest practices and food supply interventions is regularly assessed. Information generated through monitoring and research can reveal what is working, what is failing and what requires improvement. Policymakers and other stakeholders can then adjust programmes, redirect resources and introduce improved strategies. This makes the framework dynamic rather than a one-way process.

Generally, the Integrated Framework for Sustainable Food Security contributes to a broader understanding of food security by moving beyond a production-centred approach. It demonstrates that sustainable food security depends on the interaction between climate adaptation, resilient agricultural production, post-harvest loss reduction, efficient food supply chains, stable markets and strong institutional support. The framework therefore provides a comprehensive pathway through which climate risks can be transformed into opportunities for building more resilient and sustainable food systems. Its relevance is particularly strong in climate vulnerable regions such as Nigeria, where strengthening adaptation, infrastructure, finance, knowledge and governance is essential for protecting food production and improving long term food security.

8. Challenges

The implementation of climate smart agriculture and sustainable food security strategies faces several challenges that can reduce their effectiveness, particularly in developing countries such as Nigeria. One major challenge is inadequate funding. Farmers and agricultural institutions often lack sufficient financial resources to purchase improved seeds, fertilizers, irrigation equipment, machinery and other climate smart technologies. Limited access to affordable credit also makes it difficult for small scale farmers to invest in adaptation measures and expand their production. Salisu (2022) identified inadequate capital, limited access to agricultural inputs and unavailable equipment as important barriers to adopting climate-smart agricultural practices in Nigeria. These constraints can limit farmers' ability to invest in adaptation strategies and improve productivity.

Another important challenge is poor infrastructure. Inadequate rural roads, storage facilities, irrigation systems, electricity, processing centres and market infrastructure can increase production and distribution costs and contribute to post-harvest losses. Poor infrastructure also makes it

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difficult for farmers to move agricultural products from rural areas to markets, thereby reducing the benefits of increased production.

Limited access to climate information is another constraint. Farmers require timely and reliable information about rainfall patterns, drought, flooding, temperature changes, pests and suitable planting periods to make appropriate production decisions. However, many farmers have limited access to reliable weather forecasts and climate advisory services. This can reduce their ability to prepare for climate related risks. Onyeneke, Amadi, Njoku, & Osuji, (2021) also examined climate-change perceptions and the adoption of climate-smart agriculture among rice farmers in Ebonyi State, Nigeria, highlighting the importance of addressing constraints to adaptation.

Low adoption of agricultural technologies also limits the development of resilient food systems. Although technologies such as improved crop varieties, irrigation, mechanization, digital agricultural services and water conservation practices can improve productivity, their adoption may be restricted by high costs, inadequate technical knowledge, limited access to equipment and resistance to changing traditional farming practices.

The effectiveness of agricultural adaptation is further affected by weak extension services. Extension agents provide farmers with information and technical guidance on improved production practices, climate adaptation and resource management. Where extension personnel are inadequate, poorly equipped or unable to reach farmers regularly, farmers may not receive the knowledge and support required to adopt climate smart practices effectively. Salisu (2022) identified the unavailability of extension workers as one of the constraints affecting adoption, emphasizing the importance of strengthening agricultural advisory services.

Finally, poverty and insecurity represent major barriers to sustainable food production. Poor farmers may prioritize immediate household needs rather than investing in technologies that provide benefits over a longer period. Insecurity can also restrict access to farmland, disrupt farming activities, damage agricultural assets and discourage investment. Together, poverty and insecurity can weaken farmers' capacity to adapt to climate change and can contribute to instability in food production and supply.

Recommendations

- **Increase investment in climate-resilient agriculture:** Government should provide adequate funding, affordable credit and improved inputs to promote climate-resilient crops, irrigation and sustainable farming practices.
- **Strengthen food storage and supply chain infrastructure:** Government and private investors should improve rural roads, storage, processing and transportation facilities to reduce post-harvest losses and stabilize food prices.
- **Improve climate information and agricultural extension services:** Relevant agencies should provide timely weather forecasts, early warnings and practical training through extension officers, radio, mobile phones and farmer organizations.
- **Promote collaboration among food system stakeholders:** Government, research institutions, financial institutions, NGOs and private businesses should collaborate to provide climate adaptation support, finance, technologies and market access, particularly for vulnerable smallholder farmers.
- **Establish an integrated monitoring and policy-adjustment framework:** Government and agricultural agencies should regularly assess adaptation programmes across the food supply chain and use the findings to improve policies, resource allocation and sustainable food security.

Conclusion

Nigeria requires an integrated climate resilient food system approach to address the growing effects of climate change on agricultural production and food security. Strengthening climate-smart agriculture, infrastructure, post-harvest management and food supply chains can reduce production risks and food losses. Effective collaboration among government, farmers, research institutions, extension services, financial institutions and other stakeholders is essential for building resilient food systems. Thus an integrated approach can improve food availability, affordability and stability while strengthening the capacity of vulnerable households to withstand climate related shocks.

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